Hochschule Ostwestfalen-Lippe
University of Applied Sciences

UNIVERSITÀ
DEGLI STUDI DI TRIESTE

Production Engineering and Management

5th International Conference
October 1 and 2, 2015 in Trieste, Italy

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Proceedings
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October 1 and 2, 2015
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Production Engineering and Management

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Preface

The University of Trieste (Università degli Studi di Trieste) and the Ostwestfalen-Lippe University of Applied Sciences introduced the International Double Degree Master Program ‘Production Engineering and Management’ in 2011. Its aim is to give students in Italy and Germany, along with other countries, the chance to learn the necessary abilities from lecturers and each other. This Master Program has been accompanied by the International Conference ‘Production Engineering and Management’ from the very beginning.

The annual International Conference on Production Engineering and Management took place for the fifth time this year, and can therefore be considered a well-established event originating from the partnership between the University of Trieste (Italy) and the Ostwestfalen-Lippe University of Applied Sciences (Germany). The main aim of the five conferences has been to bridge the gap between production engineering and management theory and practice, by offering a platform where academia and industry could discuss practical and pressing questions. In this respect, the fifth conference (PEM 2015) continues along the same path of the first four successful conferences, which were held in Pordenone (2011), Lemgo (2012), Trieste (2013) and again in Lemgo (2014). PEM 2015 benefited further from contributions from other universities and from research and industry projects. Especially the contributions of successful graduates of the double degree Master’s program Production Engineering and Management and those of other postgraduate researchers from several European countries have been enforced in this year. The title ‘An active interaction between university and industry’ introduced two years ago to emphasize lively cooperation proved to be more than appropriate in the conference’s main orientation:

- To present current research projects and their results at a highly sophisticated scientific level
- To discuss recent developments in industry and society
- To bring professionals, specialists and students together
- To enable professionals, lecturers and professors to exchange experiences
- To familiarize young professionals and students with scientific conference procedures
- To give postgraduate and Ph.D. students the chance to present a paper
- To show the two partner regions’ uniqueness and performance
- To attract students for an international career in the industry
- To encourage students to be open-minded about different cultures, mentalities and manners

PEM 2015 took place between October 1 and 2, 2015 at the University of Trieste. The program was defined by the Organizing and Scientific Committees and clustered into five scientific sessions.
Both universities and their partner organizations debated on these topics by reporting their research, experiences and success stories. The scientific sessions dealt with technical and engineering issues, as well as management topics, and included contributions by researchers from academia and industry. The extended abstracts and full papers of the contributions underwent a double-blind review process.

The 35 accepted presentations were assigned, according to their subject, to one of the following sessions: ,'Industrial Engineering and Lean Management', 'Technology and Supporting Services for Manufacturing', 'Product Lifecycle, from Concept to Market and Use', 'Supply Chain Design and Management' and 'Management Practices and Methodologies'.

These sessions have been carefully selected by the organizing and scientific committees and are aimed at highlighting some of the current production industry's most discussed topics. Therefore, the articles sustainability and revolutionary developments in modern industry and cover not only production in a narrower sense, but also new aspects of: innovation and product development, of supply chains, of quality improvement.

The proceedings have been drawn together to form 35 full papers of the scientific contributions. The articles were reviewed by the Scientific Committee before being accepted.
As the editors of the proceedings, we would like to thank all contributors, the referees who accepted the burden of reviewing the abstracts as well as the full papers and the members of the Organizing Committee and Scientific Committee for planning such an effective conference.

Elio Padoano *Franz-Josef Villmer*

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SESSION A
Industrial Engineering and Lean Management

A LEAN TRANSFORMATION PROJECT IN A MEDICAL DEVICES COMPANY 'LIMA LEAN ENTERPRISE'

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Abstract
Lean Thinking is the way, universally known and applied in different fields and sectors, to increase efficiency and eliminate waste, optimizing the use of all the resources [1].
Lima Corporate is an Italian global medical device company providing reconstructive orthopedic solutions for the joint replacement market.
With over 600 staff worldwide, Lima Corporate has established direct subsidiaries in 23 countries in 4 of the world's top orthopedic markets (Europe, Asia-Pacific, US, and Latin America) and, combined with a network of dealers, Lima Corporate covers over 43 countries. The current footprint is completed by 3 production sites in Italy and San Marino.
The complexity of the business sector and the increasingly competitive environment, have driven the company to undertake a process of deep cultural renewing and transformation to become a 'Lean Enterprise'.
The project 'Lima Lean Enterprise' represents the way LimaCorporate has identified in order to achieve in a sustainable way the maximum benefits within the organization to ensure the reliability and flexibility required by the market.
The primary purpose is to maximize the value for the customer, eliminating all the wastes present throughout the value chain, sustaining company 'self-learning' (*hansei*) and seeking continuous improvement (*kaizen*) of all business processes.

Keywords:
Lean enterprise, maximize the value, challenge the status quo, excellent processes, people engagement and leaders commitment

1 INTRODUCTION

The Lima Lean Enterprise project was born from the desire of the Lima Corporate management team to build an organization that bases its model of excellence on the lean culture.

The ambitious mission of the project is:

- To support the company growth increasing the value of all the business processes in a sustainable way through the continuous research of operational excellence
- To spread the ‘Lean Philosophy’ as the core of the new business culture through a system of values and behaviors that go well beyond the straightforward use of tools and methodologies
- To implement a ‘Lean Transformation’ through a radical change management process

The challenge, which was welcomed by the whole organization, was precisely to go beyond the traditional projects of Lean Manufacturing, now perhaps no longer able to ensure sustainable business results over time.
The ability to manage business processes in modern and complex contest was increasingly linked to the commitment and involvement of the people at all levels of the organization, and to the standardization of processes, rather than to the mere application of techniques and tools, maybe supported only by external consultants and very little by senior members within the company.
Not many people in the industries can truly say that they have not heard about lean, but much less of these really believe in lean, have implemented lean, are the passionate change agents who have convinced senior stakeholders than lean is the way forward for their company.
Statistically, 4 out of 5 improvement projects are destined to decline after only 12-18 months, and the new scenario is sometimes even worse than the starting situation. That happens mainly because of lack of full commitment from the top management and because the biggest resisting force against any improvement process is the resistance to change.
Meeting milestones is not the primary determinant of the success of a change project.
Successful change also involves ensuring employees capacity to adapt to and work effectively and efficiently in the new environment.
If people understand the benefits of change, they are more likely to participate in the change and see that it is successfully carried out.

2 LIMA LEAN ENTERPRISE

The model designed by Lima Corporate, starts from the awareness that all the ingredients are necessary:

- Standardized, effective and efficient processes
- People motivated towards change
- Appropriate and shared tools and techniques

and that mixing them in the right proportion is the only way to have the right recipe and get a successful result.
The choice to be a *'Lean Enterprise'* represents the will to spread a positive philosophy able to activate and enhance resources, to drive the entire organization to challenge the status quo and to overcome the resistance to change and to build a new business excellence model [2].
This philosophy is founded on 5 fundamental principles, which follow each other in a virtuous circle of company development and growth:

1. VALUE

The starting point is always the definition of what is value from the perspective of the customer, both internal and final customer. Everything else is *muda* and should be eliminated.

2. MAPPING

It is important to analyze all the processes of the company, to map all the value streams, outlining all the activities and distinguishing between those value-added and those non value-added.

3. FLOW

It should be ensured that all the activities that create value make up a stream able to flow unhindered, without interruption.

4. PULL

It should be ensured that all the value-added streams could be pulled from the customer needs and requirements.

5. PERFECTION

Achieved results have to be standardized. It is important to become an organization that learns though continuous self-reflection (*hansei*) and improvement (*kaizen*) over the results achieved.

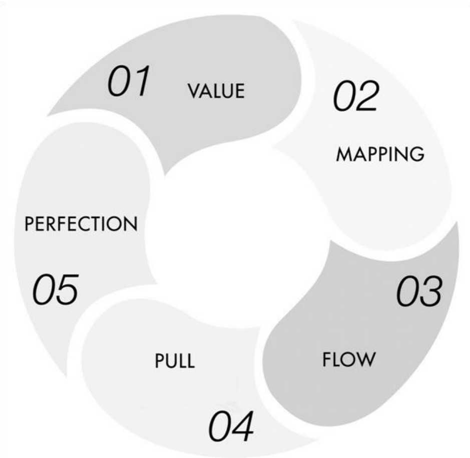

Figure 1: The five fundamental principles of the lean thinking.

The transformation process in Lima Corporate is based on four pillars:

- VISION & COMMITMENT: Through the commitment of charismatic leaders of the organization and their role model;
- EXCELLENT PEOPLE: Relying on excellent, passionate and engaged people who are able to actively contribute to the company’s continuous improvement process;
- EXCELLENT SUPPLY CHAIN: Designing increasingly effective and efficient supply chains that can guarantee to the customers the level of service they expect, through the continuous research for excellence in management and production processes;
- EXCELLENT BUSINESS PROCESS: Applying continuous improvement methodologies and techniques to all business processes (services, offices and manufacturing).

Figure 2: The four pillars of the *‘Lima Lean Enterprise’*.

2.1 Vision & commitment

The Lima Corporate management team defined and communicated to all the company staff a clear vision and the goals for the future mid-long term.
At the same time declared a strong commitment in supporting and promoting the process of change with determination and awareness.
That is the basic condition in order to empower the whole organization and to bring the rest of the team committed to change as well.
To build a solid base for successful change management has been defined an appropriate organizational structure, with clear roles and responsibilities to support the change effort.

A lean thinking department has been established with a very strong team of specialists, supported by consultants with proven experience and relevant successful stories behind.
The lean thinking manager is acting as the change agent, responsible for managing the overall change management process, including the coordination on the different work stream to be implemented.
A steering committee has been established, in which all the department managers have a place. Main responsibility of the committee is to provide overall oversight, setting the direction and the relevant targets, ensuring alignment of the several improvement projects with the strategic vision of the organization.
Inside the committee a role of change sponsor was assigned as well, with the responsibility to build and maintain the commitment for the change, particularly from leaders across the organization.
An annual plan has been defined, including all the improvement projects that were identified. Every process owner is responsible for the definition of sets of activities to be implemented and for the relevant outcomes.
About internal communication has been developed a brochure that is distributed to all the employees every quarter. The content is related to 3 main topics: training pills regarding lean tools and methods, pilot project update according to the relevant annual plan, some suggested literature and book for further insights.

2.2 Excellent people

Lean thinking is focused to eliminate 7 types of waste (transport, inventory, motion, waiting, over-processing, over-production, defects) and this is very well known in every organization that is oriented to improvement projects.
But not many organizations are able to identify the biggest and the most important waste, the 8th waste, the inability to maximize the human potential
Lima Corporate understood that the company can only grow if the people grow also. People make the difference between a successful or not successful project: thanks to this important and powerful truth, Lima Corporate developed a training program for all the employees about *'Lean Leadership'* with the aim to recognize and enhance the deep and precious value that each person owns, thus enabling to operate and share these values for the benefit of the whole organization [3].
People need to be developed in an excellent working environment focused on wellbeing, with the aim to maintain the positive energy towards improvement and to counteract the huge inertia that must be overcome, the resistance to change.
The wellbeing of the employees is to be founded working on 4 emotional engines, as described in figure 3.
Only if all the four engines are activated and only if they are able to run together, people's wellbeing makes the difference.

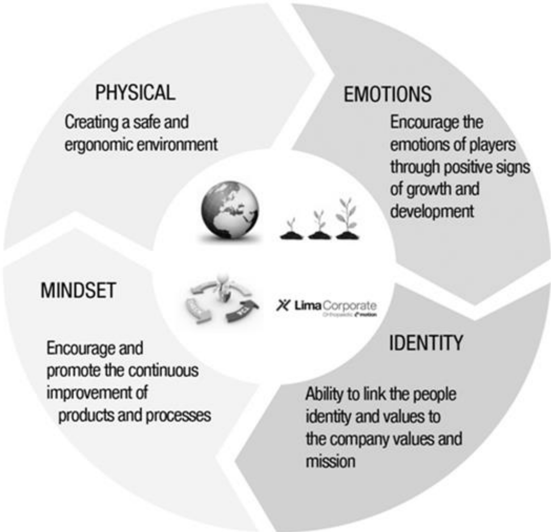

Figure 3: The four emotional engines of wellbeing.

More than 300 staff members have already been trained on these principles and on the fundamental pillars of lean leadership approach, described in fig. 4.

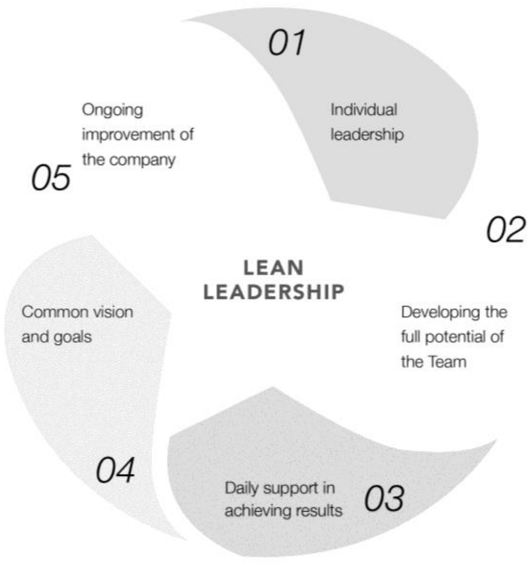

Figure 4: The five pillars of lean leadership.

A company that really wants to change the mindset needs to work on:

1. Encouraging individual leadership, developing leaders that fully understand their job, that believe in the philosophy and teach it to others.
2. Developing the full potential of the team, based on the belief that respect for people and development of their skills are the basis of continuous improvement and innovation.
3. Helping to achieve results, developing systems and habits that contribute to the daily achievement of concrete results.
4. Aligning vision and goals, enabling the compactness of the entire company around a common vision, associating people identity and value with the organization.
5. Striving for continuous improvement of the company, encouraging and supporting the willingness for innovation and continuous improvement of product and processes.

2.3 Excellent supply chain

Lima Corporate's supply chain is very complex; actually, there are at least 6 different supply chains that have not many common elements.

The company's portfolio includes a mix of products with more than 2000 different items. Besides the main 3 product families, described in fig. 5, of prosthesis for hip, shoulder, and knee, there are many versions and different solution for any pathology, for primary or revision orthopedic surgery.

Figure 5: The Lima Corporate products: prosthesis for hip, knee, shoulder.

In 2015 Lima Corporate will be manufacturing over 400.000 prosthesis components with a selling quantity of around 250.000.

The difference is easy to understand being familiar with the peculiarity of the medical devices' market.

Direct customer are orthopedic hospitals, both public and private, that require to the supplier to leave in consignment the full range of product with full range of sizes (there are about 10 sizes for every product, like as in a shoes store!) and to replenish the size of the product just used in a surgery within 24 hrs. The availability of the full range is a huge investment for the company from a manufacturing point of view and it is considered as an investment.
Direct Customers require, together with the full range of prosthesis, what is called 'instruments set', which can be described as set of tools necessary for surgery. Production of instruments sets is completely outsourced, according to the company's operations strategy. For any set of prosthesis a set of instruments is required in consignment in every hospital, and this is another big investment for the company.
Currently, direct customers cover 85% of the business and they are served for 1/3 directly from Italy and 2/3 through the net of subsidiaries. The remaining 15% of business is covered by distributors and OEM customers that are buying from Lima Corporate both orthopedic implants and instruments sets, with Lima brand and private label brand respectively.

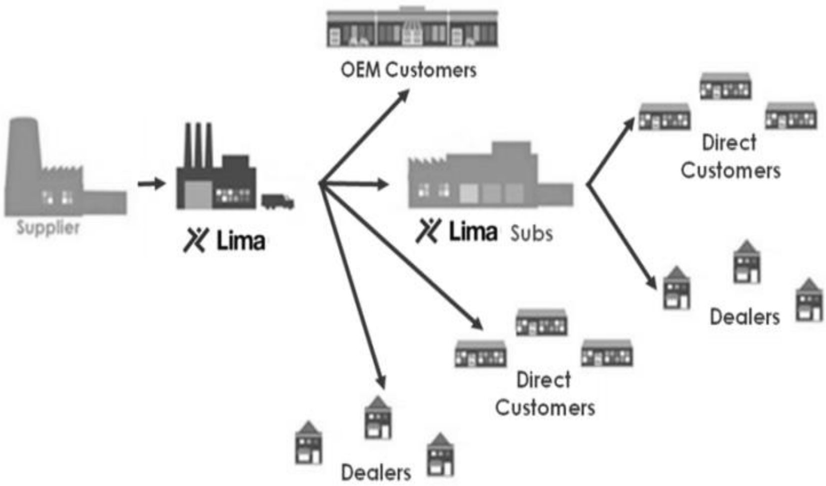

Figure 6: The Lima Corporate supply chain.

When the company started the project in 2014 the goal was to design a more effective and efficient supply chain, able to provide customers with the level of service expected, through the continuous pursuit of operational excellence in all the business processes [4].

To do this, it has been decided to apply the SCOR model (Supply Chain Operations Reference), a solid foundation for measuring performances and identifying priorities [5].
According to SCOR Model, the lean transformation began from the declination of the main company goals into the following four drivers:

1. Efficiency and Productivity: it indicates the ability of the company to balance the performance of every single resource within the entire supply chain.
2. Responsiveness: It indicates how quickly the company has to make the product available to the customer.
3. Reliability: it represents a fundamental competitive factor in medical devices market and it indicates the capacity to satisfy customer requirements.
4. Agility: it allows facing the variability and the uncertainty the market brings into the company.

According to these drivers, the following set of KPI has been chosen:

- OEE and productivity (efficiency and productivity)
- Lead time (responsiveness)
- Service level (reliability)
- Inventory (agility)

Always with the SCOR Model as reference, the team has been working on the following points:

- Selection of the supply chains to focus on
- Configuration of the supply chains by mapping all activities in 5 different cluster: PLAN, SOURCE, MAKE,DELIVERY, RETURN
- Highlighting of the critical tasks
- Identification of the future state through the definition of a detailed action plan
- Monitoring of KPI values to control correspondence with target

The ‘AS-IS’ analysis has given to the team the opportunity to detect the main points of attention on which the improvement project has been focused:

1. Deliver

- Demand planning process accuracy to be improved
- Service level and backorder not in line with market requirements
- Picking and shipping throughput to be increased

2. Make
- High corporate inventory level
- OEE and productivity to be improved
- Too high and spread lead time for internal manufacturing processes

3. Source
- No clear make or buy manufacturing strategy
- Supply base mainly build on single and local sources

An action plan has been defined with a 3 years timeline.
In the first twelve months, during 2014, three improvement projects on critical product families have been defined and realized with the purpose to significantly improve the manufacturing lead time, as shown in fig. 7.

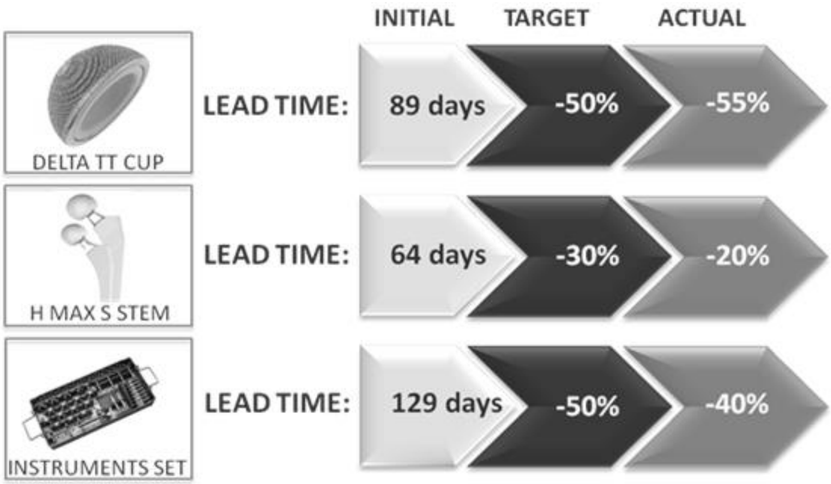

Figure 7: Projects focused on lead time reduction.

With the same short term approach, four projects on main supply chain processes have been defined and developed. The results are shown in fig. 8.

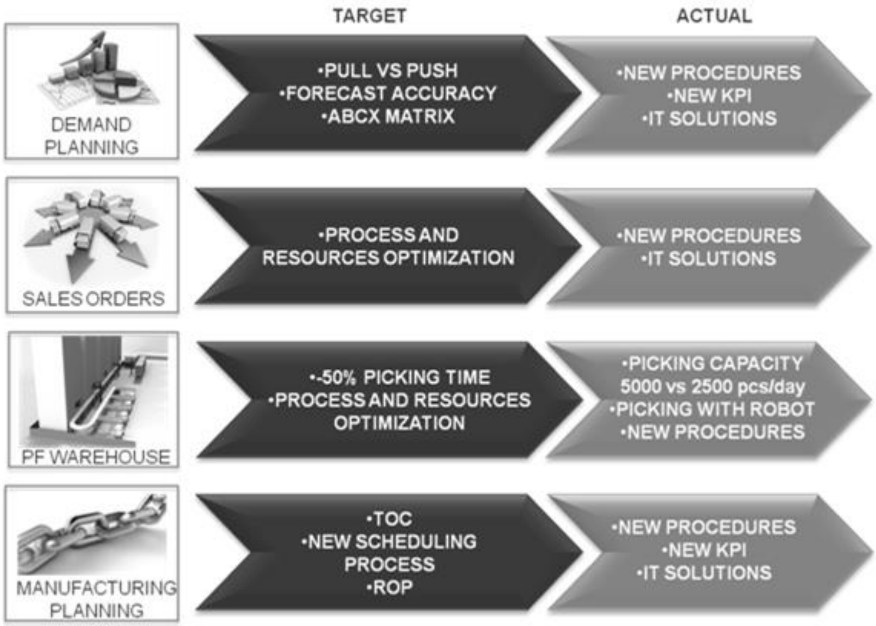

Figure 8: Project focused on main supply chain processes.

About the set of KPI that have been identified, the result after the first year of the project is shown in fig. 9.

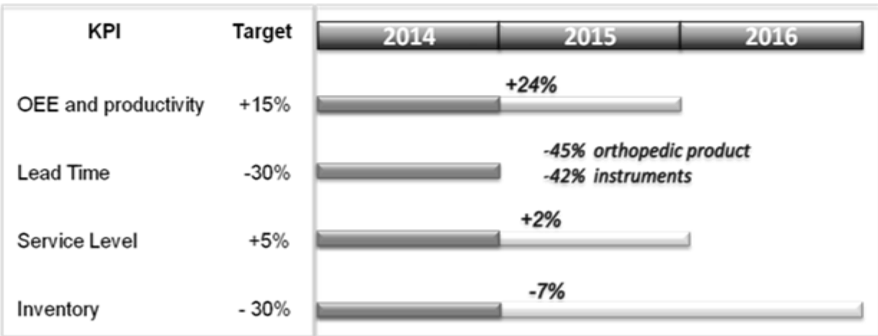

Figure 9: KPI and target with result achieved.

In the medium term the main projects that are work in progress are the following:

- Define and develop a 'Zero Backorder project' focused on improving the demand accuracy as well the service level and on reducing the backorders.
- Develop a new and international supply base with double source for critical products, both orthopedics implants and surgical instruments.
- Bring to completion the make or-buy strategy, with outsourcing of all surgical instruments and insourcing of finishing operations on prosthesis products.
- Re-engineer and innovate manufacturing processes and supply chain business processes.

Overall more than 60 staff members, with different skills and coming from 10 departments, have been involved in the whole project.
The real success, more than the very good results that have been achieved, was having an organization driven towards efficiency and effectiveness and inspired by the lean thinking approach and the Teamwork attitude.

2.4 Excellent business process

Once the project will be fully and effectively realized in term of supply chain, the focus will be oriented on other strategic processes where the application on lean thinking could give a real contribution in term of improvement.
Some projects have been already identified for the second step:

- Lean product and process development
- Lean office and administration
- Lean accounting

3 CONCLUSION

To fully benefit from the impact of an intervention of 'Lean Transformation', a process of radical change in the company is really needed.
The change not only affects the operational processes but also the:

- Decision-making process
- Methods
- Organization and roles
- Relational models
- Skills of the people
- Leadership styles

It is a huge opportunity but also a challenging change management process, which requires willingness to change habits and practices.
Carrying out this project means:

- To initiate a journey through which the company can develop a cohesive culture that promotes and embraces the change
- To become an organization that is able to adapt and learn over time
- To respect and promote all the company's employees so they are protagonists of the continuous improvement process

Build 'Lima Lean Enterprise' means to find the correct balance between technical excellence and people management, with the goal to maintain results consistently.
So, 'Lean Thinking' as a strategy, extended and applied to all business processes and 'Lean Leadership' as the way to achieve the union of well-being of the people and business results.

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COMPARISON OF COMPANIES IN TERMS OF THE APPLICABILITY OF VALUE-STREAM-DESIGN

A practical decision-making validation procedure to select process optimization methods

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Abstract
An ongoing key challenge for companies lies in the individualization of their own product and service offerings. This leads to the mastering of a wide range of models and a high product variant complexity. For this purpose continuous improvement measures, which strive for low-waste procedures and thus high efficiency, are indispensable. In order to achieve an integral and customer-oriented process optimization, a wide variety of analysis methods, as well as combinations of procedures, is available. But, when choosing a method, it is frequently unclear to what extent method-based and company-specific limitations and shortcomings will occur with each method. Thus, users are challenged by the need to choose an adequate method of process optimization in advance and the need to adjust it to apply to their particular case. Using, for instance, value stream design, a proven procedure to validate decisions needs to be developed and evaluated. In this paper the results of the research approach is presented, which begins by setting up an 'impact-model' that portrays the system behavior and performance before value stream design application.

Keywords:
Value stream design, value stream mapping, key factors, impact model

1 PRESENT SITUATION AND PROBLEM PRESENTATION

Customers increasingly demand individualized products, which forces production companies to master the growing proliferation of products and product families. A further challenge is that of increasingly volatile markets, with unpredictable order cancellations. As the last step in the process chain, production is particularly affected, above all because this area is subject to assessment according to targets such as short lead times, small lot production and stock levels (inventory), or high employee productivity. The substantial drive to change products and processes increases the pressure associated with efforts to increase production efficiency, which can only be optimized using a customer-oriented, participatory and holistic approach.

This situation requires that the company carry out continuous process optimization analyses: this is regularly confirmed by surveys such as a one conducted by Ifaa (Institut für angewandte Arbeitswissenschaft) in December 2013, where company and union representatives placed process organization, continued improvement and leadership skills as a high priority [1].

Value stream mapping (VSM), which uses classification and visualization, allows a customer-focused perspective along the company's entire process chain and participation-oriented optimization. Value stream mapping focuses not solely on production, but on the entire value chain within a company and combines production, control and logistic processes. The key to success is the consistent adoption of the customer perspective and that systematic optimization within defined boundaries occurs. It is, however, often unclear during the VSM selection process, to what extent method and business-specific boundaries will be encountered. The complexity of VSM must be taken into particular consideration, as it will be encountered in all process optimization phases (analysis, evaluation, design and implementation) [2].

2 RESEARCH OBJECTIVES

Regardless of the primary causes or drivers of the need to optimize, until now there has not been a criteria-based selection process that makes a prediction as to the effectiveness of value stream mapping possible. The inclusion of the following is of particular importance [2]:

- User competence and the participation of organizational leadership (people)
- The success factors pertaining to the methods, including individual target achievement (methods)
- The present/current state of the company, particularly the production environment (environment)

On the basis of the VSM as an optimization approach taken from Lean Production, it is therefore necessary to develop and evaluate a decision validation method. In this regard, the following question is taken as the research basis: 'With which key factors can VSM effectiveness be illustrated?' [2].

The research approach will be pursued according to an impact model, which illustrates the system behavior of a value stream project before VSM implementation. For this purpose valid VSM key factors (success factors) will be established and specified and supported using case studies. Based upon these findings, the results will be entered into an impact model, which illustrates several evaluation levels and evaluates individual production environments using valid initial criteria [2].

3 FUNDAMENTALS OF VALUE STREAM METHOD

The central objective of value stream mapping is the identification and elimination of waste in each connected process. Using this method to document value add processes, redundant procedures and operations waste is thereby also documented. From the adopted customer perspective, value added should be created as parts will be produced to customer specifications with as little waste (muda) as possible. In this respect every process in the value stream needs to be connected in such a way as to produce a production flow with optimum stocks, minimum cycle time and low defect and scrap rates. This method's optimization areas therefore consist of shortening cycle times, increasing production and reducing stock levels [3] [4].

3.1 Value stream operating principles

In contrast to examining the company layout, in which important information such as information flow and upstream or downstream process chains are not visible, value stream mapping describes the essential company procedures using simplified symbols. A concise representation of the company's business processes with regard to production, material and information flow is thus achieved. Not least due to the simplicity of use, has the value stream method been identified as a valued analysis and design tool. The application of this method requires solely the use of pencil, eraser and paper. Furthermore, through the designation of a value stream manager, competencies and responsibilities are combined. The manager also ensures that the individual sub-projects can be responsibly realized [3] [4].

In summary, it can be said that the value stream mapping is an integrated analysis, communication and design tool, which in manufacturing begins with the arrival of raw material in the warehouse, ends at dispatch and can be extended to cover all upstream and downstream processes (suppliers and customers). In this connection material and information flow is examined and this extends into administrative areas.[4]. Fig. 1 shows a typical value stream map.

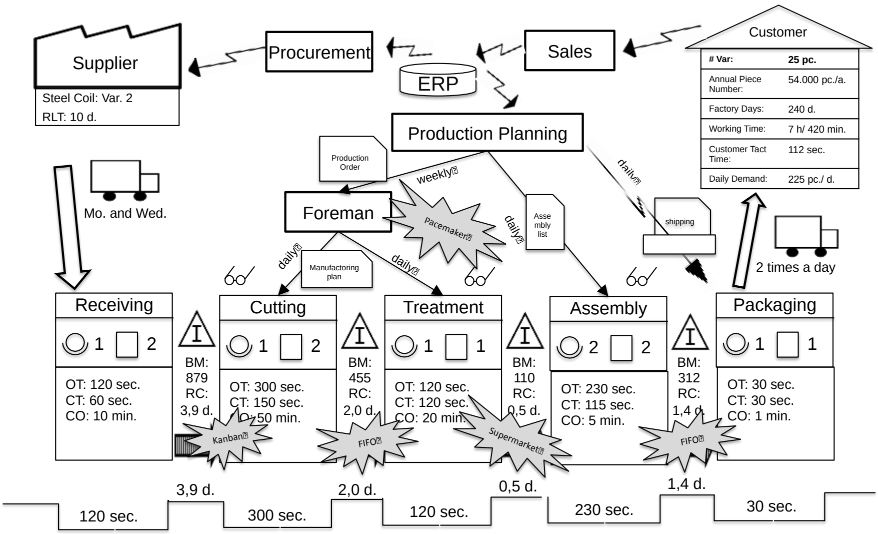

Figure 1: Value stream map example.

3.2 Value stream mapping targets

The aim of manufacturing optimization is to increase efficiency, with easy to implement measures; for this purpose, it is necessary to determine the company's current state, in order to enable appropriate target achievement rates [4]. In fig. 2 appropriate targets have been identified from relevant literature, which will be pursued using value stream mapping.

Target dimensions	**Economy, Variability, Speed, Quality**
Strategic Direction (appropriate major targets)	Attain ideal vision of flow with high value add
	Implement and improve production processes
	Establish value Stream optimized factory through use of design guidelines
	Introduce Lean principles
Main Targets (achievable targets)	Reduce lead time
	Reduce inventory
	Improve quality
	Increase productivity
	Recognize and eliminate waste and weaknesses (Kaizen)
Secondary Targets	Recognize Holistic/ Integrated flow
	Create corporate communication platform
	Create basis for discussion / decision
	Creation of transparency through symbolism / process abstraction
	Depict connection between material and information flow
	Enable visualization in one image

Figure 2: Targets pursued using value stream mapping.

Process optimization targets can be put into operation and target values can be formulated based on strategic direction. The main target dimensions have been classified into a general target system. Using the value stream method specific targets are also created, which are presented as secondary objectives arising from the use of this technique and illustrate the unique selling points of value stream mapping. Finally, target achievement rates enable the graphical representation of value stream mapping results, which is considered in the impact model [4] [5].

3.3 Value stream technique classification

At the heart of this value stream diagram is a product family, which is placed in the center of the diagram and is of direct relevance to a customer or customers. This results in an integrated customer-oriented perspective (process oriented) within defined system boundaries.
The scope of the boundaries in classic value stream mapping that can be linked to two typical models occurs on three levels:

- Plant / Factory
- Production
- Workplace / Machines

Through this, illustration of the analysis scope and design and, therefore, the way value stream mapping works is made possible.
The connection between the influence of value stream hierarchy and process on a company or production level is clearly demonstrated (Fig. 3).

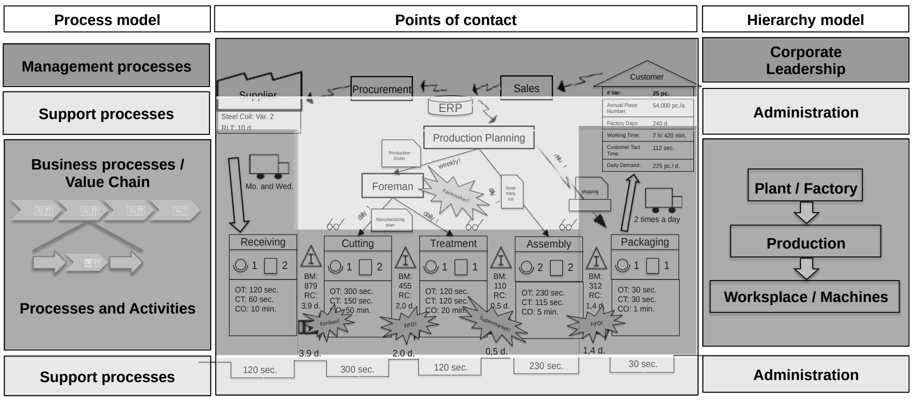

Figure 3: Comparison of process model and hierarchy model.

Based upon the manufacturing company's vertical levels in the hierarchy (depth) model, the value stream technique affects all production levels. No impact is made upon corporate leadership. Production, factory and administration areas are well documented [6]. The horizontal (width) process model illustrates recording of company processes as well as support processes. Management processes remain unaffected.

3.4 Value stream method scope parameters

Based upon these results, the spectrum of the scope of value stream techniques can be illustrated, which in the vertical ‘level of detail’ as well as in the acquisition of all relevant figures, data and facts can be illustrated through the ‘information content’. The ‘scope boundaries’ are to be determined in advance. Both scope directions have a significant influence upon the ‘effort’ required for the analysis. The ‘complexity’ of a production area should be reduced using VSM into a describable and manageable format. For this purpose, VSM is subject to the use of classifications and symbols, which can be illustrated by adherence to ‘standardization’. With respect to optimization of current business processes, employees must be included in the process in order to achieve high acceptance of the results and ‘transferability’ to further product families. These team-oriented aspects take place in VSM by involving the employees closely in the analysis and design process, which is to be taken into account when committing personnel resources to the VSM [7] [8] [9].
The scope should be identified at the start of the process and will be referred to as scope parameters below. Fig. 4 combines the value stream method scope parameters and illustrates the abstraction range of company processes. These scope parameters will be integrated into the impact model in order to display them from the start.

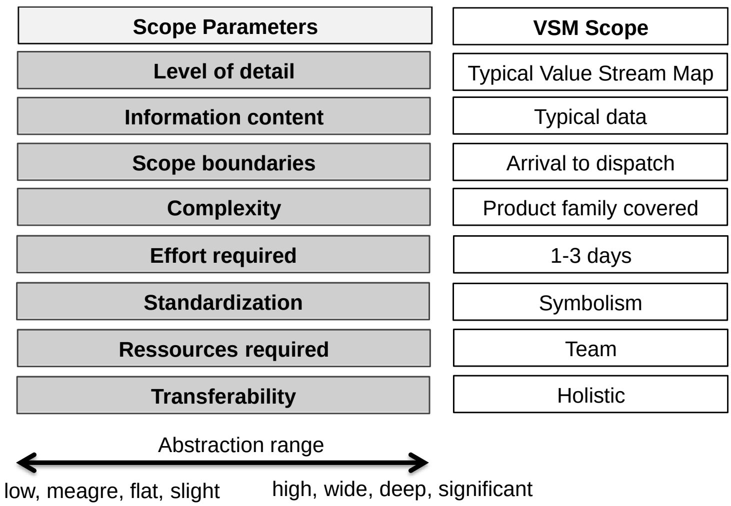

Figure 4: Value stream method scope parameters.

4 VSM IMPACT MODEL

In order to develop the impact model it is also important to identity key factors that express the success or failure of the value stream technique and, consequently influence the target achievement and scope parameters. For this purpose, fig. 5 represents a process model. The impact model will be modeled based upon the required performance characteristics of key factors, clear target reference, theory reference and should demonstrate measurability. In this way, using a questionnaire at the beginning of the value stream process, the characteristics of target achievement, operational factors and key factors can be graphically depicted and subsequently interpreted. Consequently, the value stream mapping success can be illustrated [2].

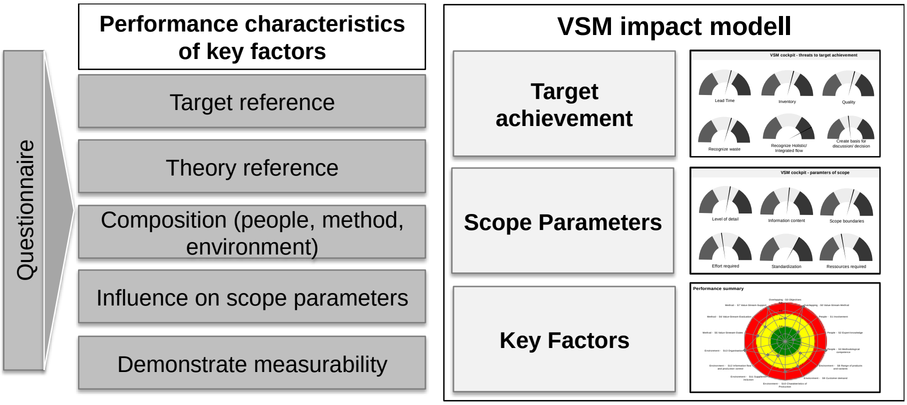

Figure 5: Process Model.

4.1 VSM key factors

Using content analysis (104 specialist articles) and an underlying study of value stream mapping [10], a total of 13 key factors have been identified with which the key to success or failure of value stream mapping can be illustrated. In figure 6 the 13 key factors and particular questions (the entry in the questionnaire) are depicted. The key factors are also classified according to the categories mentioned above: people, method, and environment.

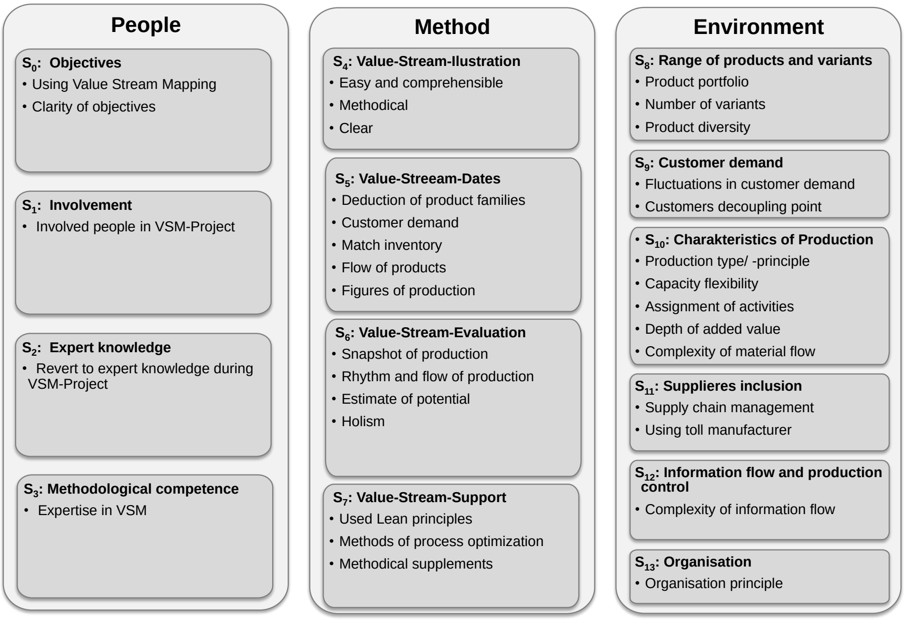

Figure 6: Overview of key factors classified.

4.2 Impact model evaluation

In 13 case study companies, aside from the measurement of the key factor questionnaire, value stream projects were implemented, supported by value stream experts. Ultimately, a comparison of the value stream project with the initial criteria was performed. It could be demonstrated that the initial key factor criteria essentially illustrated the results of the value stream project, which was run in parallel and is therefore valuable in advance. Further, that company employees can answer the questions sufficiently and that the impact model can deliver valid results, which can be used as a basis for decision-making [2].

5 IMPACT MODEL

All the possible answers are included in the impact model, which can then be evaluated using a three-stage approach and illustrated using onion and rainbow diagrams. The key factor analysis provides a general overview of the suitability of value stream methods in an assessed company. Using these results, the decision for or against value stream mapping can be taken and justified. Compensation measures can also be focused in advance of

VSM application. In-depth analysis with regard to target challenges and method specific scope parameters can also be undertaken.
Fig. 7 illustrates the results from a company with 35 employees, which produces standard and customized parts from sheet metal. This demonstrates that, ultimately, value stream mapping in this company would be of limited use for particular key factors, which are represented by red and yellow areas. For example, the basis for the value stream, including the aims, is unclear (S0). The product range (S8), due to high variety and fluctuating customer demand (S9), as well as the predominant production characteristics (S10) also present challenges to a value stream project.

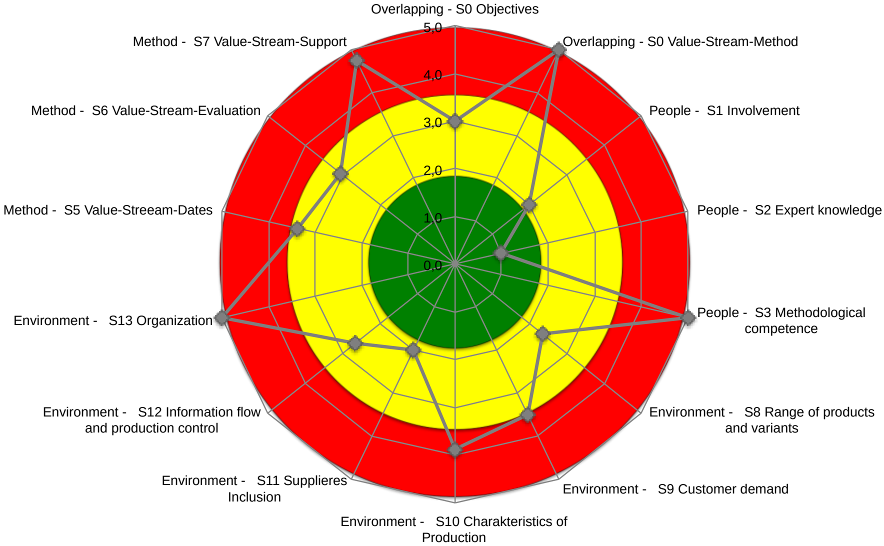

Figure 7: Impact Model Performance Summary.

Furthermore, a glance at scope parameters reveals other hurdles within the company, all of which are located in the yellow sector (fig. 8). Therefore, to get the value stream diagram within the system boundaries, with the required detail, to ultimately depict complexity, the analysis required will be considerable (more than 8 hours).

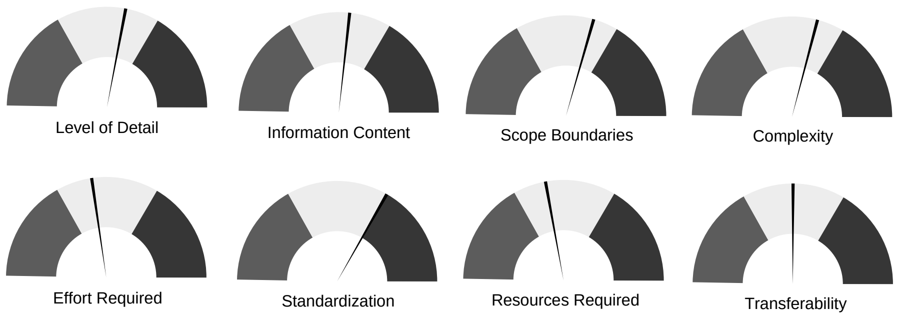

Figure 8: VSM - scope parameters.

As stated, the success or failure of a value stream project can be defined by the targets, which can differ significantly. A value stream project can said to be successful when a current situation is systematically recorded and presented in a value stream diagram, when the first qualitative potential is revealed, because, targets obtained using VSM can only be qualitative targets – for example creating transparency or to demonstrate waste. In the application presented here, analysis of mass production as well as customization jeopardizes the typical value stream procedure, which is demonstrated by the red target areas ‘Recognize Holistic/ Integrated Flow’. The illustration of the production environment through symbolism to get transparency is also impeded.

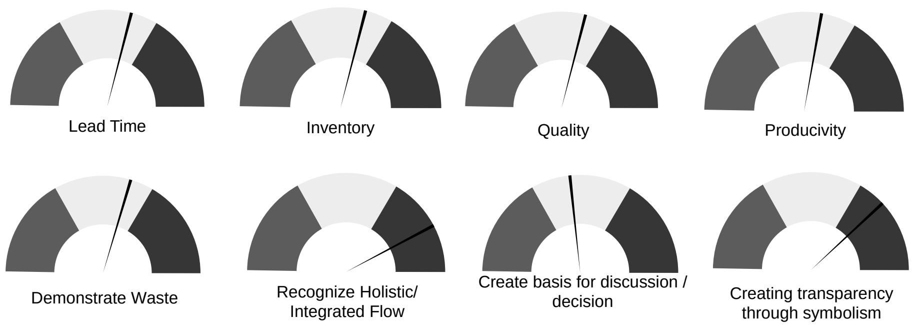

Figure 9: VSM - Threats to target achievement.

6 CONCLUSION

The impact model, in the first stage of key factor analysis, has a marked effect on the value stream project, which can be assessed generally, or with respect to a specific company. The second analysis stage provides indication of influencing the targets, which must be qualitatively assessed.
Based upon the key factors of each required target and the assignment of value stream specific targets, it may be concluded that there is a threat to target achievement, which should be interpreted as an indication. Consequently, a great influence in the red sector indicates a threat to target achievement, measures can be taken to compensate for this, such as increasing the analysis effort as well as focusing the resources in the project team.
The third analysis stage makes the influence of the research into the current state clear with regard to the operational factors, which should be given parameters within the framework of a process abstraction. Accordingly, conclusions can be drawn regarding future value stream projects and alternative ways of documenting the current situation can be shown.
The greater aim of analyzing key factors using an onion diagram (figure 6) produces a general overview of the practicability of value stream mapping in the company surveyed. Using these results, a decision for or against value stream mapping can be made and justified. Similarly, before implementing this method, possible compensation measures can be focused on and in-depth analysis regarding hazards to targets and operational factors can be undertaken and allow precise decision-making. It is worth noting here that there is a margin for interpretation in the analysis, which may vary due to user competencies, decisions must be made by a user practiced in value stream mapping.

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VALUE STREAM MAPPING TO MEET THE NEEDS OF MULTIPLE INDUSTRIES

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Abstract
Shipyards in Europe, in order to maintain continual production of all of its facilities, must analyze ways to use the present production systems for the assembly of interim products for vessels as well as other types of industrial constructions. In the case of the shipyard analyzed in this paper, which has produced various types of vessels, the management is open-minded about meeting the needs for the civil engineering construction industry as well. The authors' of this paper have analyzed the process of assembling interim products of a subsea construction for Venice using a value stream map (VSM). Applying lean manufacturing principles, the present lines of production are explained and certain realistic enhancements are drawn up and illustrated in a future improved VSM. Whereas, the present system will produce products which meet the quality and duration times of the customer, the new proposed system, illustrated in a future VSM, will decrease the non-value added activities as well. Therefore, the conclusion is that the VSM methodology developed in this paper will enable a shipyard to meet the needs of various industries and be competitive in quality, cost and delivery.

Keywords:
Value stream mapping, lean manufacturing, panel line assembly, civil engineering, shipbuilding

1 INTRODUCTION

Shipyards strive to improve the effectiveness and efficiency of their production processes in order to deliver quality products on time. Applying the principles of lean manufacturing to a production system is a significant way to improve the manufacturing efficiency of any type of manufacturing facility, including shipyards [1]. One specific tool that is used is value stream mapping (VSM) which is an illustrative display that readily identifies where waste occur in the production process. VSM visually displays all of the activities and identifies them as value added or non-value added. It can be used to map the assembly of interim products or an entire product from the beginning to the end of the process. Lean manufacturing principles demonstrate tools that can be used to assist in the identification and steady elimination of waste such as excessive use of manpower, inventory and time. It becomes very important for companies which wish to produce a quality product in both an efficient and economic manner [2]. The implementation of VSM on production of a subsea protection construction for Venice is the subject that is analyzed in this paper.

2 BACKGROUND

The principles of lean manufacturing were originally created and developed by the Toyota Corporation as a process to eliminate waste during the manufacture of automobiles [3]. According to Shook [4] value stream mapping has four steps:

1. Determine the product families,
2. Create the current-state map,
3. Develop the future-state map,
4. Determine the plan for implementation of the future state.

With the creation of a VSM, visualization is enabled, which creates the ability to see where, when and how information, materials and interim products flow through the production assembly process. This in turn allows for the recognition of waste. Therefore in a future VSM at least some of the waste can be eliminated depending on whether the waste can easily be eliminated. Value stream mapping can be defined as the simple process of directly observing the flows of both information and materials as they occur, visually summarizing them, and then envisioning a future state with much better performance [5].
The VSM process involves identifying all of the waste in the value stream and then taking steps to eliminate them [4]. Optimization of the subsea protection construction for Venice process means working on the bigger picture and improving the whole flow and not just optimizing small pieces. With value stream mapping a common language for production process is created. The five main lean activities 5S are: sort, separate, shine, standardize and sustain.

3 CASE STUDY

In shipbuilding production process, both value-added and non-value-added activities are listed: value-added activities – welding, forming, machining, processing, assembling and painting. Non-value-added activities include scrapping, sorting, storing, counting, moving, and documentation transfer [6, 7]. To implement a VSM of the production of subsea protection construction for Venice in a shipyard surrounding, it is necessary shipyard lean transformation. Value stream maps should be representations of the actually

process flow instead of supposed; therefore it causes chances for development and recognition. Also it shows accurately the steps of process activates to complete timing of stages in production process.
The goals of this article is to demonstrate how lean manufacturing tolls, when used appropriately, can help the shipbuilding industry to eliminate waste, have better control, better product quality.

3.1 Problem description and approach

The shipyard produces roll-on roll off passenger (ROPAX) vessels, tankers, bulk carriers and heavy lift vessels. However, since the shipbuilding market is undergoing a type of crisis, where few owners are ordering large series production of vessels, the shipyard management is open minded about meeting the needs for civil engineering construction industry, while making maximum use of present shipbuilding facilities.
Subsea protection construction popularly called Venice protection doors will protect the Venice harbor against high tide and the raising of the sea level and flooding of the city.
The construction will be flooded and will rest on the sea bottom during the low tide season, not getting in the way of maritime traffic or anything else. However, during the period of high tides during the fall and winter, the sea-water will be pumped from the watertight construction. This will result in the de-ballasting of the doors which in turn will thereby move to the vertical position. The height of the doors, while in the vertical position, will be more than enough to protect both the harbor of Venice and the city itself from flooding.
Subsea protection construction simulation is illustrated in fig. 1.
The interim products that make up the subsea protection construction for Venice have similar characteristics to the interim products of a ship. These include large panels, micro panels, transverse structural elements and outfitted components. There are some special positions that need to be machined, pre-heated and grinded, and the whole production process is very demanding for the shipyard to fulfill all of the requirements that are needed to satisfy the tender obligations.
In case of production and receptiveness of similarities of ship structural elements and subsea protection construction elements in the same shipyard facilities, it is possible to reap advantages of repetitiveness in the assembly of ship interim products.

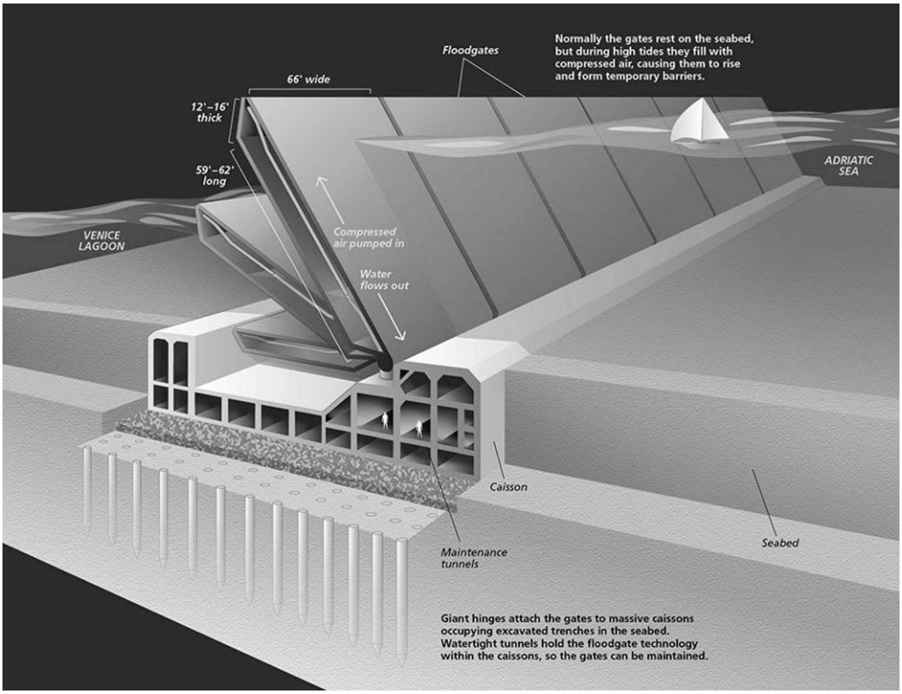

Figure 1: Subsea protection construction for Venice.

Therefore it is possible to analyze implementation of the VSM in the production of subsea protection construction.

In the case study treated in this paper, the subsea construction includes a typical module of the dimensions: abt. 21m long, 4.6m height and 18.6m width. This in turn is broken down into technological interim products which can be assembled in different production lines at the shipyard. These interim products include 7 semi-automatically assembled large panels, 10 semi-automatically assembled medium panels, 27 automatically assembled micro panels and 90 manually assembled micro panels in the shipyard downstream processes. The total weight of assembled construction is about 290 metric tons and the shipyard plans to deliver one module monthly in next few years for a total of about 50 modular pieces of the same subsea protection construction that will satisfy the needs of the Venetian harbor.

As comparison to the production of the subsea construction, it will be presented production times for typically ship hull double bottom structure of the heavy lift vessel, which was the demanding product assembled in the shipyards workshops before starting the building the Venice subsea protection construction. Double bottom hull block dimensions are: abt. 26.5m long, 26m width and 2.15m height. The interim products include 5 semi-automatically assembled large panels, 122 automatically assembled micro panels and 32 robotically assembled micro panels in the shipyard downstream processes. Total weight of assembled hull block is about 300 metric tons. Comparison of processed materials of heavy lift double bottom and subsea construction in presented in fig. 2.

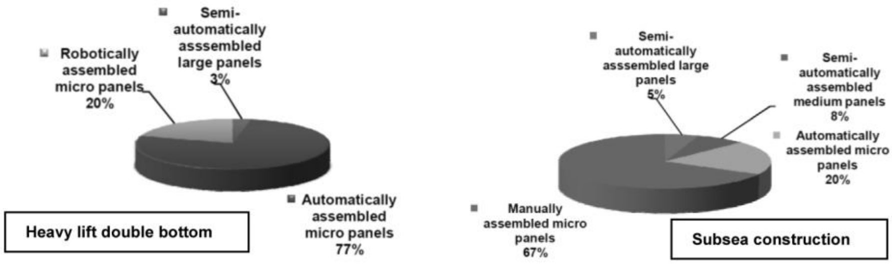

Figure 2: Comparison of processed materials.

Basically, there are differences between two processes, on the double bottom there were all automatic welding processes, while on the Venice subsea construction there was a good number of manually welded structural elements.

3.2 Production workflow

The shipyard workflow working hour is organized in daily shifts of 8 working hours. The month shipyard work period is 21 days, means 5 working days per week. Occasionally in case of short delivery timing, the daily working schedule is organized in two shifts of 8 hours working time in each shift.
The production of one subsea construction monthly is realistic and is in compliance with the construction delivery plan. In this paper, there is presented the second phase of assembly of the subsea construction, also double bottom hull block assembly process, after previously finished processes: plate and profiles delivery and storage to the yard, sorting, grit blasting and corrosive protection, labeling, cutting, leveling, and preparation of the plates edges for further assembly and welding.
The common pre-assembly process in shipyard semi-automatic welding workshop starts with panel line welding, where the first step is welding of the several plates in the large panel. For transverse gantry crane removing profiles from interim storage (IS1) (fig. 5) and lowering them on the panels for automatic welding process. Semi-automatic pre-assembly welding workshop consists of a number of different semi-automatic, robotic and manually welding machines, which work independently or are manually

operated by workers, but each machine works on a different task separately and simultaneously.

After welding the profiles on the panel, the stiffened panel is transported with conveyor rollers to the next production step, which is welding of the transversal structural elements pre-assembled on the automatic and robotic welding machines. Welding of the transversal structural element as stiffened frames is done on the semi-open hull block welding line. There are welders, grinders, fitters and repairers. Near the semi-open hull block line, especially for this project, a manually micro-panel welding line is organized. The line is supported with workshop gantry cranes and transportation vehicles. For this purpose, to organize the manually welding line, welders from other shipyard areas are relocated and organized in line, unlike conventional shipyard downstream process. After finished automatic, robotic or manually welding of the micro-panel, gantry cranes transport the micro-panels on the semi-open hull block/construction welding line (fig. 5).

On the semi-open block welding line semi-opened block is completed with transversal and longitudinal structural elements previously finished on the supported automatic, robotic and manual welding lines. After finishing the pre-assembly of the semi-opened construction, structure is transported by gantry crane on the interim storage (IS2) (fig. 5). Assembly of the construction is done in the pre-outfitting workshop and transported with transporters to the interim storage (IS3) (fig. 5) where it will be prepared after corrosive protection for loading on the interim storage (IS4) (fig. 5) as preparation for delivery on the transportation barge (shipyard activities 2015). In parallel, according to integrated hull outfitting and painting (IHOP) principles, the fabrication of pipes, passes, lifting lugs and special steel pieces that need to be pre-heated and grinded has to be completed. These pieces are removed from the pipe fabrication workshop to a separate workshop; specialist workers for these steel types are not permanently positioned in the standard pipe workshop. Instead of moving workers, the necessary special steel element that need to be specially heat treated are removed between the two workshops. On the assembly line, there are steel plate welders, grinders, repairers, fitters and pipe welders.

Assembled construction will be transported to the Venetian harbor (fig. 5) while ship hull block (fig. 4) will be transported to the erection area.

4 VALUE STREAM MAPPING (VSM)

In preparation of value stream map (VSM) the logical and simple step is the grouping of interim products. The first step is the selection of the product family. The second step is the current state mapping in order to understand how the process currently operates. It is the foundation for the development of the future improved state [2]. In the future state the aim is to enhance lean flow of materials and information. During the production of subsea protection construction module, according to the product family breakdown, four production areas are identified: automatic assembled large panels (AALP), automatic assembled panels (AAP), automatic assembled micro panels (AAMP) and manually assembled micro panels (MAMP). In order to shorten the production time and reduce man-hours, it is important to create a VSM of the actual production state, and then find possible interim products that can be produced on the same production areas. The idea is to define the where improvements can be made as well as consolidating them into new and improved processes.

4.1 Current value state map

All necessary data related to the selected production process of the subsea protection construction module have been collected. Fig. 3 shows a legend of VSM symbols; fig. 4 displays the current state value stream map of conventional hull block assembly line; fig. 5 shows the current state value stream map [7, 8] for the subsea protection construction. During the production of ship hull block, according to the product family's breakdown, three production areas are identified: automatic assembled large panels (AALP), automatic assembled micro panels (AAMP) and robotically assembled micro panels (RAMP).

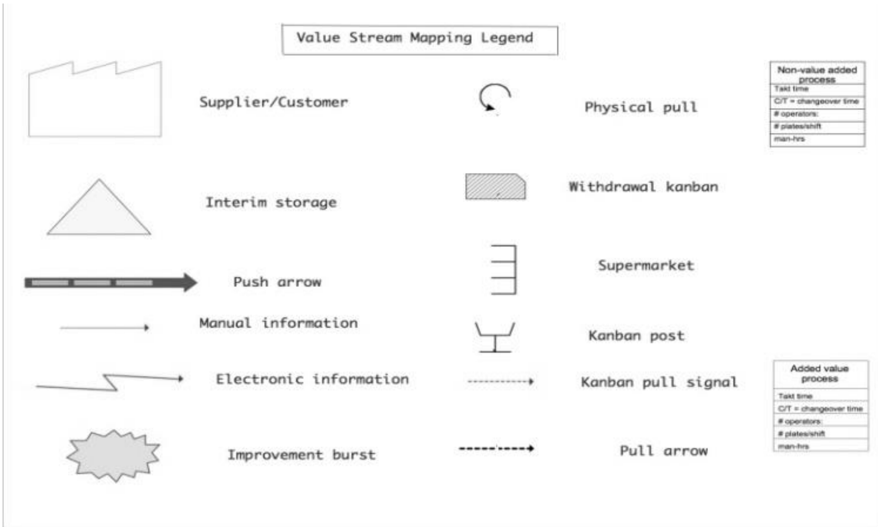

Figure 3: Legend of VSM symbols [7, 8].

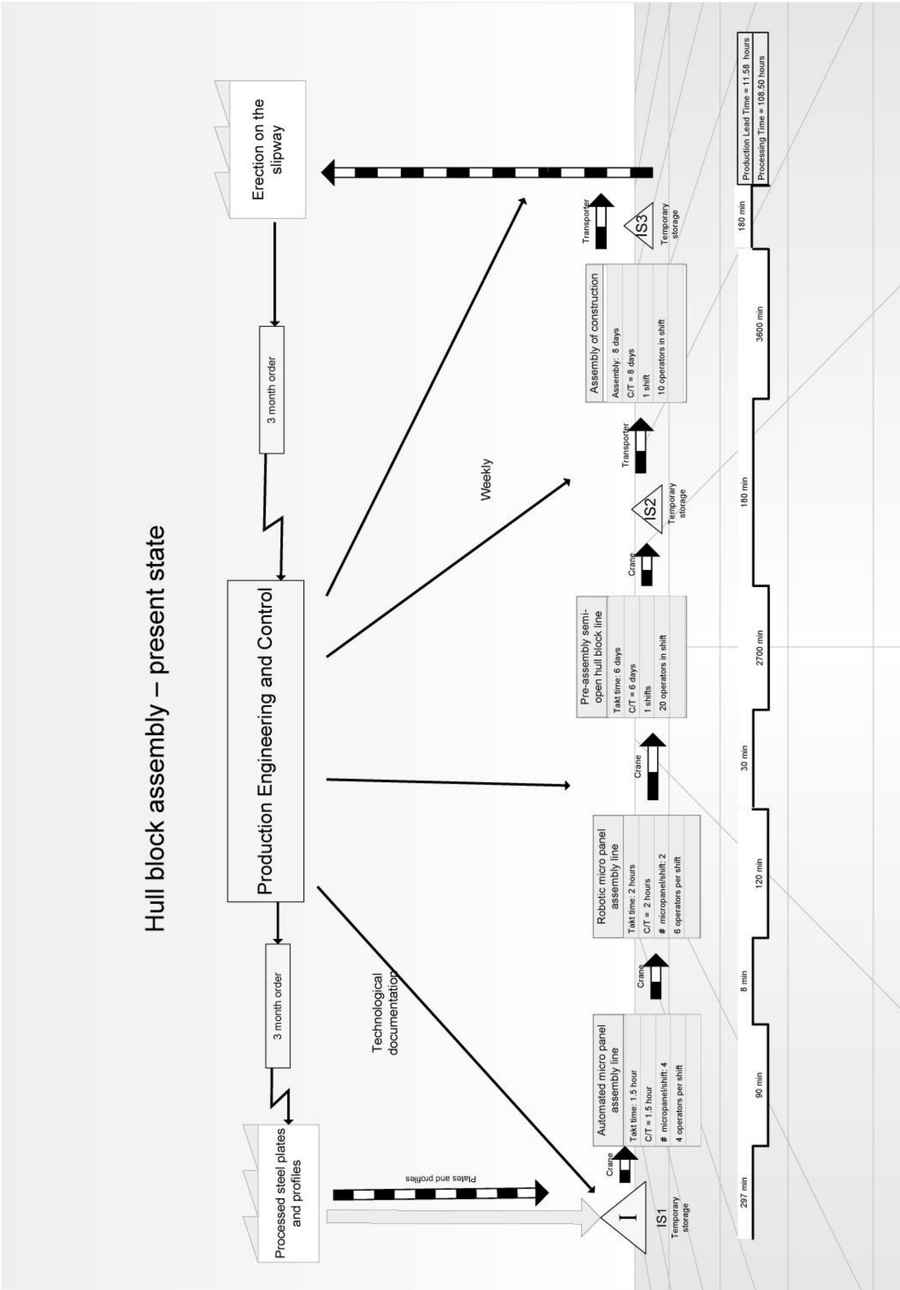

Figure 4: Ship hull block current state value stream map.

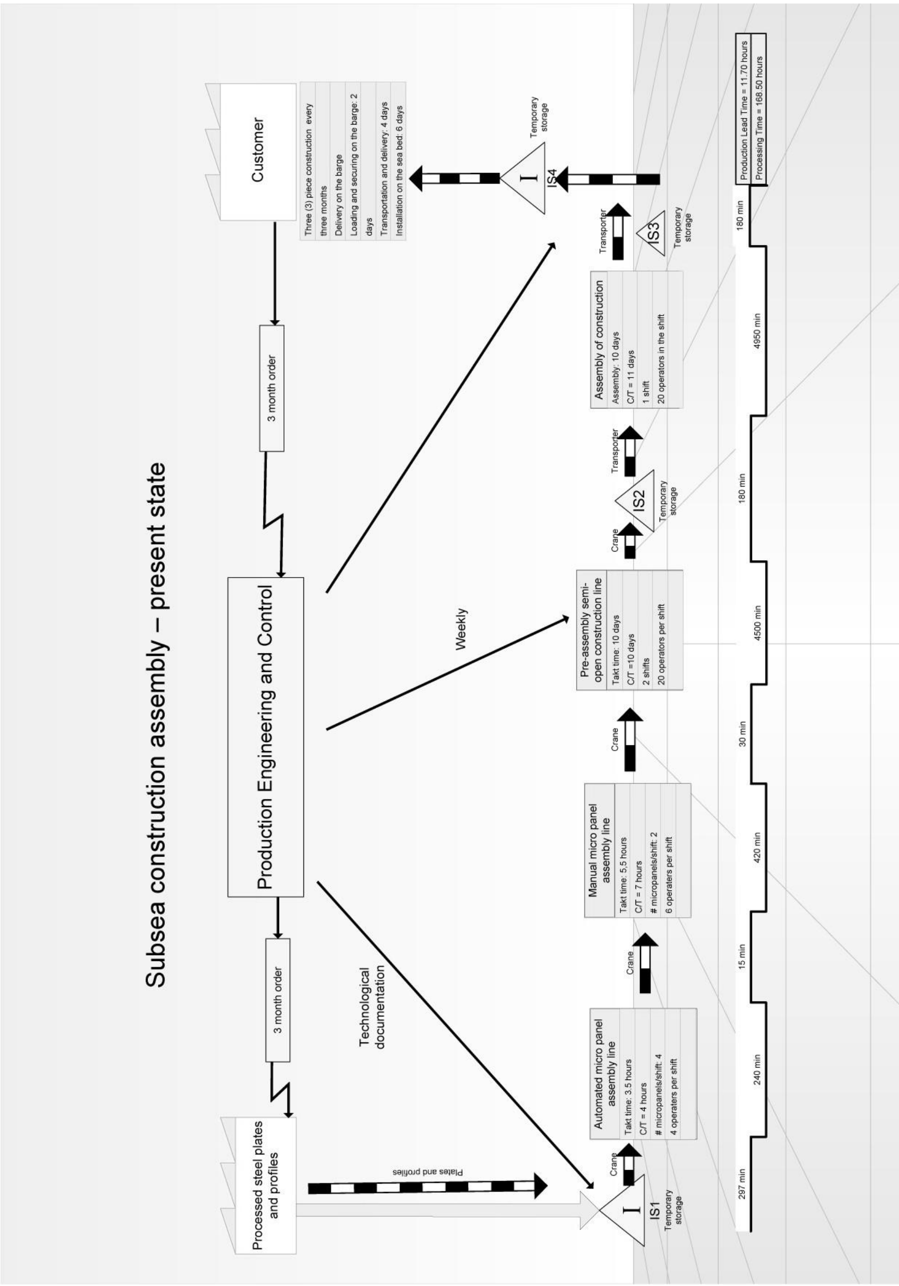

Figure 5: Subsea construction current state value stream map.

The VSM is read from the left to the right. The customer is in the top right; the processed steel plates and profiles are on the top left. In the current state process the flow of information is drawn back from customer to the production engineering and control and then to the processed material storage corrosive protected plates and profiles, welded on the panel line and prepared for the next production step.
Regarding monthly production planning, semi-opened hull welding line is prepared (ordered) by steel supplier on a three month basis.
In pre-assembly production process, material was removed from the interim storage (IS1) (fig. 5) after welding on the panel line to the automatic micro panel assembly line, manually micro panel assembly line, or in the case of the hull block assembly, to the robotically micro panel assembly line (fig. 4). The takt time, the changeover time (C/T) and the number of operators are listed under each workstation. For the automatic micro-panel assembly line, the takt time for hull block is listed as 90 min with 4 operators (fig. 4), while for the subsea construction takt time is listed 240 min with 4 operators (fig. 5). For hull block there is robotic micro-panel assembly line listed as 120 min time with 6 operators (fig. 4), while manually micro-panel assembly line for subsea construction is listed as 420 min with 6 operators (fig. 5) in two shifts. For hull block pre-assembly line is listed in 2700 min (45 hours) with 20 operators on the line (fig. 4), while on the subsea construction pre-assembly line is listed in 4500 min (75 hours) with 20 operators (Fig. 5). Semi-open block is transported to the next step of production process where is stored in the interim storage (IS2) (fig. 5).
In this workshop, the assembly line is organized for the 50 random pieces for subsea construction. The same process was used for the hull block pre-assembly with workshop cranes. The assembly process for hull block is listed as 3600 min (60 hours) with 10 operators (fig. 4), while subsea construction is listed as 4950 min (85.5 hours) with 20 operators (fig. 5).
After assembly, both hull block or subsea construction are equipped with outfitting components and corrosive protected and stored in the interim storage (IS3) (fig. 5), where they are prepared for the erection process (Fig. 4) or loading on the transportation barge (fig. 5).
Calculation of the duration time is done by adding timeline segments of all production process activities. Calculation is done by ‘conventional process method’ in eq. (1) [7, 9]. ‘Man hours are calculated by multiplying processing time of each process with the number of operators’ [7], see eq. (2).

$$DT_{Total} = DT_1 + DT_2 + DT_3 + DT_4 + DT_5 + DT_6 + DT_7 \quad (1)$$

$$\text{Man-hours}_{Total} = DT_1 \times O_1 + DT_2 \times O_2 \ldots\ldots\ldots\ldots\ldots\ldots DT_7 \times O_7 \quad (2)$$

‘DT_{Total} is total processing time, $DT_{1,2,3,..7}$ are processing times of the different processes, and $O_{1,2,3,..7}$ are the number of operators’ [7].

Production lead time for hull block assembly is 11.58 hours, while processing time is 108.50 hours. Production lead time for subsea protection construction shows 11.70 hours, while processing time is 168.50 hours. Comparison of the production times shows differences between these two processes. Both values increase in case of the production of subsea protection construction. For subsea production construction process there was not only for this project an organized manual micro panel welding line, also welders where removed from other workshops. In pre-assembly workshop was organized production line for 50 pieces of Venice subsea protection construction, there were positioned specially turning devices, steel preparation tools and NDT (non-destructive testing devices), while production process of the hull blocks uses all free workshop areas without any specific changes in shipyard downstream process.

4.2 Future improved value stream map

It is important to improve the current production process and reduce non value-added activities like setup time, movement of material in between the work processes and additional storage and processing of material. It is very important to have close monitoring of processes to reduce process variability (defects of the plates and profiles during welding, pre-heating, transportation). Efficient planned maintenance of all machines (regarding increased availability) and time reduction in all non-value-added activities are also very important in value stream mapping implementation. The future value stream map of the subsea construction is shown in fig. 6. It is necessary to improve flow and eliminate excessive transportation, interim storages time and unnecessary waiting, defects, ineffective motion. Improvements are made starting from the ordering of standardized processed steel material by kanban supermarket pull input. Because of the variable interim products in the shipyard production process, it is necessary to use standardized dimensions wherever possible. Steel suppliers will not deliver steel in one shipment, instead it will be created a kanban supermarket and steel will be delivered according to pull inputs from the production process. A prerequisite for this is standardization of steel dimensions in the design stage with Design for Production principles.

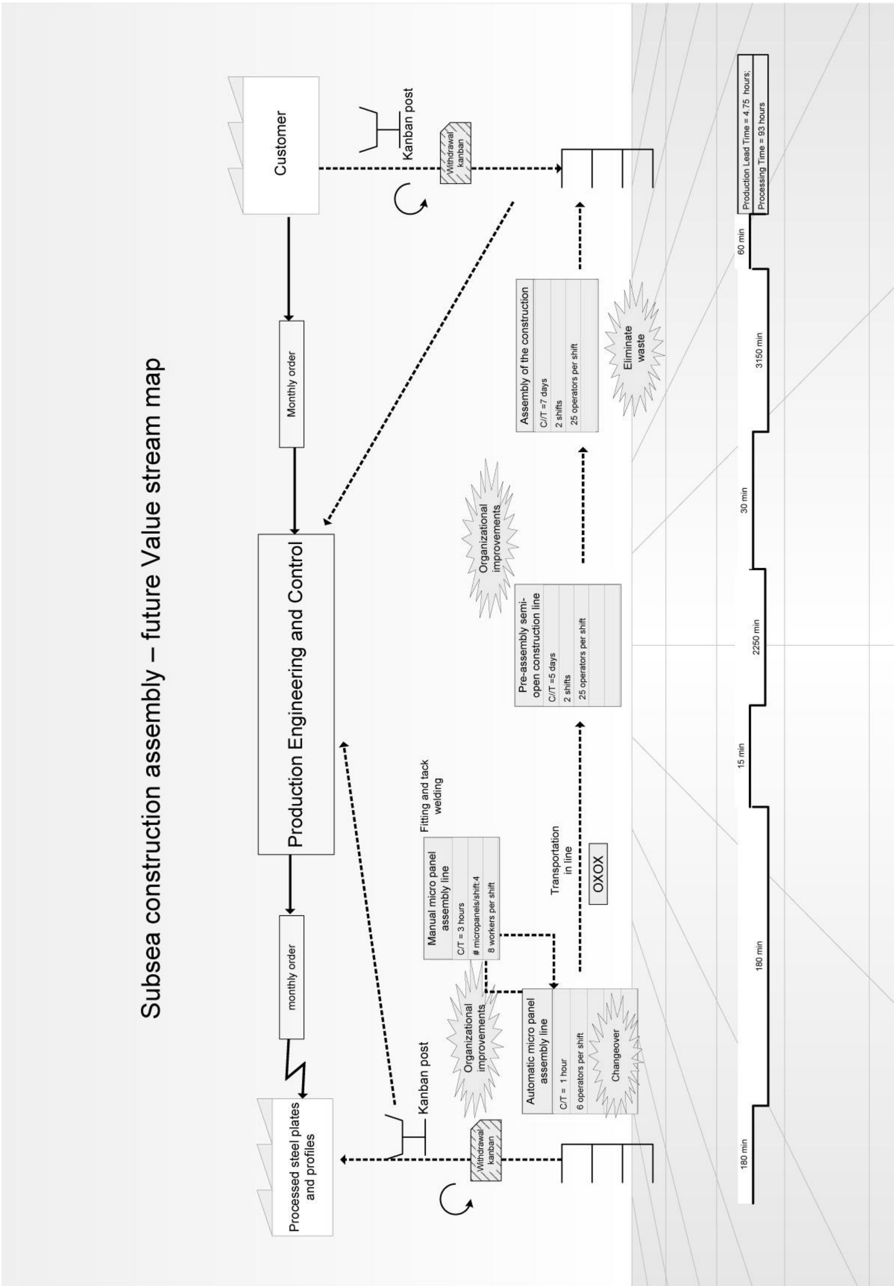

Figure 6: Subsea construction future value stream map.

In the production process, there are some improvements like parallel processes for automatic and manual welding line. Interim storages are avoided as much as possible; transportation routes shorten when the process is organized in the same transportation line of workshop. Kanban post, withdrawal kanban and production pull signal to production engineering and control and to the production stations means strongly improvement and efficiency of the production process. The OXOX represents 'load leveling' of process flow which is very important in undisturbed downstream processes flow [7, 9]. Production lead time showed improvements from 11.70 hours to 4.75 hours, improvements in production time changed from 168.50 hours to 93.0 hours (fig. 6). Comparing the results of the current state and future state for the subsea construction leads to results in terms of improvement in subsea construction production. There was no excessive production and fulfilling of interim storages in the future state, as was the case in the current state of Venice construction production. The continuous flow no longer requires interim storage between processes. The process flow in the line without unnecessary over production.

5 CONCLUSION

In the presented value stream mapping methodology a case study for the production of heavy lift hull block and subsea protection construction module for the Venetian harbor is shown. This VSM process, which incorporates the use of lean symbols and terminology, can be applied to any production process. Main concern of the value stream mapping is the inspection of defects and problem spots in similar construction production. From the future state map it can be determined that processing time but also production lead time are reduced in comparison to current state. It is achieved by applying the lean production tools and the implementation of continuous flow optimization. This new organizational change in process leads to increased net profit and acceleration of production and delivery. The presented future state needs to follow improved planning and documentation; the topics of the changes need to be better organized, more skilled workers organized as part of the standard shipyard downstream process in due time for achieving a more effective production process. Also unnecessary material transportation must be avoided and transport routes cut, as observed during the preparation of the current state map for subsea construction.
For future research the authors would recommend a more detailed analysis of the assembly and steel preparation processes, in order to demonstrate where the actual improvements can be made.

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INTERCONNECTION OF A SYSTEM- AND PROCESS-BASED MATRIX FOR VIRTUAL ENGINEERING ON THE BASIS OF THE PRODUCT LIFE CYCLE

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Abstract
The paper deals with an approach of virtual engineering (VE) that illustrates the system and process viewpoints in a generic concept called VE-matrix. The VE-matrix is characterized by a three-dimensional structure containing the most important factors.
The VE-matrix is a planning tool which helps to manage and control the product creation process (PCP) in industries. While planning the PCP a complex three-dimensional cube of elements emerges.
The VE-matrix simplifies assignment of important factors like processes, infrastructure tools and the product lifecycle (PLC). Using VE-matrix, the complete infrastructure and processes of the product can be planned in the first stage of the PLC.
Further, the VE-matrix provides a complex PCP with a transparent visualization of factors in a three-dimensional structure. This paper includes a description of the tool and an example which shows the application in industries.

Keywords:
Virtual engineering matrix, IT- infrastructure, product lifecycle, product creation process

1 INTRODUCTION

Engineers have the difficult key task to create and plan an individual and innovative product. The technical progress leads to products with interdisciplinary character. For example mechatronic products comprise elements of different domains like mechanics, electronics and informatics.
The interdisciplinary approach in the PCP increases the organization effort. The different domains have to be coordinated for the creation of a complex product.
Another important point is the increasing competition in industries heading towards to lower development costs and shorter time-to-market. Virtual engineering is an approach to solve these problems by supporting the PCP with a holistic IT- support. To integrate the concept of VE in industries

different approaches were created with various points of view. For example the virtual engineering model of Ovtcharova deals with the IT- support for different stages of the development process.
The five level modell of Warschat focuses on the IT- infrastructure. Both concepts will be described in detail in the sections 2.2 and 2.3. These approaches can be understood as guidelines for the implementation of a necessary IT- support for enterprises in industries.
The benefit of these models is organization and interconnection of the improved IT- infrastructure of a company. But the approaches have room for improvement which will be investigated in this article. To achieve an adjustment to the modern possibilities of Industry 4.0 it is necessary to create a new virtual engineering model which fulfills the requirements of modern engineering and production processes.
For this task it is important to combine the benefits of both models and add components. The virtual engineering matrix is a model which combines both models and add a product lifecycle approach on the third axis.
This paper introduces a solution, called VE-matrix, which includes the different points of view. Using this method will be a possibility to organize the needed IT- resources for the products to be developed.
Finally a use case will demonstrate the advantages of the virtual engineering matrix for a complex product.

2 STATE OF THE ART

2.1 Lifecycle model

The term ‘Product Lifecycle’ exists since the beginning to the middle of the 20th century [1]. The first investigations were focused on the general economic and management view point [2]. Important topics were price-fixing of products at different levels of maturity or the product obsolesce. In the middle of the 1980s, the product lifecycle focused on the life of a single product was emerged [2]. With this model it is possible to plan all stages of the product from the design until the recycling. An example of a product lifecycle is illustrated in fig. 1. In this generic approach the product lifecycle consists of the elemental stages from the design until the recycling specified for the developed product. The different domains like mechanics, electronics or informatics are very important for the concretization of the product because of the different requirements.

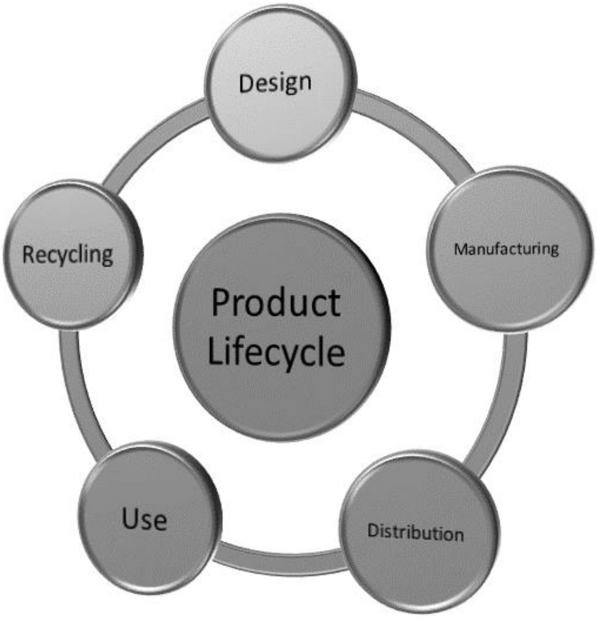

Figure 1: Example of a product lifecycle (based on [3]).

The concept is supported by different software environments called product lifecycle management (PLM) tools. These tools interconnect different development and organization software. For example computer aided design- (CAD) or computer aided engineering- data (CAE) can be used for the production planning management or the customer needs management. A PLM system has to interconnect the data of different software of the enterprise.

The product lifecycle model is a generic approach utilizable for every developed product. The following models of virtual engineering have the task to support the development of complex and interdisciplinary products like mechatronic products.

2.2 Five level model

The five level model of Warschat describes a systematic view on the IT- infrastructure of enterprises in industries. It is an important component of virtual engineering and gives an overview of necessary IT- applications [4]. The five level model gives an overview of the necessary IT- infrastructure for enterprises and structures it by five different levels of granularity.

The model consists of five different levels which are structured in three levels of IT- infrastructure und two levels of process- infrastructure illustrated in fig. 2.

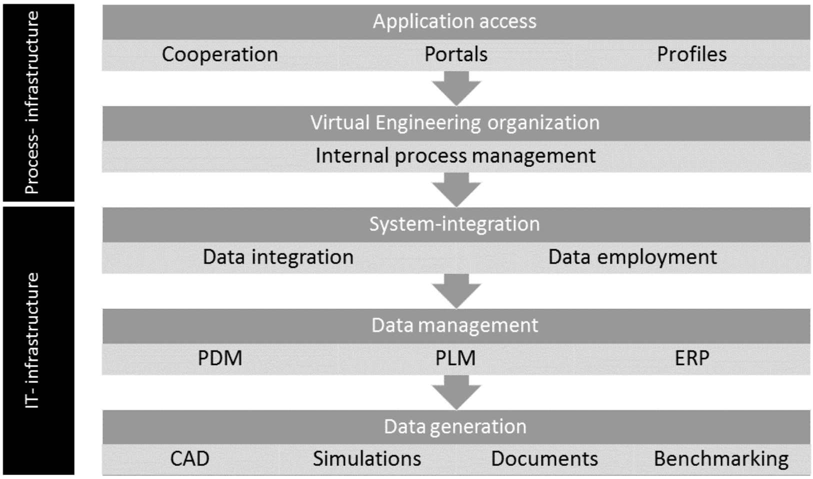

Figure 2: Five level model (based on [4]).

The first level of the IT- infrastructure is the data generation including necessary data in the PCP. For example CAD draws of the developed product have an important role and are part of the data generation. The second level is the data management superior to the data generation level. This stage includes systems which assign the data to suitable databases. In modern industrial enterprises product data management (PDM) systems are used to structure data of the construction, simulation and production. An advantage of these systems is management of product data through at the product lifecycle. Fig. 3 shows an overview of the PLM process in comparison to the PDM system.

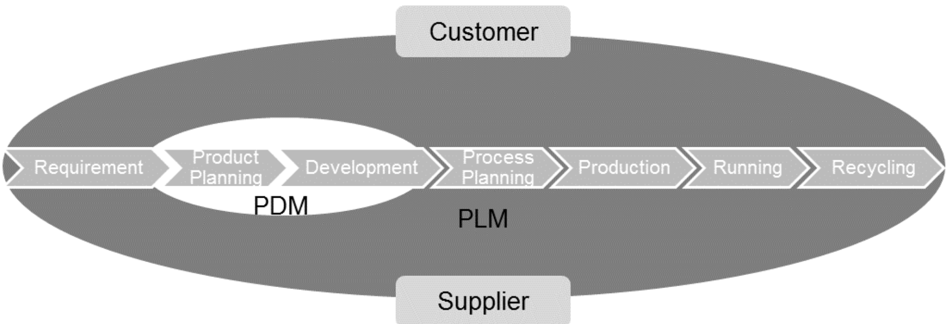

Figure 3: Comparison of PDM and PLM system (based on [3]).

The virtual engineering organization level is the first process- infrastructure level and has the task to integrate an internal process management in the whole enterprise. The last level is the application access which promotes the internal and external communication in and between enterprises.

2.3 Virtual engineering model

The virtual engineering model by Ovtcharova has another point of view. In comparison to the five level model of Warschat there is not a focus on the IT- infrastructure but a concentration on the development process of a product [5].
The concept consists of six different stages forming an iterative development cycle. Fig. 4 shows the whole model with the different stages which can be divided in three different areas with the usage of different IT- solutions.

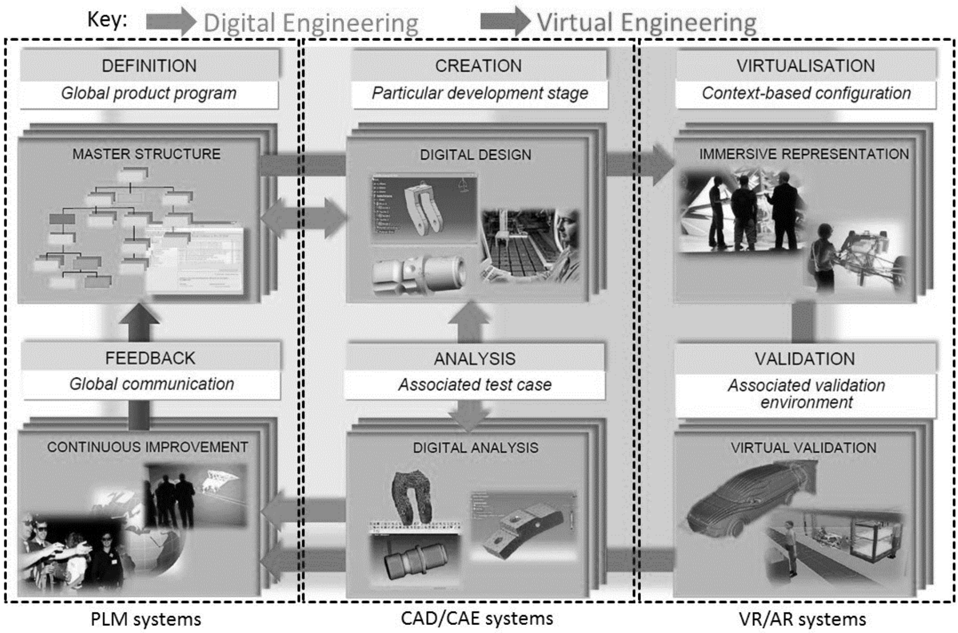

Figure 4: Virtual engineering model of Ovtcharova (based on [5]).

3 VIRTUAL ENGINEERING MATRIX

3.1 Model overview

After the description of two established models in section 2 the generic Virtual Engineering Matrix will be explained in this chapter. Fig. 5 illustrates a diagram which focuses the three-dimensional character of the new model. It

combines information of the developing product, the process stage in the development and the possibilities in the IT- infrastructure.
The first axis depicts the product life-cycle view with the different stages from the requirements definition until the recycling of the product. On this axis all characteristic information of the product is depicted. An example is the requirements definition stage which deals with all requirements of the several stakeholder groups. This axis concentrates on the information of the product which is important for the development process of the product. The requirements of the product of the first stage are important for the fulfilling of the product´s idea.
The second axis describes the process view of the development. It contains aspects of the virtual engineering model of Ovtcharova with the focus on the iterative development process from the definition to the modification stage.

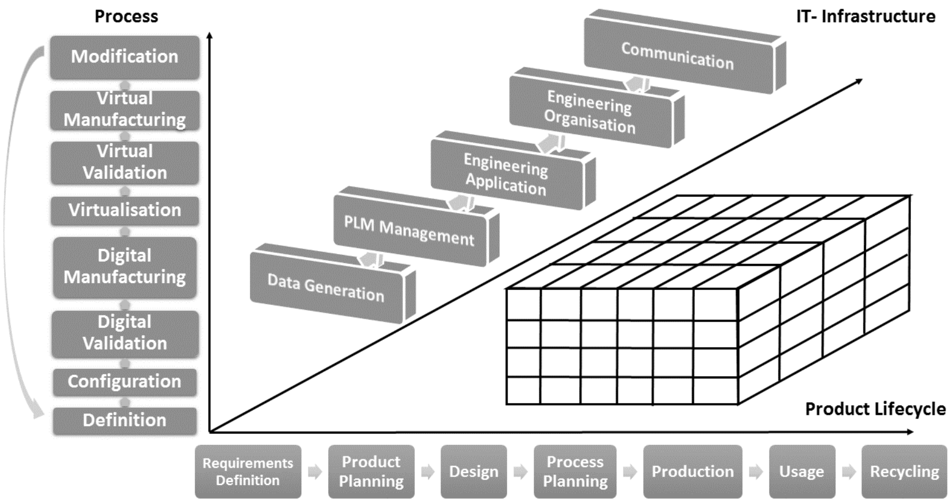

Figure 5: Virtual engineering matrix (based on [3], [4] and [5]).

The process view delivers the methods for the extraction and creation of the product information. The definition stage for example contains methods like SWOT analysis or product concept catalogue in combination with the requirements definition stage of the product life-cycle view. This axis supplies the methods for the localization of the information.
Conclusively the virtual engineering matrix has a third axis for the IT-Infrastructure view which creates a three-dimensional model. The IT-Infrastructure view includes main aspects of the five level modell of Warschat for the deployment of an intact IT- environment in an enterprise. The IT- infrastructure is determined by different characteristics of the

enterprise. The size of an enterprise has an influence of the IT- environment for example the server architecture. Another example is the action field of the company. A carmaker needs another infrastructure than a craft enterprise. For example the stage data generation describes the generated development data and the correct data formats.
The virtual engineering matrix has three different perspectives on the PCP. All information is provided to generate a complex product. For every combination of these three axis a cube can be build which integrates information of all axis.
The generated construct which can be created by these three axis includes all necessary information about the PCP and can be a planning tool as a first step of the product planning.
The created three-dimensional matrix is not filled in every element completely. Some combinations do not include information of all axis. For example a combination of recycling, virtualization and communication has not a value generating character.

3.2 Significance of the VE-matrix

The section 3.1 has described the characteristics like the three dimensions. This includes reasons for the importance and significance of the VE-matrix.
The tool can be used in the first stage of the PCP to plan the creation and whole PLC. The intensive planning with the VE-matrix needs at the beginning of the product development a higher period of time. But the detailed planning prevents errors and saves lots of time for the implementation of the product development. This emphasizes the frontloading character of the tool. The importance of a planning tool is shown by 'The Rule of Ten' which describes the correlation between the stage of the development and the costs of the error rectification [6]. The debugging in subsequent development stages leads to an increasing of the debugging costs. The planning stage is the cheapest possibility to decrease the debugging costs.
Another capability for the VE-matrix is the using as a management and controlling tool. After the planning the PCP has to be controlled for not exceeding the time-to-market. The information of the VE-matrix can be used as a check list to surveil the level of development. It delivers a qualitative result and remembers the goodness of fit of the methods on the process axis and the IT- infrastructure for the optimal support of the PCP.
The VE-matrix tool makes a complex process transparent and simplifies it. The resulting cube of the VE-matrix which contains inputs of process, PLC and IT-infrastructure includes all necessary information for the PCP. The compact form of visualization makes it transparent and simple.

4 USE CASE

The virtual engineering matrix provides several use cases for every industrial project. Especially projects which involves several domains in the development like mechanics electronics or informatics are interesting for the using of the virtual engineering matrix. A pedelec is a cross-domain product illustrating the advantage of the VE-matrix. To summarize information of all steps would go beyond the scope of the publication. Because of that two combinations of the three viewpoint axis will be investigated for the chosen product.
The first element of the matrix in fig. 6 combines definition of the process axis, requirements definition of the PLC axis and data generation of the IT-infrastructure axis.

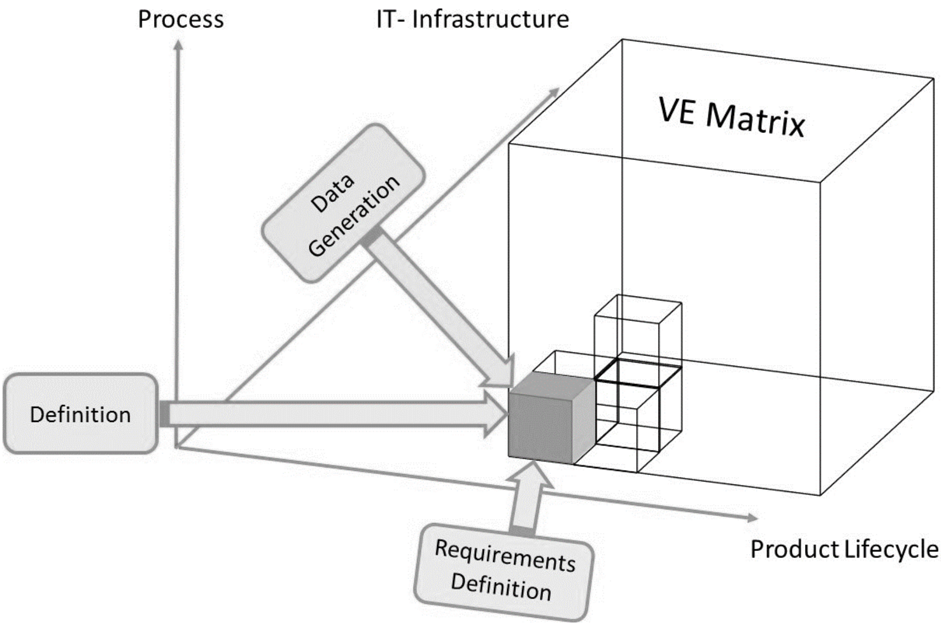

Figure 6: Combination of the first three viewpoint (based on [3], [4] and [5]).

This combination generates the first important information for the product, the methods for the extraction of information and the IT- integration into the enterprise structure. The process axis delivers methods like customer survey [7], check list, key characteristics list [8] or identification matrix [9] for the identification of requirements. The IT- infrastructure axis includes different data formats which are the basis of the software. IBM DOORS (Dynamic

Object Orientated Requirements System) is an example for IT- support in the requirements definition. The requirements definition of the PLC axis possesses characteristic information of the developing product like the main function of the product which are driving, speeding and braking for a pedelec. With the help of the different viewpoints a requirements list of the product can be generated. The IT-infrastructure provides the uniform inclusion, the methods of the process are useful tools to identify the requirements and the characteristics of the developing product delivers important constraints.
The second combination which is demonstrated in this publication in fig. 7 includes product planning of the PLC axis, configuration of the process axis and PLM management of the infrastructure axis. Configuration of the Process axis describes methods and elements of construction methodologies [10].

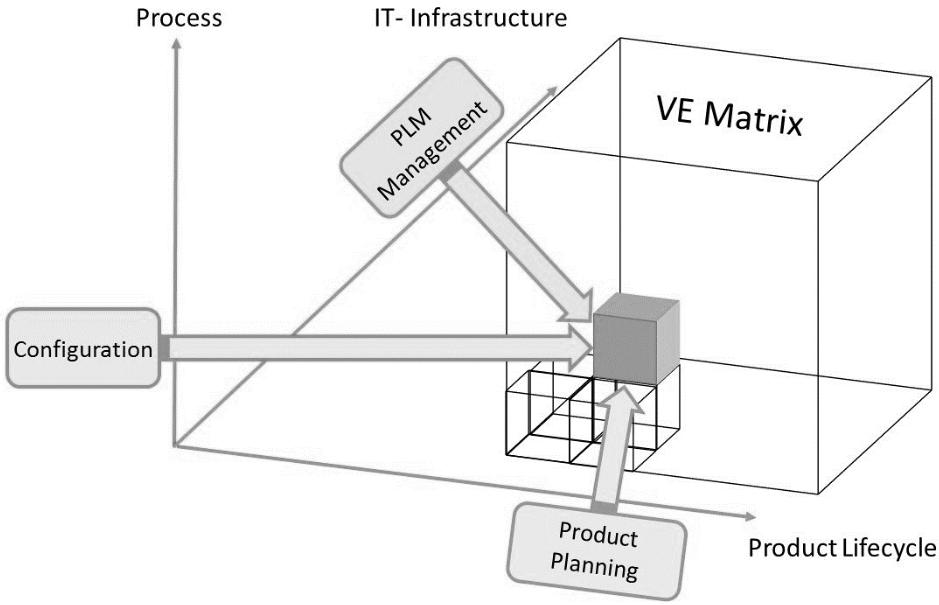

Figure 7: Combination of the second three viewpoint (based on [3], [4] and [5]).

There are product-market-based situation analysis and methods for the generation of product ideas. The PLM Management of the IT- Infrastructure axis supplies the PLM software with aspects of the product planning. The product planning stage of the PLC axis has characteristic aspects of the product like information of the whole product life cycle which are already known. The addition of these three viewpoints provides an overall picture which gives possibilities for an enterprise. The choice of different methods or IT- solutions can influence the success of companies. But it is more important that the VE-matrix is a planning tool which supports the frontloading of the PCP. The users of the VE-matrix can regard all aspects and combinations and will not forget important information for the realization of an innovative product.

5 CONCLUSION AND OUTLOOK

The VE-matrix is a concept to support the planning stage. In the development of cross-domain, complex products it becomes more important to intensify the planning of the whole PLC in the first stage of the PCP. Using the VE-matrix delivers necessary information of three different viewpoints. It combines the PLC, process and IT- infrastructure point of view. The idea of the VE-matrix is a comprehensive organization of the whole PCP which does not lack important information.

The described two combinations in the proposed use case are only a fractional part of the complete VE-matrix. Certainly the use case shows that the type of the product influences the selection of methods and software solutions. But it does not influence the structure of the VE-matrix. The combination of the three different viewpoints PLC, process and IT-infrastructure forms the core of the tool.

The presented content is the first concept of the planning tool. The next step is an in-depth research on the various combinations within the VE-matrix. It must be investigated which is most important for industrial applications. On this the several combinations must be evaluated. Based on this, databases for the process and IT-infrastructure viewpoints will be created and thus the optimal combination for individual products will be selected.

Following this, the concept will be implemented in an IT- solution. The implementation will increase the usability and the collaborative using which is important for the penetration in the companies.

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ANALYSIS AND INSTALLATION OF A NEW LINE FOR ASSEMBLING HEAT EXCHANGERS

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Abstract
The study concerns the implementation of lean manufacturing in a company that manufactures heat exchangers in order to improve the performance of an assembly line. After analyzing the value stream in the current situation, changes were made to the layout and the operations, aiming to eliminate activities that do not add value for the customer, reduce lead times and increase the speed and flexibility to changes in demand in terms of volumes and product mix. Changes to the system were introduced in a model to simulate both the present situation ('as-is') and the future situation of the value stream (analysis 'to-be') and to identify the configuration of a new assembly line that allows for the improvement of material handling and reduction of lead time. A new layout was developed, and a supermarket was introduced to feed materials to assembling operations.

Keywords:
Assembly line, lean manufacturing, simulation

1 INTRODUCTION

Lean manufacturing promotes continuous improvement by means of improvement actions at tactical and operational levels: production departments are therefore a typical target of lean projects. The application of lean methods and practices in manufacturing cells or lines has been discussed in previous research [1] [2]. Studies have been published that deal with line capacity problems when demand varies [3], and simulation techniques have been implemented to flexible assembly cells [4] or job shop assembly departments [5], in particular using just-in-time (JIT) scheduling [6].
The study presented in this article concerns a line that assembles compact or cross-flow aluminum heat exchangers. It was aimed at reorganizing the final assembly and packaging of the production order to improve the assembling flow, reduce the throughput time and improve the control on the operations.
The study consists of two stages: the analysis of the situation 'as-is' and the reconfiguration of the assembly line. In the first stage, an investigation was

made to identify the waste sources (‘muda’) and the possible areas of improvement. The investigation took into consideration the assembly workstations, the packaging area and the warehouses that feed the components to or receive the finished product from the line.

2 DESCRIPTION OF THE ‘AS-IS’ STATE OF THE ASSEMBLY LINE

The line manufactures few hundreds of end-items, therefore, in order to individuate the key items the analysis of the production sold in the 21 months before, a time horizon that the company considers sufficient to account for demand fluctuation. Both quantities and turnover share per item were collected and an ABC analysis was performed. Table 1 shows the results and the classes obtained with respect to the total turnover in the time horizon. In addition, the end-items were subdivided into four classes (P, M, G, E) according to their price, which depends on the item’s size and manufacturing complexity.

Table 1: Classes of end-items.

.Class (2012)	*Total codes*	*% of codes*	*%* turnover	*Class (2013)*	*Total codes*	*% of codes*	*% turnover*
A	83	19.04	70	A	72	17.43	70
B	178	40.83	25	B	177	42.86	25
C	175	40.14	5	C	164	39.71	5
Total	436	100.0	100	Total	413	100.0	100

By the joint use of the two classes, it was possible to identify 69 items (16.9% of the total) which make up 70% of total turnover; among those, 17 items were identified as ‘best sellers’ both in terms of quantity and revenue compared to the other items. The unit production time of those 69 items was taken into account to measure the performance of the line before and after the improvement. In addition, the target cycle time (takt time) was assessed for P/M/G classes, which was based on demand data collected by the company’s information system.

Field time sampling allowed the assessment of 14 value-adding (VA) and 10 non-value-adding (NVA) activities in the current situation. Total average cycle time was 413.7 seconds, of which 272.4 s are VA activities and 141.3 s are NVA activities: by eliminating the NVA activities it is therefore possible to reduce the total cycle time by 34.2%. Field observations were employed to draw the value stream map of current state (fig. 1) and the spaghetti charts of fig. 2. Such charts highlight the distance covered by the operators to perform their activity.

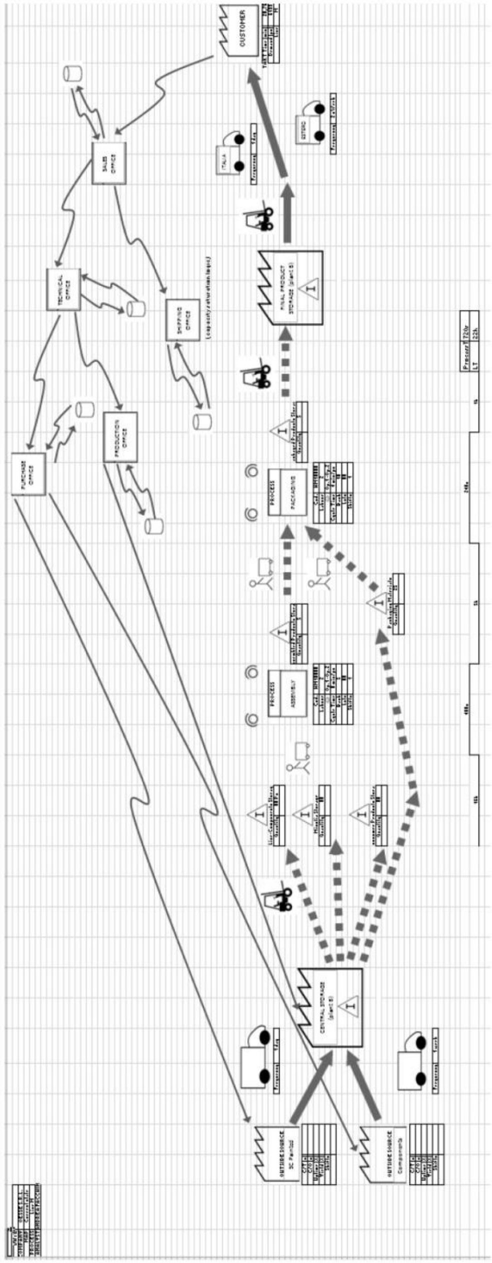


Figure 1: Value stream map of ‘as-is’ state.

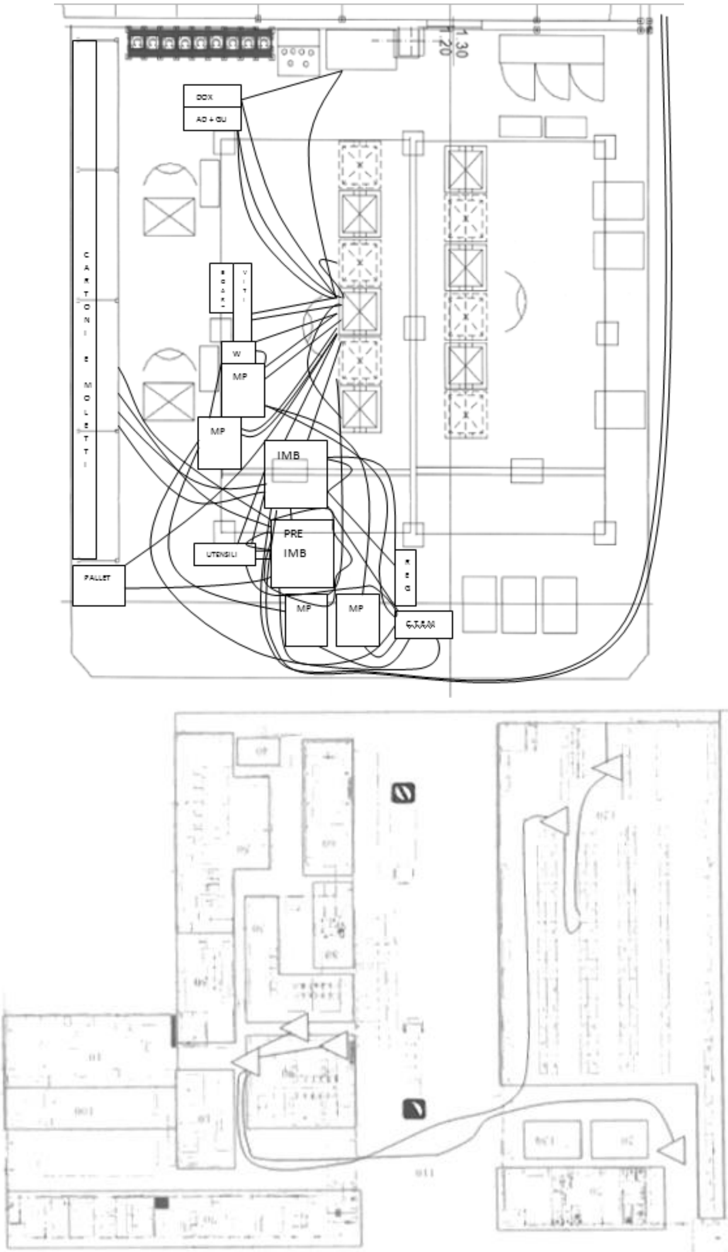


Figure 2: Spaghetti charts of 'as-is' state.

3 SIMULATION OF THE 'AS-IS' STATE

A simulation model of the 'as-is' state was designed and run using an object-oriented software package. The model uses the data collected in the field, and simulates 460 minutes of operation, which correspond to a work shift (fig. 3).

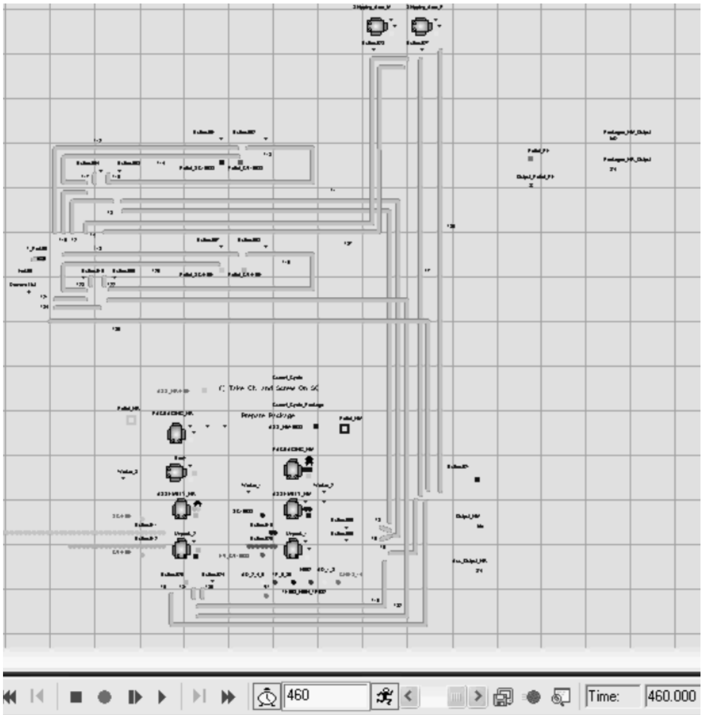


Figure 3: Model of the 'as-is' state.

In a shift 50 heat exchangers are assembled and packaged (5 pallets). The used capacity of the assembly line is 65.5% (fig. 4), which includes VA activities (51.5%) and work order setup (14%).

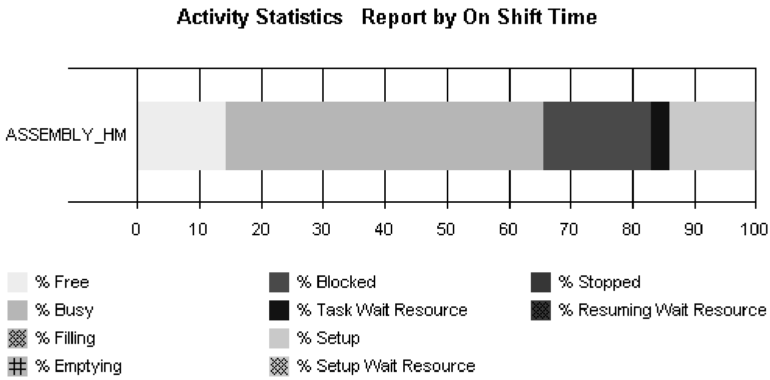


Figure 4: Activity states during a simulation.

4 SIMULATION OF THE 'TO-BE' STATE

The simulation model of the 'to-be' situation reproduces a pilot assembly line that manufactures items of class M: this class includes the majority of items, the line therefore represents a modular model that can be used for the other classes too. The 'to-be' state of the line characterized by the following main aspects (fig. 5):

- The assembly line is located in one building with reduced distances between work centers
- Material flow is pull-based
- One-piece flow
- Assembling and packaging of different item families is managed by means of mixed-model
- Component flow is managed by a kanban system

Several improvements were made in the new line. A supermarket kanban decouples feeding from assembling. A kitting system prevents waste due to lack of material, unnecessary in-line stocks and inefficient assembly operations. Small stocks are available long the line, thus reducing unneeded movements. Packaging operations are standardized. Visual management is applied in the line so that the assembly process is smooth and work-in-process minimized. The assembly line is ergonomically improved with benefits for the operators and their activity. Tasks are plainly assigned and distributed among the line workers, who benefit from a fair work balance; still, the number of line operators has not changed making therefore possible the improvement of the line's performance without additional resources. All these solutions were implemented in the simulation model and then tested.

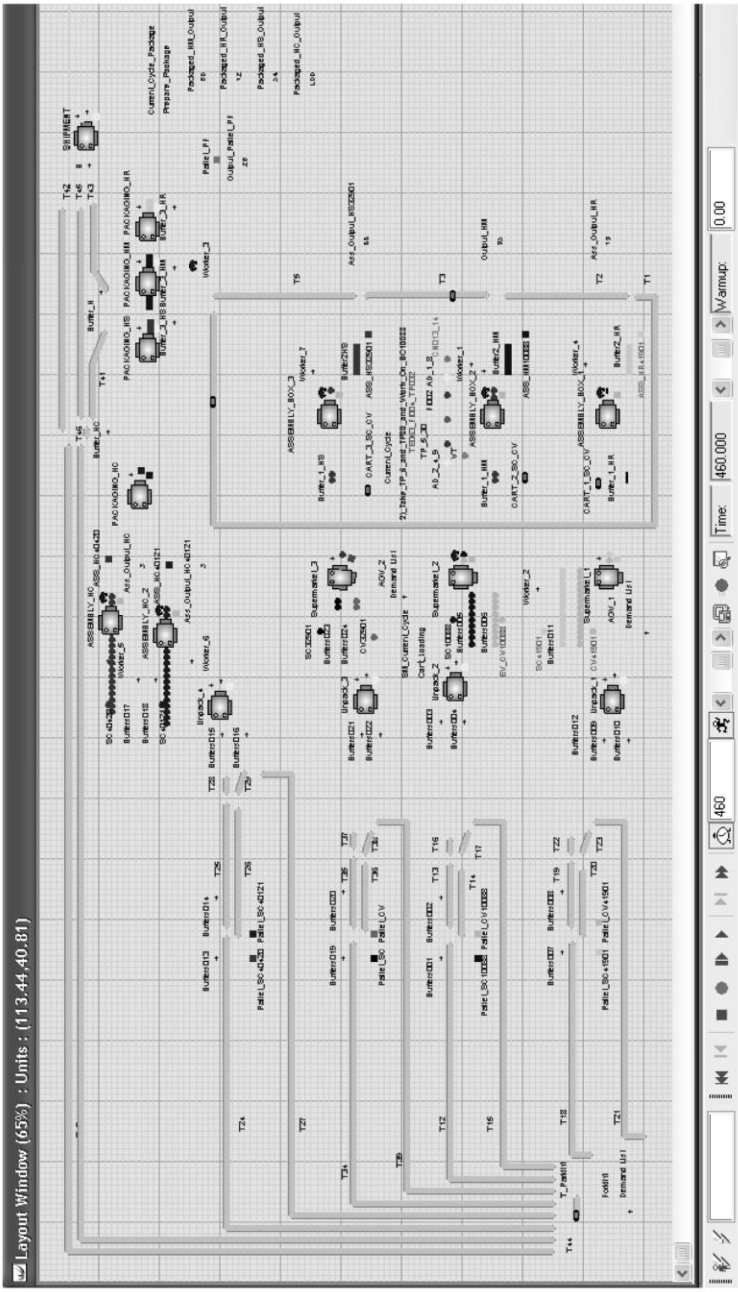


Figure 5: Model of the ‘to-be’ state.

Several improvements were made in the new line. A supermarket kanban decouples feeding from assembling. A kitting system prevents waste due to lack of material, unnecessary in-line stocks and inefficient assembly operations. Small stocks are available long the line, thus reducing unneeded movements. Packaging operations are standardized. Visual management is applied in the line so that the assembly process is smooth and work-in-process minimized. The assembly line is ergonomically improved with benefits for the operators and their activity. Tasks are plainly assigned and distributed among the line workers, who benefit from a fair work balance; still, the number of line operators has not changed making therefore possible the improvement of the line's performance without additional resources. All these solutions were implemented in the simulation model and then tested.

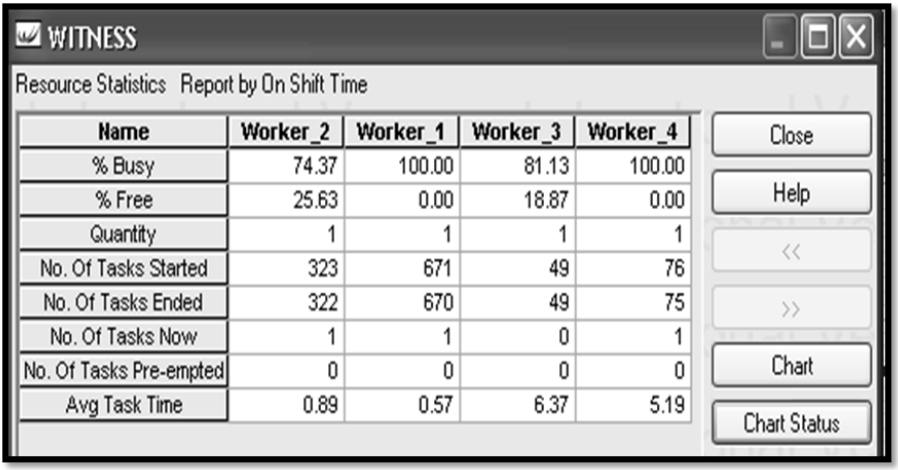
The distribution of tasks allows a clear distinction of roles. A truck driver collects material from the central warehouse and feeds the supermarket; he delivers pallets of finished products to the shipping area. The supermarket operator replenishes, from the supermarket, in-line stocks by means of a kanban two-bin approach; he prepares assembly kits and loads the basic component of a product on a platform truck that is queued at the beginning of the line. The line operators perform the assembly tasks and the line set-up if needed. Items are assembled on the platform trucks and then moved to the packaging area. The packaging operator unloads the end-items from the platform trucks queued at the beginning of the area and puts them into a pre-assembled container. When the packaging contains all items reported on its packing list, the operator closes, straps, and labels it.

Time measurements were taken on the pilot line: results show that the reorganization of tasks positively affected production flow time and cycle time. In regard to class M, the following production rate increases were obtained:

- 72.7% for assembly (the average daily production rate increases from 55 pieces to 95 pieces)
- 60% for packaging (the average daily production rate increases from 50 pieces to 80 pieces)

The simulation shows a good distribution of work among the operators and 34.5% increase of utilization of assembly, which is the stage with highest value-adding activity (fig. 6 and fig. 7). It is worth noting that the truck driver, in this balanced configuration, uses 73.1% of time for feeding the assembly line (fig. 8).

The new configuration and layout of the assembly line were designed so that the areas for in-line feeding stocks were available, reducing movements and transports.



WITNESS

Resource Statistics Report by On Shift Time

Name	Worker_2	Worker_1	Worker_3	Worker_4
% Busy	74.37	100.00	81.13	100.00
% Free	25.63	0.00	18.87	0.00
Quantity	1	1	1	1
No. Of Tasks Started	323	671	49	76
No. Of Tasks Ended	322	670	49	75
No. Of Tasks Now	1	1	0	1
No. Of Tasks Pre-empted	0	0	0	0
Avg Task Time	0.89	0.57	6.37	5.19

Figure 6: Summary of the simulation results ('to-be' state).

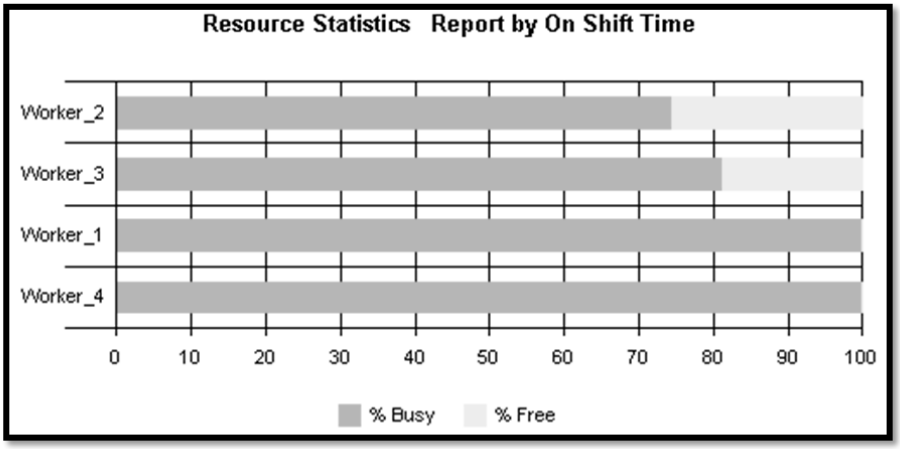


Figure 7: Resource states.

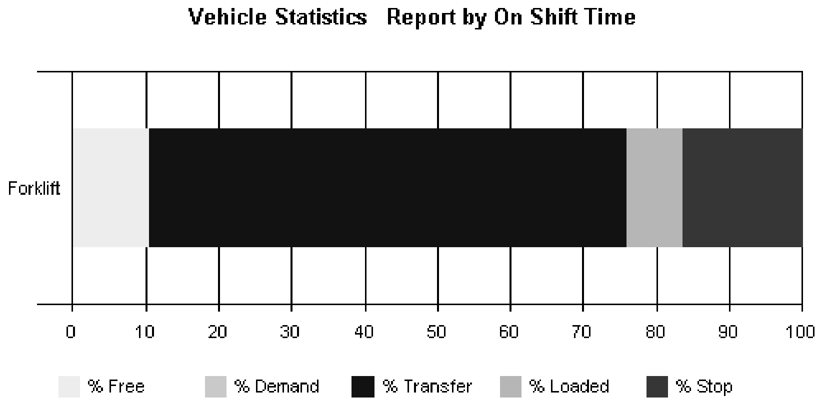


Figure 8: Activity report of truck driver.

5 CONCLUSION

The reconfiguration of the assembly line, based on lean manufacturing principles and tools, brought significant improvements to the process performance. Simulation had a key role in the study, because it enabled to test possible solutions or changes on a model without the need to implement them on the actual line. Nonetheless, the final configuration of the new line was tested in the field, showing production rates that were in accordance with those produced by the model.

This opportunity encourages discussion about solutions, which can be immediately verified by means of the model, and their consequences on the system. Using this approach, possible problems or ineffective modifications to an existing line can be prevented, avoiding the introduction of errors in the design or realization stages.

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CPPS - BASED MARKET ACCESS OPPORTUNITIES FOR PRODUCTION CAPACITY PROVIDERS

New channels for cross-enterprise collaboration through automatized supply and demand synchronization in cloud-based production environments

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Abstract
The combination of cyber-physical production systems (CPPS) and cloud-based manufacturing services introduces new market access opportunities for production capacity providers. In an environment of cloud-based collaboration with CPPS, enterprises are enabled to cooperate in a dynamic value chain. The cloud-based cross-enterprise production platform serves as a market place matching supply and demand. Disposition and pricing are based on a set of process indicators. This new form of collaboration enables new business models for production capacity providers and questions existing business models of original equipment manufacturers (OEMs). The main activity of the production capacity providers will shift from providing parts to the provision of manufacturing services. An excellent manufacturing capability does not ensure a long-term strategic advantage. The focus of existing OEM business models will shift to an innovation-driven enterprise coordinating the dynamic value creation network.
This new form of cooperative value creation requires further research on automated cloud-based decision making and underlying business models.

Keywords:
Cyber physical production systems, cloud-based production platforms, Industry 4.0 business models, collaboration networks, factories of the future

1 INTRODUCTION

Established production control systems are called into question by the development from automatized centralized production systems to manufacturing environments formed by autonomous cyber-physical production systems (CPPS). CPPS are production systems formed by multiple cyber-physical devices [1]. This enables the dynamic adaption of value creation networks [2]. Such networks benefit from the independence and autonomy of CPPS in manufacturing environments. Each CPPS can act

as an individual manufacturing service provider. The current static, dominant interconnections between production systems are dissolved by CPPS [1].
This paper provides an analysis of cloud-based cross-enterprise collaboration facilitating such dynamic adaptable value creation networks. The paper is divided into six sections. The following section summarizes the initial state of the art concerning collaboration along the value chain, cyber-physical production systems and the impact of such systems in existing manufacturing environments as well as associated developments. The third section focuses on the ManuCloud project as one state of the art-example of cloud-based manufacturing. The research approach in the topic of cloud-based cross-enterprise collaboration is presented in section 3. Based on these findings possible business models and impacts on existing business models are discussed. Section 5 outlines further research topics in the field of cloud-based cross-enterprise collaboration based on CPPS.

2 STATE OF THE ART

2.1 Collaboration along the value chain

In the context of industrial production the value chain is a sequence of processes in order to produce a valuable product for the market [2]. The supply chain is the network of organizations that participate in this sequence of the value-adding process.
These supply chains are mostly hierarchical. OEMs invite tenders for sub-processes to select a Tier 1 supplier. Tier 1 suppliers delegate the sub-processes and commission Sub-Tier suppliers. The connections are agreed through binding contracts. A once established relationship, defined by a contract, is hard to dissolve. An example of this collaboration along the value chain through one OEM is shown in fig. 1.
The reasons for the integration of suppliers are numerous. Within this paper, detailed looks at the collaboration through dynamic, cloud-based contract manufacturing and the implications for business models are taken. Nowadays, contract manufacturing is one way to implement the concept of extended workbench. Usually this form of collaboration is used for basic, low specialized tasks and parts. New forms of collaboration are value networks. In value networks the coordination of the value chain is not processed by the OEM but by the network itself [3].
Fig. 2 shows an interactive value creation network. The OEM will take the role of the coordinating instance. The initiative for the value creation is given by the OEM acting as the procurer to the customer. The coordinating instance (agent) is reliant on the contracts to the network members in charge of the different processes.

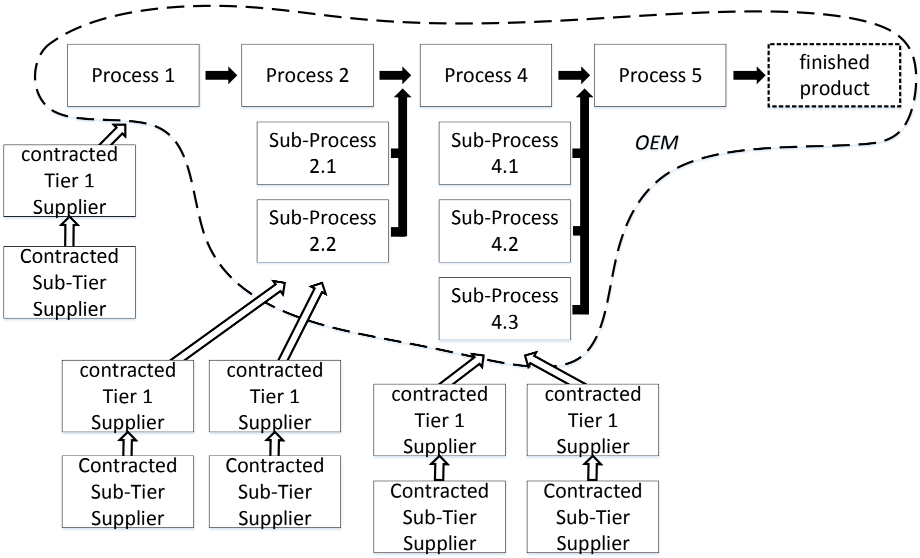

Figure 1: Hierarchical collaboration along the value chain.

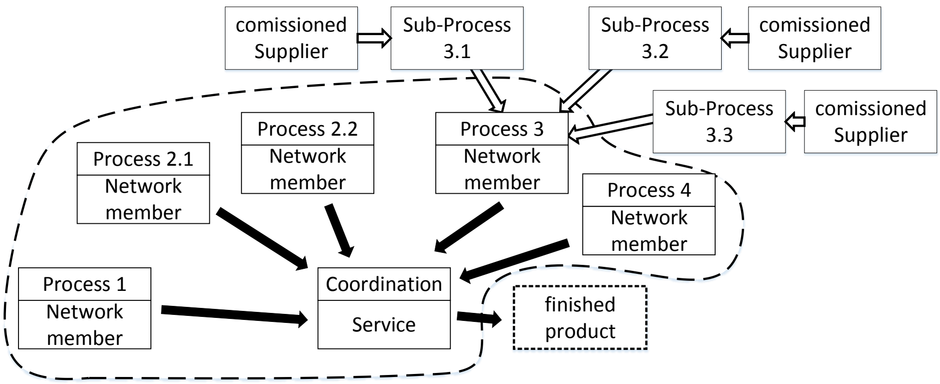

Figure 2: Value network with coordination service.

2.2 CPPS

A CPPS consists of linked, collaborating Cyber-Physical Production Devices (CPPD). A CPPD is an embedded system which has an additional networking interface to communicate with other CPPDs. Its task is to control or observe physical production processes through sensors and actors [1].
Through the connection of multiple CPPDs, the data exchange among them and connections to superordinate collaboration platforms, CPPS can gain

holistic information on their given tasks. This thesis leads to the idea of dividing the manufacturing process into certain autonomous production systems.
A main difference between CPPS and existing production systems is the improved ability to gather and process the information. This improved information processing enables an embedded cognition and artificial intelligence of the CPPS. CPPS offer a higher flexibility of the production system due to self-X abilities [5]. The higher flexibility is demanded due to the impact of trends such as mass customization.
Among mass customized products the point of individualization is varying [4]. By employing CPPS and a flexible, self-optimizing production, the point of individualization can be shifted even more to the front stages of the value creation process. An even better fit to the customer demand can be achieved by a flexible value chain.

2.3 Impacts of CPPS

Significant changes in the manufacturing processes of existing enterprises are expected to occur [6]. As a consequence of the division in separate, autonomous manufacturing units along with the decentralization of production control, a dissolution of the conventional automation pyramid is likely [1]. Hence the central enterprise control elements, like Enterprise Resource Planning System (ERP), production planning system (PPS) and manufacturing execution system (MES), do not need to break down orders to the single production processes and units. Instead the tasks of central business management applications will shift from controlling processes and systems to a provision of the necessary master and transaction data. This conversion is shown in fig. 3.

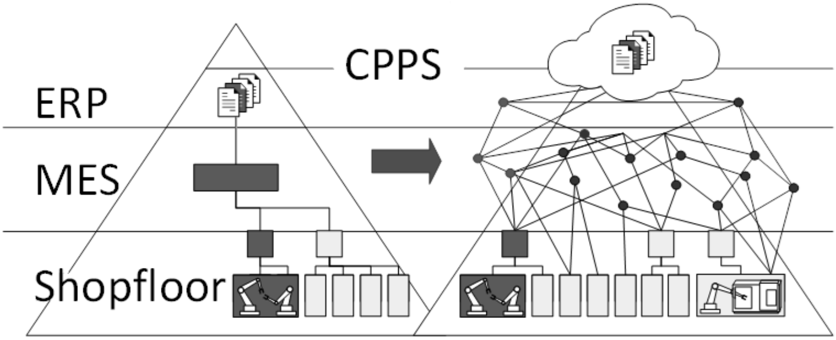

Figure 3: Decentral organization of the production [1].

3 CURRENT RESEARCH

The ManuCloud project is a research project funded under the Seventh Framework Program for Research (FP7) addressing the problem of integrated value networks in a cloud based environment [7].
The aim of the project is to develop a cloud-based platform (fig. 4) based on cloud-enabled, federated factories to provide manufacturing capabilities of configurable, virtualized value chains [8].

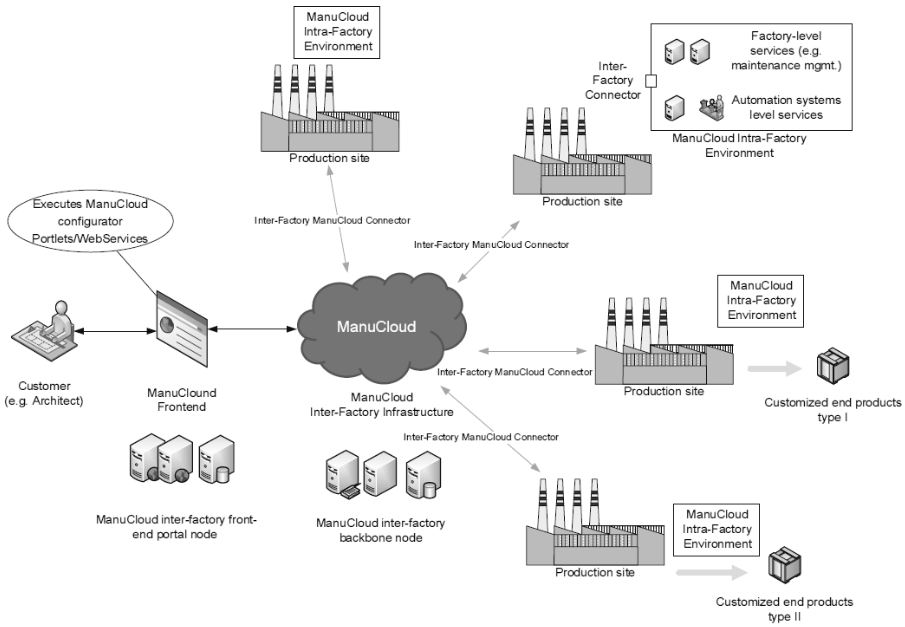

Figure 4: ManuCloud architecture [7].

Within the ManuCloud project, cloud manufacturing is the key essence in the collaboration of enterprises within the value chain. Wu et al. define cloud manufacturing as '[…] a customer-centric manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resource loading in response to variable-demand customer generated tasking' [9]. Cloud manufacturing is the transfer of cloud computing into manufacturing environments. Dynamically configuring a manufacturing supply chain enables Manufacturing-as-a-service (MaaS) for complex products [8]. MaaS describes the paradigm of offering manufacturing services rather than manufactured products. The ManuCloud project focuses on the development of service descriptions of enterprises participating in the cloud as well as on the development of the required MaaS infrastructure. The standards defined within the project are developed as open standards not limited to a specific branch or product [10] [10].

4 CLOUD-BASED COLLABORATION

This section outlines the aspects of cloud-based collaboration in manufacturing environments. Current research projects such as the ManuCloud project mostly look at difficulties of IT concepts behind cross-enterprise cloud-platforms [11]. This paper focuses on analyzing underlying collaboration forms and possible impacts on business models.
As stated in section 1.3 one possible outcome of the implementation of CPPS can be the functional separation and thus the autonomization of CPPS-controlled manufacturing segments.
A cross-enterprise, cloud-based production control platform using agent-algorithms could be used in such an environment to execute production processes beyond enterprise boundaries. The production process sequence derived through customer input is then executed by the assigned agent.

1. The agent looks for suitable CPPS which can perform sections of the sequence. The search is done in the directory of the platform. According to the specification of the production systems the suitability is tested.
2. If suitable production systems are found, a negotiation process similar to market place applications is started. This negotiation process determines if the selected production system can provide the required service according to desired quality, time and costs. Corresponding to the negotiation the order is scheduled.
3. If no suitable production system can be found, the service needs to be procured externally by the coordinating company. In this case the agent resembles restrictions for external procurement such as delivery timeframe, maximum costs and mandatory requirements.
4. If no external resource can meet these restrictions the complete order needs to be processed manually.

If more than one suitable production system can be found the agents decide between the competing production systems. The decision making process is described in subsection 3.2.
Such an open collaboration platform implies new challenges for the cross-enterprise cooperation. A structure for the cross-enterprise collaboration of several companies is described in the following subsection 3.1.

4.1 Cloud structure

The cloud collaboration platform is an internal control structure for the cross-enterprise production collaboration. The order from the customer is processed by one coordinating company. This company is the only participant in the collaboration platform with direct contact to the final customer and takes the responsibility for the order. The production capacity providers and the coordinating company are linked by the platform. The coordination of one order is processed by an assigned agent of the coordinating company. An agent is a virtual element of the value creation network and the production control system.

Through the platform these agents gain the ability and the legitimation to include and schedule external resources in the same way as internal resources. The suppliers, usually providers of production resources, own and operate manufacturing equipment which they offer independently to the platform. These resources need to be controlled by platform-integrated CPPS which can be accessed and controlled by the agents. The providers need to offer services like machining, testing, assembly, packaging and other. The provision of complete parts fades in the background as the service of the providers is offering the production process itself (compliant with the definition of MaaS). This change causes a complete reorganization of established collaboration forms and business models of both suppliers and OEMs outlined in section 4.

Developments in production and automation engineering like CPPS and an increase of flexibility of production system enable this development of provision of production capacity instead of supplying complete parts. The vision of CPPS-integrated manufacturing systems requires an interchangeability between production processes due to the increasing flexibility. This interchangeability is a mandatory requirement for such a collaborative production control platform.

The collaboration in such platform leads to complete new opportunities of cross-enterprise cooperation. The agents need to take and change decisions in real-time according to changes in the production schedule.

Therefore the normal, bilateral binding contracts will not be suitable for such an environment. Instead of the bilateral contracts each member in this platform needs to rely on mutually agreed collaboration rules. These rules are mandatory for each enterprise. The rules need to include agreements concerning payment, delays and quality deficiencies. Only if such an environment with mandatory rules instead of bilateral contracts is established, concepts of cloud-based collaboration can be achieved.

4.2 Decision making

The agents need to decide which CPPS shall process the production. This is indicated once more alternative CPPS are capable of taking the order. As mentioned in section 3.1 this decision making-process is done via automatic negotiations between the CPPS and the agent similar to a market place application.

To select which CPPS is most suitable, decision rules have to be defined. The suitability depends on quality-, costs- and timely-aspects. Quality and time are normally hard restrictions which need to be considered during the selection process. All influences on the decision are summarized in a single decision variable. This decision variable is mostly determined by the costs. The costs for the service mainly result from the used capacity and resources, the material and transportation. Therefore the CPPS needs to calculate these costs and needs to guarantee a desired provision. Additional information like former quality issues and past delays may also influence the decision making process. This additional information is taken into consideration by adding factors to the decision variable. The agent chooses the CPPS with the lowest decision variable considering the adherence of all requirements.

5 BUSINESS MODELS

The usage of CPPS in manufacturing environments does not only affect the collaboration of enterprises along the value chain. The cross enterprise collaboration has a differentiated impact on the business models of the collaboration enterprises.
According to Osterwalder, a business model is ‘the rationale of how an organization creates, delivers and captures value’ [12]. In the context of cloud manufacturing, two perspectives are taken into account:

- The first perspective covers the possible business models for the production capacity providers.
- The second perspective tangles the possible impacts on the business models of established enterprises in a cloud manufacturing environment.

For production capacity providers, the possibility to offer production capacities to a broad range of customers facilitates the establishment of business models similar to the ‘layer player’ pattern described by Gassmann et al. [13]. In this business model pattern an enterprise is specialized on a single activity or a few activities along the value chain. Enterprises using this pattern offer their activities to a broad base of possible customers in various market segments (MaaS). Due to the broad field of application, the offering of production capacity will not be limited to a single market segment or sector. In addition production capacity providers will benefit from economies of scale.
Regarding the coordinating company receiving the service of the production capacity providers, the focus shifts from possible business models to possible impacts of cloud manufacturing on the business models of these enterprises. By employing cloud manufacturing, enterprises can gain higher

profitability due to a decrease in production costs. The decrease is caused by economies of scale and specialization of production capacity providers. The coordinating companies can access manufacturing resources easily without the need of a fixed investment into a resource. This causes higher flexibility for the customers. Coordinating companies will possibly be able to achieve not only better productivity, but also improved quality due to a higher specialization of production capacity providers in manufacturing processes offered to the cloud-based marketplace. By means of cloud manufacturing, integral parts of the value creation process will shift from coordinating companies to production capacity providers, decreasing the vertical range of manufacture for the coordinating company. This affects various components of the business model in the Osterwalder canvas such as value proposition, profit formula, key partners or key resources.

Due to the possibility of a value creation based on cloud manufacturing, enterprises are forced into a trade-off between costs and vertical range of manufacturing or flexibility.

A participation in a cloud manufacturing environment will then possibly shift manufacturing and process competencies to the production capacity providers. The coordinating company’s profit formula will shift from profits due to the integration of (possibly critical) manufacturing processes to the earlier phases of the value creation. The production of the material manufactured product will not be in focus. This is caused by the integration of external production processes. Instead, the innovation of new products or technologies will gain higher importance for the enterprise. By empowering cloud-based manufacturing resources, the amount of bound capital for manufacturing resources is decreasing.

Since all enterprises will benefit from the increasing procedural knowledge of the production capacity providers, the key value proposition of an enterprise will therefore be in question. This applies to enterprises whose strategic advantage is only based on the procedural knowledge of the manufacturing process. The strategic advantage of an enterprise relies on the potential to create innovative products. The ability to anticipate market and technology trends and demands will play a crucial role in the achievement of a strategic advantage. Due to the strong focus on innovation and the possibility to access cloud-based manufacturing capacities, the length of the innovation cycles will decrease. In addition, established enterprises will face new competitors such as start-ups which will benefit from decreasing entry barriers. Entry barriers such as high investments into machinery and production facilities will be superseded by cloud manufacturing.

In order to face the decreased length of innovation cycles and the potential threat of market entrance by innovative start-ups, enterprises may, in addition to an innovation of their business model, be forced to efficiently use their innovation potential to keep a strategic advantage. Disregarding the possibility of increased R&D budgets, open innovation can be a suitable solution to increase the innovation potential. Open innovation is a paradigm in which internal as well as external knowledge is implemented as a source of innovation [14]. Especially the improved attractiveness (increased fit-to-market) is a crucial factor in the occupation of strategically advantageous positions for enterprises.

6 POTENTIAL IMPACT AND FUTURE WORK

The implementation of CPPS is the basis for the foundation of cloud-based collaboration in dynamic value creation networks. Besides the technical aspects, several problems occurring with the collaboration have to be solved.

Dynamic cloud-based contracting on an autonomous basis requires a detailed set of rules for decision making. These rules are integrated in the target system of time, quality and costs. Depending on the enterprise specific weighting of these three factors, decision rules have to be adapted. The automated decision support is a key implication for future research. Another important aspect is the impact on existing business models of manufacturing enterprises. Besides the opportunities for new business models for production capacity providers, the implementation of cloud-based manufacturing will develop a significant impact on existing business models for manufacturing enterprises. Future research will also have to focus on the business model impacts.

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APPLICATION OF THE 80/20 ON MARGIN CONTRIBUTIONS IN MANUFACTURING COMPANIES

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Abstract
Responding to the request of a company in pushing the income statement in profit, the authors of this article propose to apply to the products a contribution margin of the 80/20 principle.
We have conducted an ABC analysis of all contribution margins of the products valued at standard cost, and we proceeded to classify the contribution margins from the lowest to the highest in families of groups of finished products
They were then applied to a cycle ‘loop’: the rationalization of products starting from group 1 and so forth until you reach the desired result of the income statement. After this analysis was developed, the new total cost of the company according to the budget forecast of sales highlighted all items of income and expense in surplus and defined the resulting operational plan.
The result of this analysis is a restricted company operative only products contribution margin based on the 80/20 principle. The consequence is a redrafting of the company's business.
Considering the result above mentioned, the development of this methodology can become a standard for the corporate restructuring in a state of crisis.

Keywords:
80/20 principle, manufacturing company, contribution margin

1 INTRODUCTION

The recent crisis, in 2008 has hit the world economy, and it led the vulnerable and sensitive SMEs to manage this critical situation carrying on projects of company restructuring with specific projects [1]. This kind of project allows the companies to find a solution for the financial crisis that leads to decisions in the bankruptcy and informal (out-of-court) renegotiations [2].
Many people try to solve the problem through a careful analysis of the costs, finding out the best decision investment [3] and, second, a contribution to

solve the weaknesses in the important methodological and organizational principles system of cost accounting [4] [5] or identifying cases of success or failure of the turnaround, that is the plan of reorganization and restructuring of a company in deep crisis [6]. In order to support the SMEs' turnaround external organizations or consultancy firms become involved [7].
To provide support for the creation of a project of requalification, the authors want to propose a methodology that does not only reduce the industrial costs or other activities that lead, at least, to the break-even point of the income statement, but simultaneously also an analysis based on the 80/20 principle which is applied to the products contribution margin [8]. This activity will reshape the turnovers, and at the same time it will change the income statement from loss to profit.
The development of this methodology, considering the result obtained in a case study, will become a standard for the company restructuring in state of crisis.

2 METHODOLOGY PROPOSAL

During crisis periods companies are in the condition that the value of the production is lower than the total cost of the production, and the income statement highlights a loss.
In general, for the manufacturing companies the industrial cost is about 80% of the total cost. A significant number of companies under investigation has proven this, so we are going to focus on this topic. Considering that it is impossible to reduce the company consumption and work force, we will work on the selection of the products that guarantee the appropriate contribution margin, right to obtain profit in the income statement. This will redraft the sales and market size, cause the loss of customers and orders, and the business will restart from a value very close to a small size business. The classical phase of company restructuring focusing on costs reduction or increasing sales will not be considered anymore, due to the fact that at the status quo is not a reasonable cut of the total cost, especially the industrial costs.
This is the method of 80/20 that is applied only to the product and, consequently, to its contribution margin.
The application of this methodology requires the involvement of the executive management that has to understand the organizational process in order to make choices that ensure a positive result. Particularly it is important to simulate the consequences of this choice on the forecast (5 years) for several times in the income statements, in order to certify the industrial plan.
The preliminary operational analysis that the management body should carry out after the application of the 80/20 principle [8] [9] should foresee:

a) Obtaining from the enterprise's information system the ABC of the contribution margins in the final balance of the previous year and in the current semester on the standard costs.
b) Updating the database cost with the increases for manufacturing purposes and work force.
c) Comparing the contribution margins to sales volumes for each product;
d) Removing the products with an insufficient contribution margin from the final balance and updating the database.
e) Calculating the new bills of materials (cycles and materials) from the new volume of production and calculate the new timing of direct labor cost, the cost of materials and external processing.
f) Reducing the indirect and white collar labor cost with a focused analysis done by an expert on the new tasks and considering the annual number of working hours.
g) Updating the database in order to calculate the new income statement and verify the situation of the profit. If the result is suitable, you should analyze the consequences of this plan on the market and on the customers and nevertheless on the sales agents whom would suffer an economic loss.

It is therefore necessary to perform this analysis and verify that this new solution is able to generate profit for the company that in this condition will be able to generate a project of corporate restructuring and reconditioning.

3 THE CASE STUDY

A furniture producing company of kitchen and baby rooms has been analyzed. The income statement for the year 2013 is reported in percentage in the following chart (tab. 1); a significant loss is shown by the data.
The proposed methodology has been applied to analyze each group of products and the generated turnover. The results of this first analysis are reported in fig. 1 where it is possible to see that the main groups of products do not generate any relevant turnover.
The analysis shows that 20.3% of the turnover is generated by five groups of products corresponding to 0.8% of the total number of groups of products.
In the same way the contribution margins have been analyzed for groups of products; the results are reported in fig. 2, which shows a characteristic K parameter which is defined by the ratio between the current sales price and the current costs, per each group of products.
Considering the interest of the entrepreneur in having a profit not lower than a certain specific value, a specific calculation program has been developed.
The program allows determining a profit or a loss in the income statement generated by the removal of groups of products, and starting from the characteristic K parameter higher than zero, so that it is possible to achieve the minimum return on investment required by the entrepreneur.

Table 1: Income statement for the year 2013.

Production value (A)	100.00
Industrial cost (B = C+D)	68.37
- Consumption (C)	51.30
- Labor cost (D = E+F+G)	17.08
* Worker (E)	4.53
* Indirect workers (F)	2.75
* Direct workers (G)	9.70
Total industrial cost (H = B+I+J+K)	76.04
- Maintenance (I)	1.88
- Cost of energy (J)	1.35
- Amortization of direct goods (K)	4.44
Total cost (L = M+N+O)	109.45
- Sales cost (M)	21.54
- Administrative costs (N)	7.60
- Amortization of indirect goods (O)	4.37
Profit/loss (A–L)	- 9.45

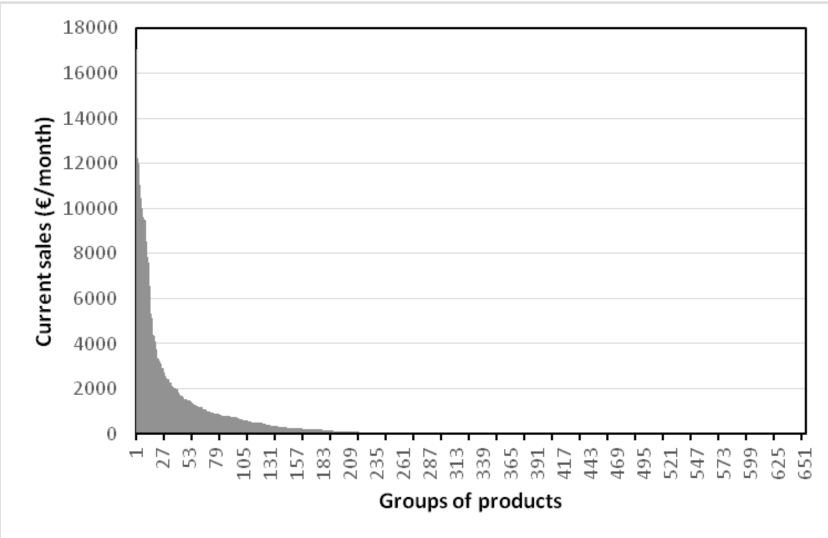

Figure 1: Current sales as a function of the groups of products.

In particular, starting from K higher than zero and eliminating the different loops of simulation of the groups of products, which have a value of K greater than 0.1 points for each iteration and a specific turnover for single groups of products, it may be noted that profit has been achieved (fig. 3). The value obtained must be compared to the desired value by the management.

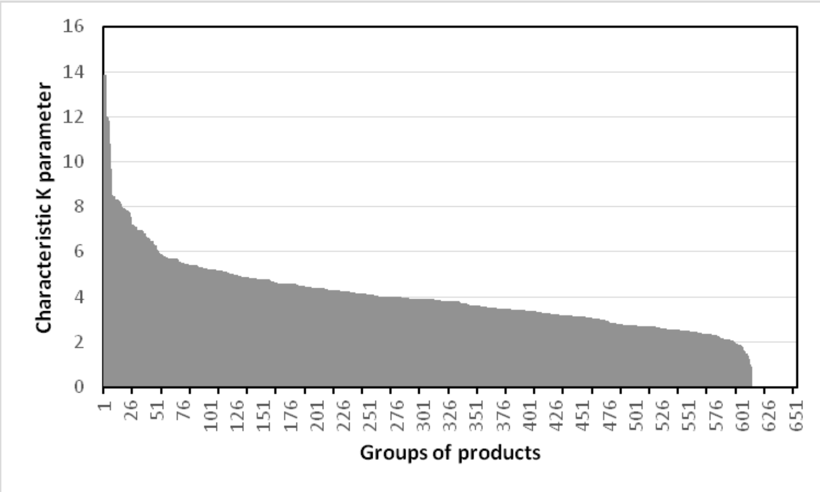

Figure 2: Characteristic k parameter as a function of the groups of products.

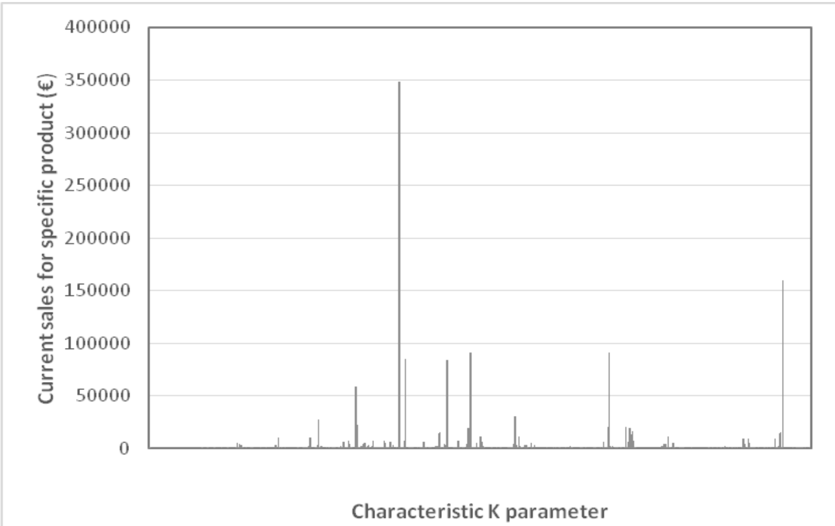

Figure 3: Current sales for specific product as a function of the characteristic K parameter.

The number of iterations has shown that it is possible to consider a limit value 3.5 for K, which is able to guarantee a return on investment as desired by the management (fig. 4).

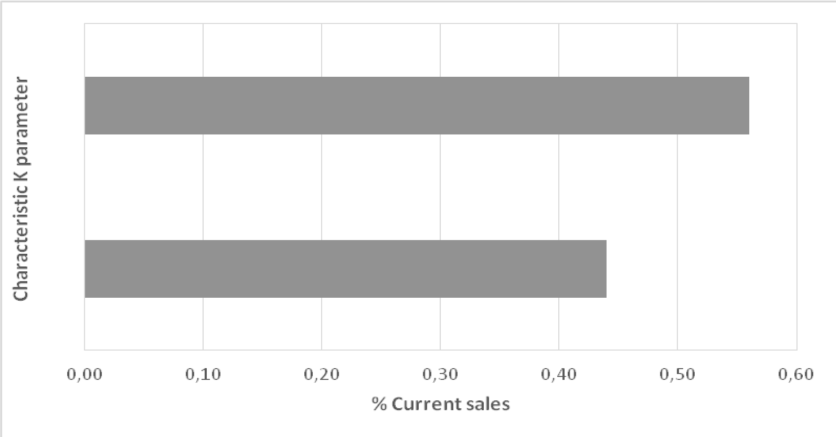

Figure 4: Characteristic k parameter as a function of the % current sale.

The result is a new company that will produce only products that have a characteristic K parameter higher than 3.5 and that allows realizing 55% of the previous turnover by 32% of the groups of products and generates profit.

4 CONCLUSION

The authors proposed a methodology which has the purpose of applying the 80/20 principle to the contribution margin of the products.

Knowing the results of the last business year it is possible to implement a rationalization of the products that generate loss by an ABC analysis of contribution margins compared with those at standard costs, and envisage those products that produce profits greater than desired by the management.

The methodology was applied to a case study that highlights the strong points of the methodology developed and the results achieved, and can be considered as a standard which is applicable in the corporate restructuring.

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SESSION B
Technology and Supporting Services for Manufacturing

PROCESS QUALIFICATION IN THE WOOD INDUSTRY

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Abstract
The analysis of the qualification of manufacturing and production processes to confirm that they are able to operate at a certain standard during sustained commercial manufacturing has been established in different industries. Especially in the automotive industry and the manufacturing of metal and plastic parts, respectively, processes have to be qualified and proved by the calculated process capability. Many large companies in this sector introduced company standards for process qualification, used already in the purchasing process of new machines and production equipment.
In general, the process qualification enables the manufacturer to fully understand the process – once it is qualified. During the analysis the manufacturer learns the critical parameters and furthermore gets a framework in place to routinely monitor operations.
However, in the wood working industry process qualification is rarely considered due to the special properties and the material behavior of wood and wood-based composites as well as the fact that many quality characteristics are not being measurable. Such characteristics like the impression of a sanded wood surface can only be evaluated by means of a sensory quality assessment with trained persons and their perceived impression, converted to an objective evaluation. The results of a sensory quality assessment require a different approach for process qualification investigations. The sample quantities must be reduced with a developed methodology and a modified statistical method must be used to calculate the process capability. But also measurable characteristics like dimensions require a special approach for wood and wood-based composites due to the inhomogeneous, porous structure of the material and the shrinkage and swelling in case of moisture content changes.
The effects of the material and the different quality assessment methods on the process qualification have been investigated and are presented in this paper together with the developed approach for process qualification investigations in the wood industry.

Keywords:
Process qualification, process capability, wood industry, material behavior of wood and wood-based composites, subjective quality characteristics

1 INTRODUCTION

The wide introduction of statistical process control (SPC) primarily in the aerospace industry but also in the automotive sector [1] has led to the question whether manufacturing processes, which had to be statically controlled, could ever achieve constant results. From the 1990s on, the methods of process qualification were therefore refined [2]. Today, various standardised methods for machine and process capability analysis are available [3] [4] [5]. Numerous work standards [6] and federation standards [7] expand the procedures almost to confusion. In the wood working and furniture industry, this type of process qualification is rarely used. Possible reasons for the limited application are:

- The classical field of SPC, monitoring of geometrical tolerances (length, shape, location), is difficult to access, because of the shrinkage and swelling of wood and wood-based composites [8].
- The quality characteristics to be checked are wide-ranging. Both functional and aesthetic features are important. Often, the characteristics are not precisely defined, so that a comparison of characteristics with fixed tolerances cannot be made.
- In general, the inspection features of a work piece are rarely precisely defined. A specific drawing notation is usually not available. The communication of quality standards is carried out separately and in the field of surface quality almost exclusively by patterns. But it is not possible to derived specification limits from a single comparison standard.
- For some of the test methods, there are currently no guidelines on how SPC processes or qualifications may be applied. Sensory tests (visual, tactile) of aesthetic quality features can currently not be integrated in SPC control loops.
- Routinely performed quality assurance measurements are based on traditional craftsman methods. Scientific or statistical expertise is often lacking. The methods are not well documented in educational books.
- The methods have been developed for large production quantities. Most of the manufactures in the wood industry do usually not produce this large number of similar products.
- The range of variation of some production processes is high and does not allow process qualification investigations or SPC.
- The cost-benefit ratio is considered to be unfavourable. Costs of statistically reliable studies are overestimated.

Currently, the technical committee FA 102 ‘wood processing’ of the Association of German Engineers (VDI) is working to solve the mentioned deficiency in the wood industry and is planning to publish the guideline VDI 3415 sheet 2 in 2016 to give appropriate recommendations for action, especially for machine acceptances. First studies are outlined in the following chapters.

2 MACHINE AND PROCESS CAPABILITY ANALYSIS

By means of machine and process capability analysis over a shorter period of time (mostly described as machine capability, usually with 50 but also up to 200 identical workpieces) or a longer period of time (process capability), it is possible to determine whether the process related deviation of a quality characteristic is so small that the specification limits (tolerances) are reliably met (figure 1).

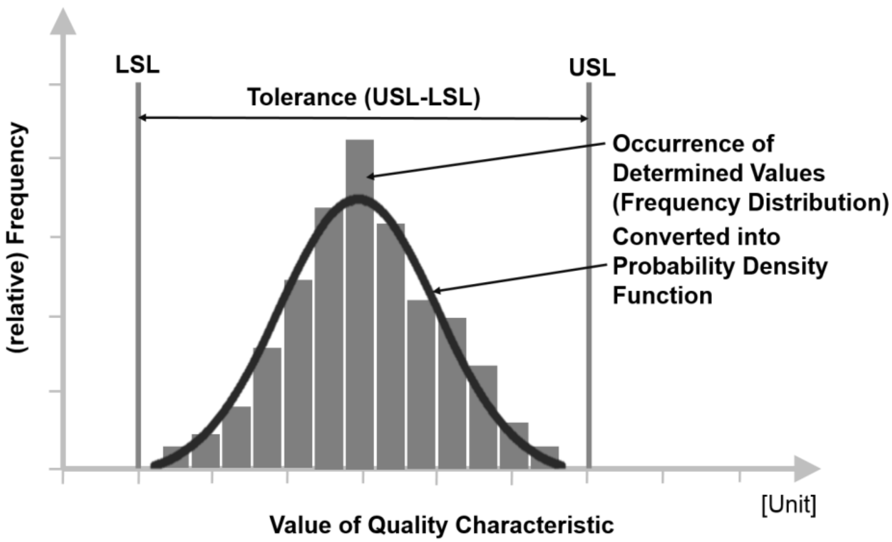

Figure 1: Process dispersion with respect to the tolerance.

The amount of ‘reliability’ of a process related to the compliance with the tolerance of a specific quality characteristic is described as process capability C_p and defined by [9]

$$C_p = \frac{USL - LSL}{6 * \sigma} \quad (1)$$

with standard deviation σ and upper USL as well as lower specification limit LSL. In addition, the minimum distance between sample mean μ and specification limit centre is defined as critical process capability C_{pk} and determined via

$$C_{pk} = \min\left\{\frac{USL-\mu}{3*\sigma}, \frac{\mu-LSL}{3*\sigma}\right\} \quad (2)$$

Equations 1 and 2 represent an algorithm for the process capability analysis for normally distribute data. Not normally distribute values require different algorithms, which are also described in [3] or [4], since such distributions cannot be defined only by the mean and standard deviation likewise the Gaussian distribution.
For this procedure, at least 50 values are necessary for the expression of a quality characteristic. Thus, 50 consecutively produced work pieces have to be evaluated regarding this particular feature. To calculate and display the distribution type, different statistical tests are available in literature (e. g. Chi-squared test) [9] [10]. In general, measuring values are grouped into classes with a certain range for the testing of the distribution type or to plot a histogram (cf. figure 1).

3 GAUGE CAPABILITY

Furthermore, it must also be ensured that the dispersion of the property testing or measuring process itself is so low that a sufficiently precise assignment of the measuring values into one of the classes is feasible (figure 2).

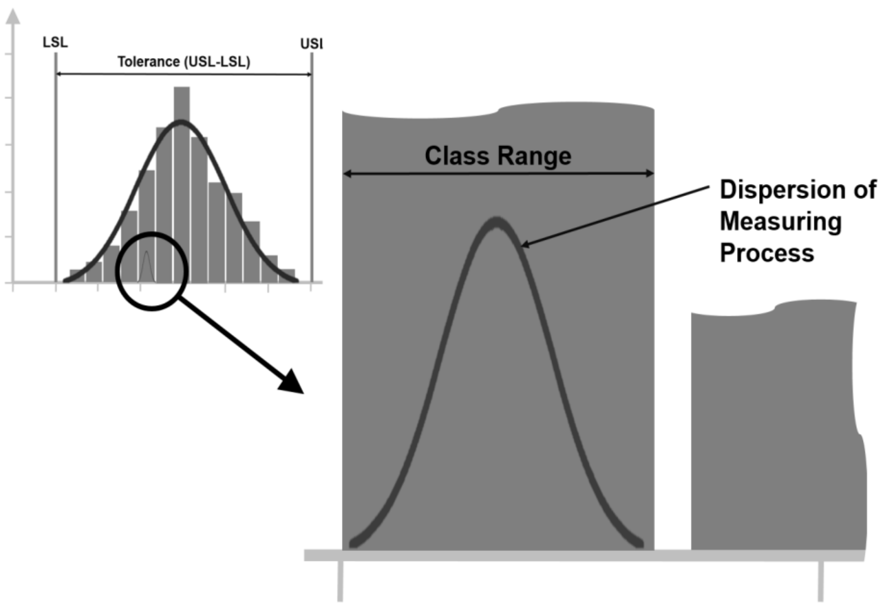

Figure 2: Measuring device dispersion in relation to class range.

The resolution and reproducibility (as a multiple of the standard deviation) of the measuring or testing method should therefore be significantly smaller than the tolerance of the quality characteristic (figure 2). This inspection process is part of process or gauge qualification. Gauge capability analysis can be done by two methods substantially.

Firstly, as already stated for C_p, gauge capability C_g is computed via determined dispersion (multiple of standard deviation s) of the testing or measuring device by means of the same work piece in relation to the tolerance T of the characteristic or the assumed or known standard deviation of the manufacturing process as [6]

$$C_{g(6s)} = \frac{0,2 \cdot T}{6 \cdot s} \tag{3}$$

or [2]

$$C_{g(4s)} = \frac{0,2 \cdot T}{4 \cdot s} \tag{4}$$

with 20 % characteristic tolerance as reference quantity. Obviously, equations 3 and 4 differ regarding the multiple of standard deviation depending on the respective work standard which in turn has to be adapted to the individual conditions. Furthermore, the percentage characteristic tolerance differs likewise.

Secondly, gauge capability verification can be carried out based on the extended measuring uncertainty U [7]. Accordingly,

$$U = k \cdot u_c \tag{5}$$

with extension factor $k = 2$ (corresponding to suggested 95.45 % confidence level [11]) and combined standard uncertainty u_c. The latter includes the inaccuracies of each individual part or sub-process of the measuring device (e. g. tolerances of a testing fixture (dimensions) or superposition of signal and sensor blurring (non-dimensional measures)) computed as sum of the single variances (in the linear case).

$$u_c = \sqrt[2]{\textstyle\sum_i u_i^2} \tag{6}$$

Finally, measuring system qualification Q_{MS} is evaluated via

$$Q_{\mathrm{MS}} = \frac{2 \cdot U}{T} \cdot 100\ \% \tag{7}$$

where $Q_{\mathrm{MS}} \leq 15\ \%$ according to suggestion [7] which in turn is defined considering individual conditions.

Nevertheless, wood and furniture industry only pays little attention to these aspects of a modern quality assurance and standardization beyond. Furthermore, own test series even show that it is almost impossible to meet the required gauge capability for height offset measurements of flooring panels according to [12] to prove corresponding tolerances.

4 SENSORY QUALITY ASSESSMENT

Sensory analyses, as they are generally stated in [13] and especially for the woodworking and furniture industry in [14], lead directly to histograms and thus meet the statistical requirements for process capability analysis, at least at first glance (cf. chapter 2).
In sensory tests a multi-skilled panel of assessors determines one or more quality characteristics. This can be done in accordance with [15] with quality levels, consisting of a preferably six or nine levels scale (figure 3).

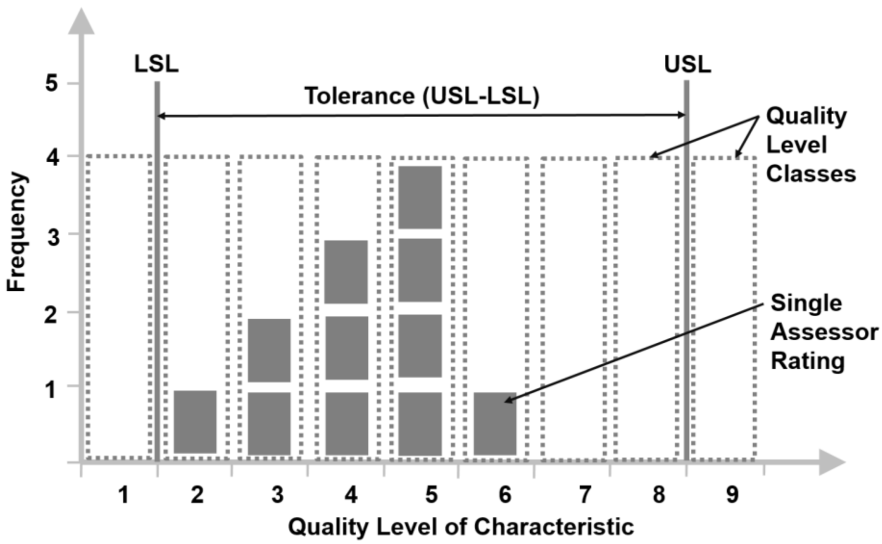

Figure 3: Design and result of a sensory quality assessment.

If the scale is defined in such a way that the two outermost assessment levels are just outside the specification limits, seven levels remain for and inside the tolerance respectively (figure 3). The histogram would be created through the individual votes of the examiners themselves and would be statistically exact enough for the detection of gauge capability values of 1 ($C_g = 1$) in case of seven classes for distribution type test and histogram plot (figure 3). In this case, the resolution of the 'measuring process' would have the same width as the class range within the tolerance (cf. figure 2). However, the mean of e. g. the votes of five assessors for a single work

piece would create a process similar to a measuring process with a variable quality characteristic and could prove even higher gauge capability values.
The real problem, however, is purely of practical nature: It is hardly possible that an assessor is able to test 50 work pieces sequentially with the required differentiation. Even if reference samples would be available for each scale level, the dispersion would be high according to experiences of the authors with real panels of assessors in the wood industry.
In general, standardized tactile or visual tests allow a better differentiation and have approximately 15 classes (cf. [16]) which generate a higher resolution of the test method. For visual test it is proved that the perception of the assessor can be improved by means of appliances (e. g. devices, special lighting etc.). However, the effect of appliances on tactile tests to improve the perception has to be investigated.
Thus, it will still be very difficult to prove the gauge capability of a comprehensive sensory quality assessment (visual and tactile) even if intensive assessor training has been developed and carried out. Test series have shown that a 'small' sensory assessment with focus on a few quality characteristics is sufficient [17] and allows also gauge capability analysis e. g. by means of a statistical sequential analysis [18].

5 MACHINE CAPABILITY ANALYSIS IN THE WOOD INDUSTRY

In chapter 2 to 4 different aspects of process qualification in general and with particular focus on the wood industry are presented. However, the introduction of process qualification analysis in the wood industry starts best with machine capability analysis – especially considering the purchasing process of new machines and production equipment. This enables the different companies to easily introduce SPC in their production after the machine capability analysis was carried out.
To this end, a simplified approach for machine capability analysis is recommended such as described in [5]. The approach solves the problem of too many required samples by only considering the range of the measuring values for the capability calculation. This requires only a small set of samples, thus a small amount of work pieces. By this methodology, the real distribution type is not considered and remains unknown. Without any statistical verification of the distribution type, this methodology leads to lower significance.
The limits for mathematically proper application of this methodology are obvious, but the practicable conclusion is amazingly simple: A range with wide distance towards the specification limits results in a feasible machine capability (figure 4).

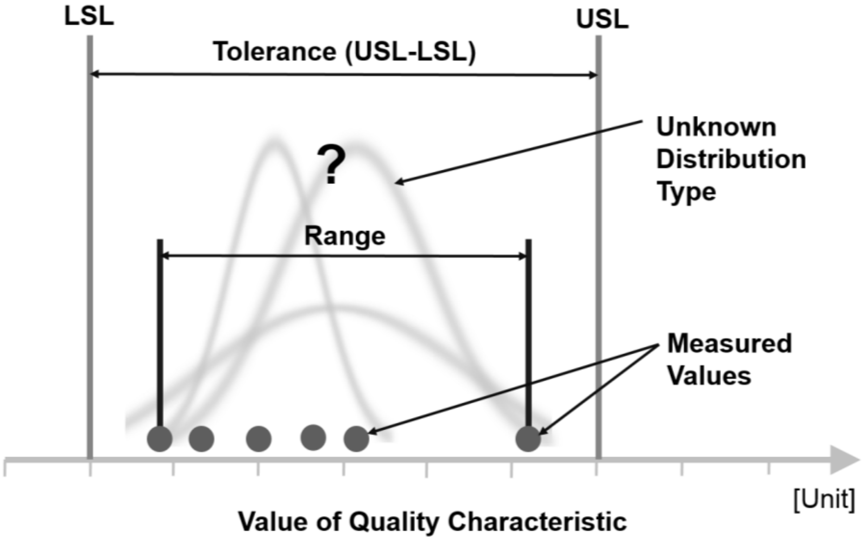

Figure 4: Capability analysis from the range of measuring values.

The process is similar to current practice in machine acceptance where an agreed, rather small amount of work pieces are produced and all characteristic values must be within the specification limits.
In contrast, the methods according to [5] quantify the distance to the tolerance limit in a manner similar to [4]. Thus, the confidence level is increased considerably. Again, a sufficient gauge capability must be provided. This is even more important, since the uncertainty in identifying the two measuring values representing the range drastically effects the calculated machine capability. As a precondition for the application of SPC, this type of machine capability analysis cannot be used. The uncertainties are too large without considering the real distribution type and its parameters.

6 CONCLUSION

The methodology according to [5] seems suitable – even of the inconveniences – to improve the current practice procedures considerably regarding machine acceptances in wood industry. Also, the inclusion of test results ascertained by sensory quality assessment for aesthetic quality characteristics (cf. [14]) seems possible. Regardless of the problem that most manufacturing processes are not normally distributed (e. g. the tool wear only in very small periods of time), an adequate gauge capability analysis is the key factor. Unfortunately, the presented methodology [5] does not focus on the gauge capability analysis. Finally, following advantages of the methodology used for machine acceptances and machine capability analysis in the wood industry can be pointed out:

- Comparatively simple comprehensible procedures which can also be understood without knowledge of statistics,
- Reduced number of sample work pieces to be produced sequentially compared to today's standards (cf. [3], [4]) in other sectors,
- Lower testing costs due to the small number of sample work pieces, which also enables the elaborate sensory test methods and their application,
- For range estimation, only the most extreme values have to be found, which reduces the effort significantly.

Despite the mentioned advantages of the methodology the problems with the unknown distribution type, the small sample number – whereby long term effects (e.g. climate oscillation, fluctuations of material properties etc.) are not considered – only allow a rough estimation of the process capability. Hence the methodology needs to be refined and further developments have to be carried out. This will be one part of the future work of the technical committee FA 102 ‘wood processing’ of the Association of German Engineers (VDI).

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DEVELOPMENT OF AN ALGORITHM FOR MEASURING THE QUALITY OF HIGH GLOSS SURFACES CORRELATED TO HUMAN PERCEPTION

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Abstract
While common measurement techniques like gloss or color measurement are widely used in industry for quality assessment of furniture high gloss surfaces, they indicate only a weak correlation to the quality perceived by the customer. Topography based approaches achieve higher correlation to human perception but are often based on linear measurement which cannot be applied for an overall assessment of larger surfaces. Thus an algorithm was developed to calculate a specific value based on topographic features, such as orange peel, within the research project 'Development of a comprehensive quality concept for furniture high gloss surfaces', funded by the federal Ministry of Education and Research. For the evaluation of short waved structures on furniture high gloss surfaces the ratio of hill height to hill area was chosen. This parameter proves to be applicable for an evaluation of the extent of a single.

Keywords:
High gloss, surface measurement, topographic features, quality assessment

1 INTRODUCTION

The quality of high gloss surfaces in furniture industry is most often evaluated by visual inspection and measurement of single attributes like color or gloss. While attributes like brilliance or mirroring are important for the customers´ buying decision [1] they are usually not assessed by objective measurements but by unsystematic visual inspection. The results of this visual inspection are always influenced by the assessor´s experience as well as by his daily fitness and state of mind [2] and do thus show a low reproducibility compared to measurement results.
On the other hand the results of the measurements applied in quality evaluation of high gloss surfaces in some extend show a weak correlation to human perception. This was evaluated as a part of the research project 'Development of a comprehensive quality concept for furniture high gloss surfaces' and it was found that results of color and gloss measurements do not correlate to the perceived quality of the high gloss surfaces. In contrary

linear waviness parameters, especially those of the motif system, showed a much higher correlation as described in [1].
Additional test series are applying a linear laser scanning of the high gloss surface, which is well established in automotive industry with the WAVESCAN by BYK Gardner, also showed a high conformity with human perception, but also indicated some weaknesses of the linear measurement: While the first measurements correspond with the perceived quality, a second measurement in a different direction of the surface – perpendicular to the first one – shows a weak correlation. [3]
To overcome the weaknesses of the current state of the art it seems promising to develop a measurement system based on topographic features that works with an extensive measurement providing three-dimensional data.

2 THREE-DIMENSIONAL SURFACE ANALYSIS

2.1 Measurement of high gloss surfaces

Capturing the three dimensional topography of a high gloss surface is challenging due to the optical properties of these surfaces and requires a technology that can cope with mirroring surfaces as well as with transparent top layers which may be used in the multi-layer buildup of the coating. Due to the wavelength of the relevant structures and the distortion of single characters on the surface the measured area needs to have an adequate size, which means at least some centimeters in x- as well as in y-direction.
As the existing parameters do not meet the requirement of showing a high correlation to human perception, an algorithm needs to be developed to analyze the surface data. For further analysis in this project, the data captured should be processible with standard calculation software such as MATLAB.
In test measurements the phase stepped deflectometry was identified as a suitable technology. Here a periodic grid is projected on the surface and its reflection is captured by a sensor. As every distortion of the ideal surface will lead to a variation of the ray path and results in a displacement of the point´s position on the sensor the slope in each surface point can be calculated by a phase shifted repeated projection of the pattern [4]. On this data mathematic operations like differentiating and integrating can be applied to calculate the curvature and the three-dimensional topography of the surface [5]. This three-dimensional data is saved in a 3D matrix and used for further processing.

2.2 Topographic elements

Topographic elements known from geology can also be applied on technical surfaces. They are described in [6] and can be classified in the categories of point, line or area elements, according to their expanse. Figure 1 gives an overview of the different elements.

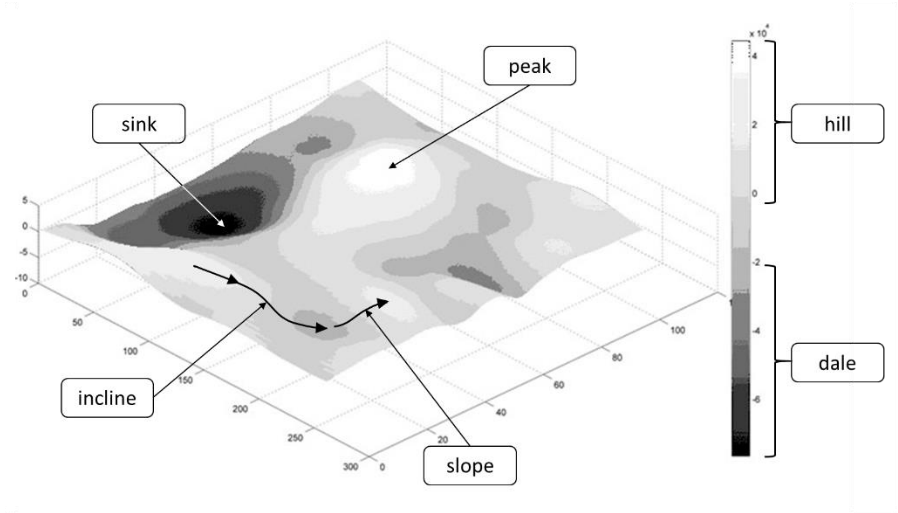


Figure 1: Topographic elements of a surface.

The peaks and sinks are point elements, inclines and slopes are line elements and hills and dales form the category of area elements.
As these elements due to their influence on the reflective properties strongly affect the human perception [7] they form the basis for the analysis of the surface data.
The motif parameters for the profile method described in [8] are also based on the definition of hills and dales but are only applicable on two dimensional profiles. For the further analysis this definition was transferred into the description of a three dimensional motif or pattern recognition. Following the concept used in [8] this should be a dale surrounded by watershed lines. As hills and their shapes seem to be the more prominent characteristics of high gloss surfaces this definition was inverted and the further analysis uses a three dimensional motif consisting of a hill and its surrounding dales.

2.3 Data analysis

For the data analysis the matrix with the three dimensional surface data is loaded into the calculation software MATLAB where filters and algorithms are established to identify the relevant topographic elements. Prior to the analysis itself some pre-operation are applied on the data. To enable a visual comparison of the processed data and the image output of the original measurement device the matrices are flipped horizontal to standardize the position of the point of origin. Next approximately ten millimeters are cut on either side of the measurement field as due to the reflective properties of the surfaces failures may occur close the edges.

Now the matrix contains the vertical coordinate in microns corresponding to the pixel position on the sensor of the measurement device. To enable the use of standard length units the resolution of the matrix is calculated and all further calculations work with x- and y-coordinates in millimeters.
The data analysis aims at extracting short wave surface deviations like orange-peel or lacquer sinking. They differ in form and frequency from others like roughness or waviness of the substrate. Signal noise and very short waved components of the profile are suppressed by applying a low pass filter on the data. For the filter operation an areal robust Gaussian filter according to [9] is chosen. This filter is chosen as it is especially suitable for surfaces containing single, pulse like distortions [10] like spots or pinholes, which can be found on high gloss surfaces.
The chosen filter is described by the following Gaussian weight function:

$$s_{klij} = \frac{1}{\gamma^2 \lambda_c{}^2} e^{-\frac{\pi}{\gamma^2}\left(\frac{x_{ki}{}^2 + y_{lj}{}^2}{\lambda_c{}^2}\right)}, k = 1, \dots, m, l = 1, \dots, n \tag{1}$$

Table 1: Explanation of variables according to [9].

Variable	Explanation
s	The Fourier transform of the discrete representation of the weight function
π	Number pi
x	The distance from the center (maximum) of the weight function in x-direction
y	The distance from the center (maximum) of the weight function in y-direction
λ_c	Cut-off wavelength
γ	Constant (0,7309)

For the implementation of the filter the Gaussian weight function is truncated at a value of Lc = 0.5 which is recommended for general applications in [11]. According to [8] a cut-off wavelength should be chosen referring to [10]. It is also stated, that structures with wavelength smaller than one third of the cut-off length are eliminated. The smallest structures in lacquer surfaces that affect the perceived quality show wavelength in the size of 0.02 mm to 0.06 mm [12]. To ensure that they are not eliminated by the filtering operation a cut-off wavelength of λc = 0,025 mm is chosen. No form correction or high pass filtering is applied on the data as the analysis works with relative heights corresponding to the definition of the three dimensional motif.
According to the definition of topographic elements hills can be identified by means of finding their peaks. As a peak is always surrounded by points with a lower height it has to be a local maximum. In the three dimensional data

matrix a maximum can be defined as a point, where the local slope changes from positive to negative. These maxima are identified in the data matrix by a crosswise search in rows and columns, with the peaks being a maximum in both directions. These points are stored in a separate matrix.
The hills on high gloss surfaces do often show a kind of double peak, as shown in figure 2, which cannot be distinguished from common viewing distances. Thus the number of peaks is reduced by combining adjacent peaks.

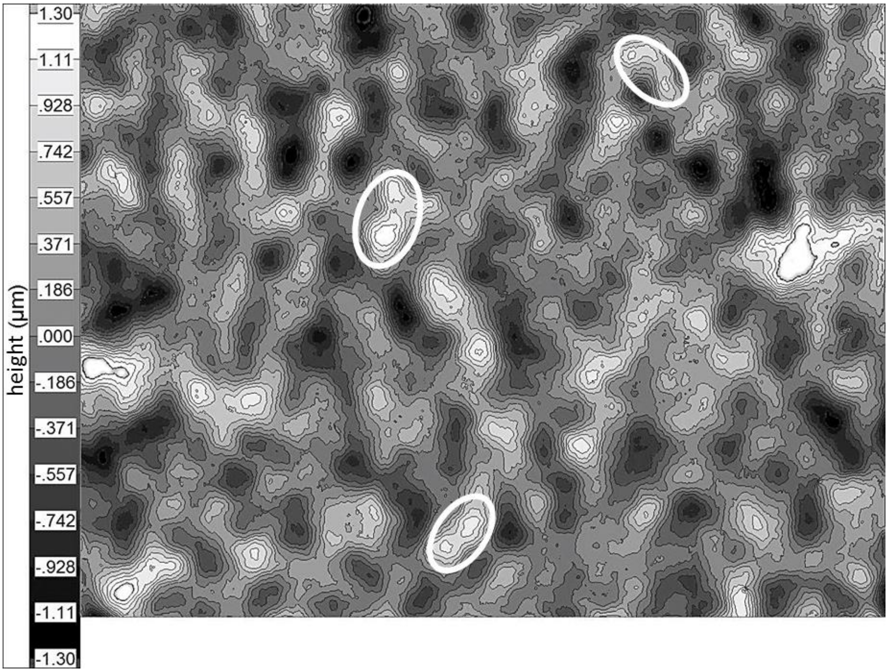


Figure 2: Double peaks on high gloss surface with orange peel.

This approach is also based on the analysis of two dimensional motif parameters [8] where small peaks are suppressed by combining them with larger ones. For the combining operation a threshold is required which has to depend on the concrete topography, as the distance between the peaks depends on the kind and size of the different characteristics. Thus the Euclidean distance between all the adjacent peaks and their cumulative frequency are calculated. The threshold is defined as 95% of the cumulative frequency. Thus all the peaks with a smaller distance are combined while single peaks are separated via the top 5%.

Applying the change of sign of the slope for identifying the peaks ensures that also small hills, which are positioned in larger valleys, are found. This cannot be ensured applying a threshold height for the peak search. As on high gloss surfaces a lot of characteristics with different wavelengths and amplitudes overlay, a threshold based search can easily mask out those elements, e.g. a small orange peel inside a larger sanding line might not be found.

Besides the peaks also the surrounding valleys need to be identified for a comprehensive description of the single hill. They are identified by searching the adjacent minima of each peak along the x- and y- axis. After determining the peak and the surrounding valleys the characteristic size of each hill can be calculated. The height of the hill is the difference between the z-coordinate of the relevant maximum and the average z-coordinate of the surrounding minima. The rectangular area of the hill is calculated based on the distance of the minima along x- and y- axis.

These characteristic sizes are used to calculate the specific value for describing the hill: the ratio of hill height to hill area (hill height/area). As this ratio also describes the gradient of the hillsides, it gives an indication for the reflective properties of the surface and with this also for the perceived quality. This specific value for each hill is presented in an Excel sheet together with a number of additional figures like x-, y- and z- coordinate of the peak or the mean slope along x- and y- axis. In this list, hills with a very high ratio of hill height/area are filtered as they do often form irregular characteristics like spots, which are not subject of the on hand analysis. After deleting these outliers a mean value is calculated and added to an additional Excel sheet that includes the mean values for all measurements on one sample.

Additional results of the MATLAB routine are 3D plots of the original surface and the filtered surface as well as a contour line plot in which the relevant maxima are marked. These plots are mainly used for the visualization and verification of the algorithm.

3 EVALUATION OF THE MEASUREMENT PROCESS

3.1 Process validation

As a completely new algorithm is applied for the data analysis in a first step it is necessary to ensure that it gives constant results. For this one matrix with three dimensional surface data was copied and analyzed by the routine 25 times. This gave exactly the same results for all analyses, which shows that the algorithm in MATLAB works continuously.

In a next step the repeatability of the whole measurement process was validated. For a first test one sample was measured 25 times. To ensure that always exactly the same area of the sample was measured, the measurement device was not moved between these measurements. For the ratio of hill height/area this delivered an average of 0.15643 1/mm with a standard deviation of 0.00221 1/mm. As the algorithm is proven to provide constant results, this variation must be caused by the measurement of the surface data. This can also be found in the data matrices, where a variation of the z-coordinate of up to 0.1 µm in each point can be identified.

To get more resilient data regarding the repeatability of the measurement system, a larger test series was inspected. For this a choice of 36 samples from a real production line were measured 25 times each. For each of these the average and the standard deviation of the ratio hill height/area were calculated, which are visualized in figure 3.

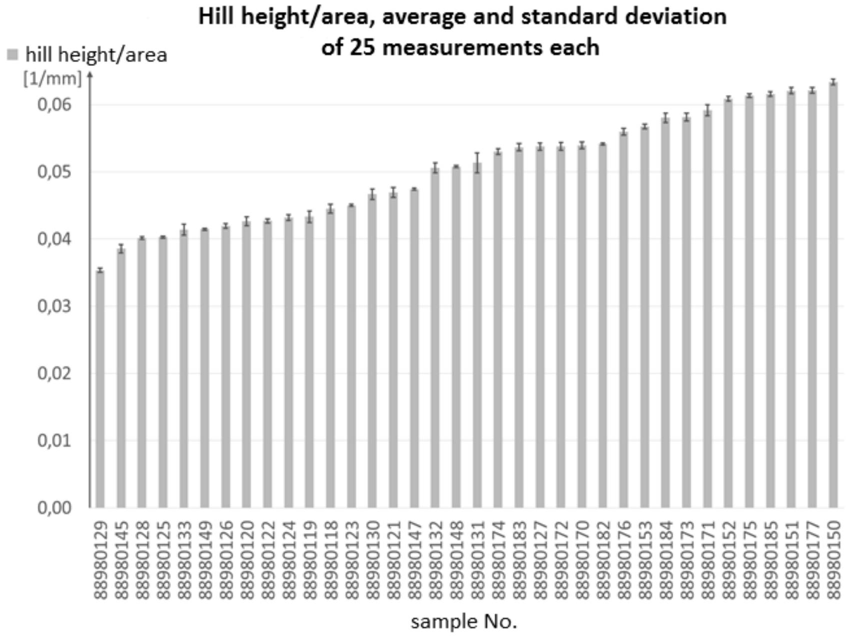


Figure 3: Hill height/area, average and standard deviation of 25 measurements each.

The analysis of this data shows a maximum standard deviation of 3.9 % of the average. For this calculation one sample 88980131 was excluded as its results show a very high variation, which cannot be assessed properly, as the mathematical operations of the measurement device a not known in detail. The expanded uncertainty was calculated for each sample, based on DIN V ENV 13005 [13]. Table 2 gives an example of this calculation.

Table 2: Calculation of extended uncertainty according to [13].

sample: 88980145

Test series hill height/area

measurement:	1	2	3	4	5	6	7
hill height/area:	0.03931	0.03788	0.03736	0.03719	0.03658	0.03749	0.04003
measurement:	8	9	10	11	12	13	
hill height/area:	0.03947	0.03891	0.04012	0.03951	0.03749	0.03958	
measurement:	14	15	16	17	18	19	
hill height/area:	0.03723	0.04012	0.03750	0.03720	0.04028	0.03742	
measurement:	20	21	22	23	24	25	
hill height/area:	0.03743	0.03966	0.03960	0.03947	0.04000	0.03694	

best estimated measurement result				
average of indicator (N=25)	m=	0.03834	1/mm	
known systematic bias	e_{sys}	0.00000	1/mm	
best estimated measurement result	m_{korr}=	0.03834	1/mm	$m-e_{sys}$

Type A uncertainty

standard deviation	s=	0.00125	1/mm	
standard deviation of the average	U_A=	0.00052	1/mm	t=2.064*

Type B uncertainty - not applicable

combined uncertainty

Type A uncertainty contribution	U_A=	0.00052	1/mm
combined uncertainty	U_C=	0.00052	1/mm

expanded uncertainty

coverage factor k	k=	2.00000	-	**
expanded uncertainty	U=	0.00103	1/mm	

measurement result:	0.03834	± 0.00103	1/mm

*factor t according to Student t-distribution for n=24, double-sided confidence interval=0.95

$$U_A = \frac{t*s}{\sqrt{n}}$$

**according to DIN 1319-3:1996 [14]

As sample 88980131 also was excluded, this gave an uncertainty of 0.03798 ± 0.00088 1/mm in worst case.

3.2 Correlation to human perception

As a low correlation to the human perception was identified as one of the drawbacks of existing devices for surface measurement, it is important to evidence an improvement of this situation with the application of the new algorithm. To achieve this, the measurement data was compared to the results of a sensory assessment of the high gloss surfaces carried out by a panel of trained assessors [3]. For this comparison a set of nine samples from one production series was taken. The best and the worst one were defined as threshold samples. In an investigation of profiles the assessors were asked to choose a rank from 1 to 9 for each sample, where 1 equals the best threshold sample and 9 equals the worst threshold sample. Each sample could be compared to both threshold samples, but not to the other ones. The average and the standard deviation of the ranking from all assessors was calculated and compared to the measured ratio hill height/area. Figure 4 shows the result of this comparison.

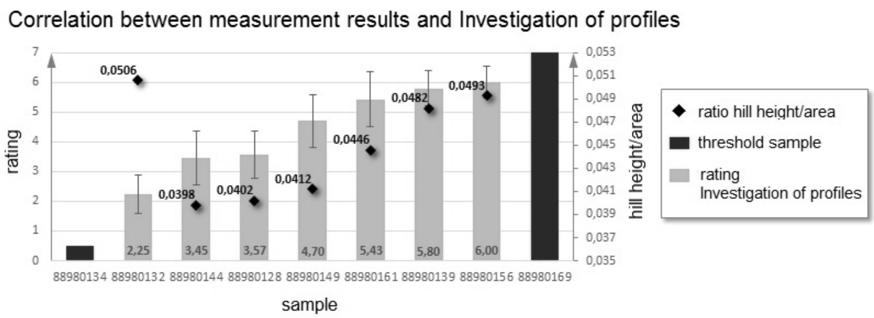
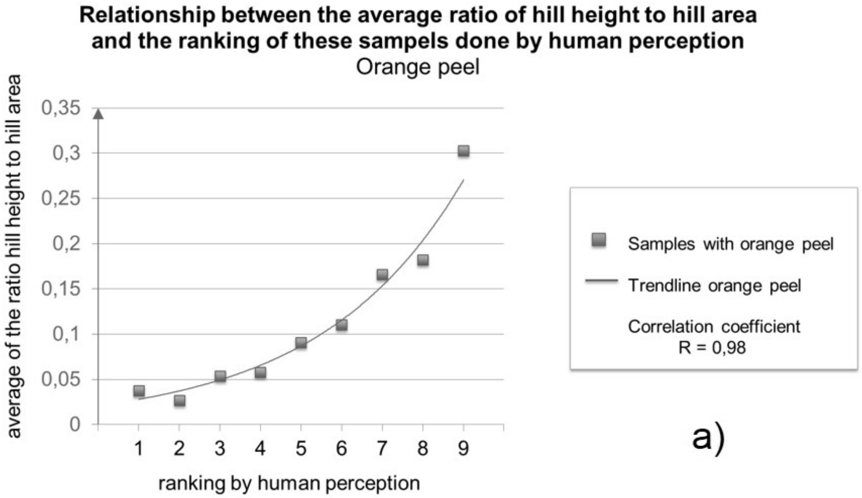


Figure 4: Correlation between measurement results and Investigation of profiles.

For six out of seven samples the measurement results correspond to the sensory evaluation. Only for sample 88980132 a discrepancy can be observed. This may be caused by a directional character of the surface structure, which strongly influences the evaluation. While the results of the sensory assessment do not allow a sharp differentiation due to overlapping range of variation, the measurement results show a clearer difference between the samples. This indicates a higher resolution of the measurement system compared to human perception.
In a next step structures of the different attributes orange peel and lacquer sinking were analyzed. Tests for the analysis of the attribute orange peel

were applied on a set of orange peel standards, used in automotive industry. This are ACT Orange Peel Standards by ACT Test Panel Technologies. Different samples of black liquid coatings on wood-based panel were used for the evaluation of the attribute lacquer sinking. The results of the correlation analyses are presented in figure 5.



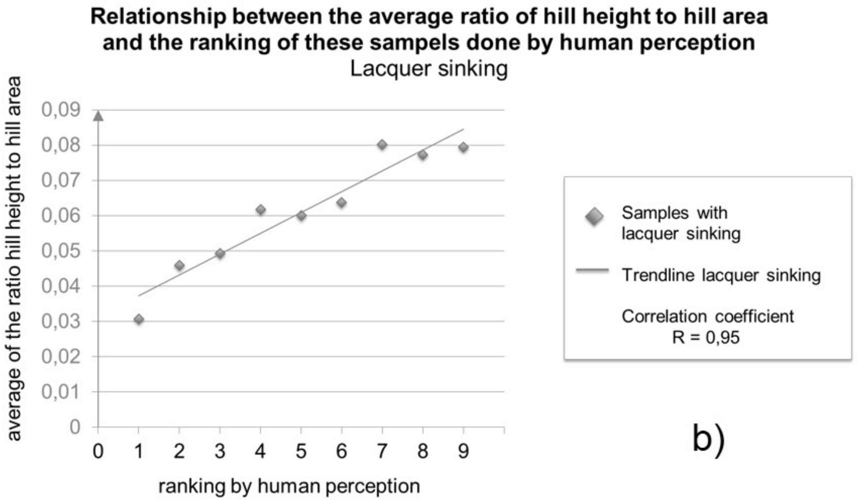


Figure 5: Relationship between ratio hill height/area and ranking
a) orange peel, b) lacquer sinking.

These analyses show a strong correlation between the ratio hill height/area and the ranking based on sensory assessment for both evaluated attributes. For the attribute orange peel an exponential correlation with a correlation coefficient of R = 0.98 can be determined. In contrast for the attribute lacquer sinking the results show a linear correlation with a correlation coefficient of R = 0.95. For interpreting these results it has to be taken into account that the extent of orange peel represented by the ACT Standards is usually not found on furniture high gloss surfaces.
Based on the results of the correlation analyses the calculated ratio hill height/area proves to be applicable evaltuating the extent of a single attribute. Nevertheless further comparison of the results shows that the absolute values of hill heigt/area do not differ between the two different attributes. Thus the ratio is innapropriate for distinguishing one attribute from an other. First approaches based on the contur length of topografic elements or the ratio of their expanse in x- and y-direction did not enable a sharp differentiation of attributes.

4 CONCLUSION

The ratio hill height/area can be applied as a specific value for evaluation of furniture high gloss surfaces. The algorithm developed for the calculation of the value delivers consistent results and – together with the measurement device – enables a measurement with sufficient repeatability and uncertainty for the estimated application.
As the ratio hill height/area enables a measurement of the extent of single attributes as well as an assessment of the overall quality concerning surface structures, it can be applied in quality control and its changes indicate variations in the production process. Nevertheless the value does not enable the identification of the root cause of a process variation. At the current state this still requires the knowledge of a well-trained expert for differentiation of various attributes.
Further benefits for the process control could be achieved by developing a more complex interpretation of the three-dimensional surface data that enables the separation of attributes. This can probably not be achieved by analyzing a single attribute and will require a set of specific values and some kind of fuzzy logic for a differentiation.

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LARGE-SCALE 3D PRINTERS: THE CHALLENGE OF OUTGROWING DO-IT-YOURSELF

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Abstract
Many low-cost 3D printers have been brought to market over the last couple of years. Most of them apply a Fused Layer Manufacturing (FLM) process, and have made 3D printing a great success amongst hobbyists, the maker community and students. One drawback of such inexpensive equipment is a limited build envelope, which prevents this from becoming a significant contributor to industrial production. To overcome these limits, it is not sufficient to simply upscale dimensions, but the overall concept of such machines must be completely re-thought, as well as the concepts behind several building blocks, components and the process software system.
Problems such as shrinkage of build material, support material and machine parts in combination with long printer head travels, temperature distribution and moisture effects all have to be solved. In addition, larger parts need longer process times. Therefore, reduction of process times and an increase in productivity are necessary in order to enable economic production.
Some of these problems can be solved by using more than one printer head for production, by using new materials and inventing new nozzle systems as distinct solutions for big printers. Nevertheless, to solve all these problems, the development of special machines for large parts is necessary: not component-wise but as a whole system. Large parts could then be successfully produced in several industries, using large, inexpensive FLM-machines.

Keywords:
3D printing, FLM, build envelope, large-scale, thermoplastic polymers

1 INTRODUCTION

In the last few years, additive manufacturing has progressed from lab-oriented testing stations, to more professional production machines. These machines allow for printing prototypes, or unique products, using a considerably cheaper and faster process than is possible with conventional technologies. There are currently several available technologies, some using epoxy resin, some powder and some applying filaments; the materials used can consist of almost anything. There are a number of indicators in favor of FLM technology in large-scale printers. Firstly, the consumption of material

is much lower than it is with other technologies. Secondly, there is no need for protective gases, sophisticated climate control, or a light shield and a complicated optical system. Thirdly, the well-established machine design and construction makes it easy to build individual large-scale printers using FLM technology. The simple and inexpensive technology has enabled the existence of a great number of consumer level printers.
However, it is absolutely insufficient to merely enlarge the existing low-budget printers, without rethinking the whole concept and design. In the field of additive manufacturing technologies, a huge number of patents have been filed, which cover the principal processes. Some of them have expired over the last few years. In the 1980s, the principal patents for Stereo-Lithography (STL) (US patent 4575330, 1986, 'Apparatus for production of three-dimensional objects by stereolithography'), Layer Object Manufacturing (LOM) (US patent 4752352, 1988, 'Apparatus and method for forming an integral object from laminations') and Selective Laser Sintering (SLS) (US patent 4863538, 1989, 'Method and apparatus for producing parts by selective sintering') were issued [1]. The patent for Fused Deposition Modeling (FDM) (US patent 5121329, 'Apparatus and Method for Creating Three-Dimensional Objects') was granted in 1992 [1]. Therefore, the development of large-scale printers will probably not be limited by current patents, if they rely on standard processes. According to the Wohlers report of 2015 [2], the current patent activity worldwide focuses mainly on particular applications. The majority of additive manufacturing patents submitted during the last few years cover medical applications, followed by manufacturing technology and material developments.

2 STATE OF TECHNOLOGY

2.1 Process

Fused Layer Modeling, which was invented by Scott Crump and developed by the American company 'Stratasys' under the name Fused Deposition Modeling (FDM), is one of the processes which use a solid wire-shaped raw material (filament). To build the part, the filament is melted in a heated nozzle and laid onto a platform (print bed), that may or may not be heated. In order to do this, the print head travels back and forth repeatedly, and places the melted filament on the print bed until the entire part contour and filling are completed. Then the print head moves to the next layer and repeats this process until the part is completely generated, as shown in figure 1. The plastic filament is unwound from a nearby roll [3]. The surface quality of parts produced in this way is usually lower than that of other processes, caused by the thickness of the filament and the so-called staircase effect. The FLM process is not very complex and the entire equipment is therefore available at low cost [3]. With certain part geometries, such as overhangs, undercuts or larger hollow areas, a support structure may be necessary to ensure stability during the build process. The support structure has to be removed afterwards in an additional post-processing step. This can be done manually, by the use of chemicals, or water (wash away) depending on the support material employed.

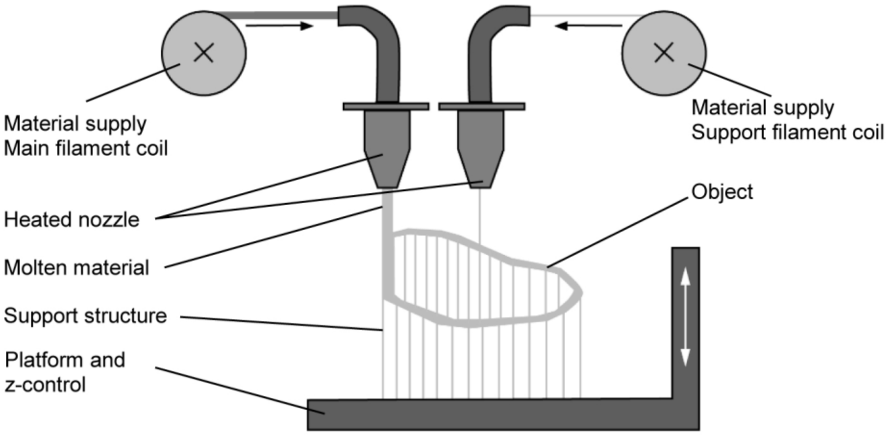

Figure 1: Schematic diagram of Fused Layer Modeling.

2.2 Material

The material for FLM processes is regularly extruded into a wire form, which can be described as a monofilament. These materials should have amorphous characteristics because of the wide process temperature range of up to of 280°C maximum. The settings for crystalline and semi-crystalline thermoplastics are much more difficult to control and the low viscosity of these materials makes the process even more complicated.

The materials provided primarily consist of thermoplastic materials such as **p**oly**la**ctide (PLA), **a**crylonitrile **b**utadiene **s**tyrene (ABS), **a**crylonitrile **s**tyrene **a**cetate (ASA) and **p**oly**su**lfone (PSU). PLA, which is widely used, is produced from renewable raw materials, such as corn, including lactic acid molecules and is biodegradable in industrial composting plants [4]. Visually, PLA and ABS plastics cannot easily be distinguished from each other, but they differ in their mechanical and thermal properties. During the FLM process they exhibit different adhesion to the print bed. To remain firmly on the print bed, ABS requires a higher temperature, while PLA may also be printed on an unheated platform [5]. PLA has lower temperature resistance, whereas ABS requires a higher print temperature and shows higher thermal shrinkage [3].

Wood or plaster particles can be used as filling materials to obtain organic component composites. For extremely resistant parts there is a **p**oly**a**mide 6

(PA 6) filament, which has particular advantages in the automotive industry, for example in gears or bearings [6].
The most commonly used materials for technical applications are **a**crylonitrile **b**utadiene **s**tyrene (ABS), **p**oly**c**arbonate (PC), **p**oly**la**ctide (PLA), **p**oly**p**henyl**su**lfone (PPSU) and **p**oly**e**ther**i**mide (PEI). An environmentally friendly **p**oly**v**inyl **a**lcohol (PVA) filament can be used as a support structure, which easily dissolves in water after printing, and can be safely disposed of with waste water [3].
The material can be provided in so-called filament rolls, with different filament diameters, i.e. 3 mm, 2.8 mm and 1.75 mm. Filaments for FLM must provide a round cross section, the diameter should have a maximum tolerance of +/- 0.15 mm and they have to be free of vacuoles to guarantee stable processing. The storage temperature of ABS should be close to 70°C, with a maximum humidity of 5%. Additives and fillers should be used to minimize thermal decomposition. While filament material is produced in an extrusion process, the special 'Fuse Stick Deposition' sticks, which are used in some FLM equipment, are produced by Exjection® molding.

2.3 FLM machines

Classification
Current FLM machines can be classified according to three categories. The low-price category includes all machines below €10,000, including most of the well-known home printers, many of the machine producers, material producers and the maker community are currently focusing on this group. The effect of this is that there are many different machines and several materials on the market, offered in nearly every color and a variety of different thermoplastics.
All machines up to €50,000 are semi-professional machines, which are generally able to produce higher-quality products. Only a few machine and material providers are currently active in this area of the market, all of which apply cartridge systems to facilitate material handling. Thus every manufacturer produces material that can only be used with their proprietary machines. The postprocessor software is normally included in these systems and the user can choose only very few parameter settings. For research activities, such machines are unattractive, but they ensure reproducibility and process stability for production purposes under predefined conditions.
Machines costing more than €50,000 include most large-scale machines and belong to the high-price, high-quality and special sizes field.

Machine setup
The setup of the machine has a considerable influence on quality and printing time. The mass, size and motion control of the machine has a major effect on the possible speed, build size and accuracy of the whole process. The setup of a FLM machine can follow different motion concepts.

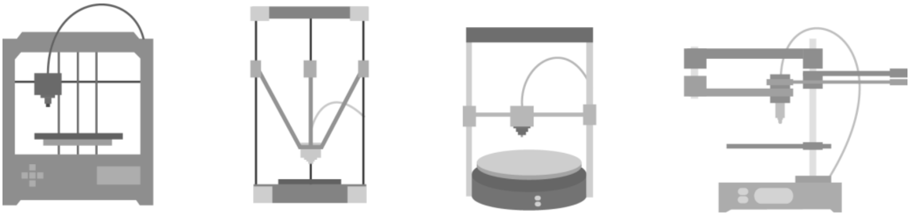

Figure 2: Printer motion concepts.

Fig. 2 depicts the most common approaches to building FLM printers today, displaying from left to right: Cartesian FLM Printer, Delta FLM Printer, Polar FLM Printer and a SCARA FLM Printer. The Cartesian principle resembles a portal milling machine and is the most commonly used concept. It is also the structure that is used by professional, large-scale machines from Stratasys (Fortus). The Delta printer uses the parallelogram kinematics principle, and is an advantageous option for parts which are small in x and y direction, but large in z direction. The head can also be programmed to give a slightly sloped position. The concept of the polar printer is a mixture of the Cartesian and the Delta printer, the z axis and the x axis work like a portal machine, whereas the y axis is realized with a rotating print bed. It is used for round small-diameter parts with bigger z extension. The SCARA (Selective Compliance Assembly Robot Arm) uses robotic technology for the x and y axes, only the z axis is similar to the Cartesian kinematic. There are also approaches using robotic arms such as those used for welding robots. Fraunhofer IPA has built such a machine for testing purposes.

2.4 Software

As always with additive manufacturing, a 3D CAD model is required. Most CAD-Software solutions can extract the STL format, which is a quasi-standard format for data transfer from CAD to 3D printer. The next step is to convert the STL data into a machine format, which most often uses G-code. Using established companies’ standard software, the required postprocessor software is included and the machine control software performs the conversion automatically. When using open source or individual machine control software, the application of a special postprocessor software solution for 3D printers is necessary, for example Slic3r or Simplify3d are available. Such software systems, which are used to set all printing parameters, influence the process considerably.

3 LARGE-SCALE FLM MACHINES

Scaled-up FLM machines are necessary in several industries, to enable large seamless parts, for example in the automotive industry in order to build complete dashboards in one part, particularly when the limited surface quality of FLM parts is not especially important, because they will require mandatory coating or surface treatment anyway.

To analyze the requirements and find potential solutions for the development of large-scale FLM machines, the process itself, as well as all possible problems, must be defined in detail. This is necessary because simply increasing the well-functioning small versions to larger versions without considering design problems does not deliver satisfactory results. Increased performance is required in all relevant areas, such as material, machine size and software. The most important requirements and solutions of large-scale FLM printers are identified in the following section.

The standard sized Mendel-Prusa and the large-scale Stratasys Fortus 900 can be chosen as examples to analyze these problems, as comparing their build chamber size and accuracy provides an idea of the challenges encountered when producing larger machines. The Mendel-Prusa is a typical home-use FLM machine that comes with a build chamber of 200 x 200 x 120 mm^3 and tolerances of +/- 0.3 mm. In contrast to this the professional Stratasys printer Fortus 900 has a build chamber size of 914 x 610 x 914 mm^3 and enables tolerances of +/- 0.1 mm [7]. Simply increasing the size of the Mendel-Prusa printer will further deteriorate tolerances, which is not acceptable for industrial applications.

Currently, the Fortus is the professional machine with the largest build chamber. Existing individually made large-scale printers can reach build chamber sizes of over 1 m^3, for example the large-scale printer BZT M5 with 1500 x 500 x 250mm^3 build chamber produced by BZT and Material4Print.

3.1 Material

Established producers such as Stratasys or 3D Systems supply only a limited choice of materials for large-scale machines. The most commonly offered and applied thermoplastic polymers for these machines are ABS, PC and **t**hermoplastic **p**oly**u**rethane (TPU). Contrary to the home printer market, the variety of colors is quite limited in the professional sector. This limitation can currently only be resolved by building an individual large-scale printer, because only an independent software system allows programming with parameter sets outside the pre-sets.

Another considerable problem with large-scale printers is the warping effect, which also exists on smaller machines, albeit on a lesser level. Warping is a particular thermal bending effect of the part as shown in fig. 3, and results from the thermal shrinkage of thermoplastic material during the cooling phase.

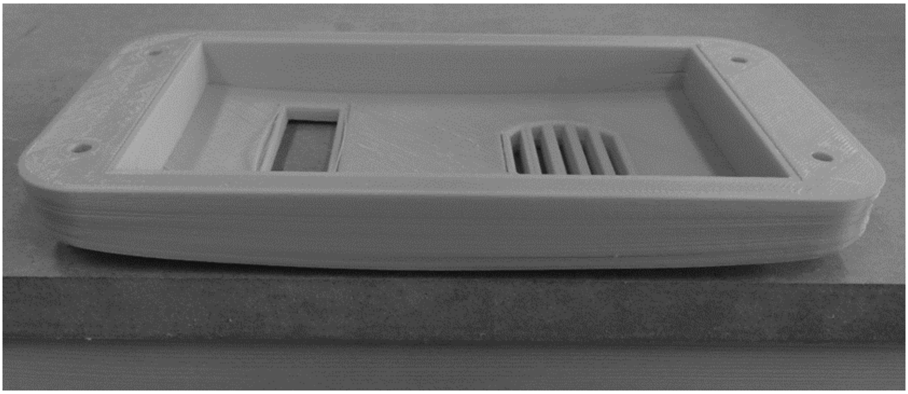

Figure 3: Part displaying warping effect.

While the upper layers are being built up, the lower layers are already cooling down and consequently shrink, because of the increased tension stresses inside the part, so the edges of the part bend up. This effect is particularly pronounced when using standard materials on large-scale machines, as the parts are much larger than standard ones, higher temperature differences develop between the layers, which subsequently causes major tension stresses and warping. Using a heated print bed and having a temperature control inside the build-envelope can reduce this effect. Another way to solve this problem is the use of fillers, which are thermally inactive, such as minerals, for instance the well-known 'Laywoo-3D' material, which is made out of 60% PLA and 40% wood fibers, has never shown any sign of warping.
The temperature control of the whole process including the build chamber, the nozzle and the print platform will have huge impact on the material properties. An overheated material will induce melting of the whole part, while fusing layers will become difficult if the temperature is too low.

3.2 Machine

Many large-scale machines are currently just scaled-up versions of standard machines. Examining these stretched machines, they often show unstable behaviors and insufficient rigidity, producing vibration, which causes problems in the part being produced. Machine concepts with printer heads attached to more rigid machine types show much better process results. There are two main types of machines for large-scale processes: On the one hand there is a robotic arm with an attached printer head, which at first glance, seem to be acceptable regarding motion speed, accuracy and number of axes. More than three axes are not provided by standard software solutions. Therefore it is necessary to write a special postprocessor program for such machines. Furthermore, the high speed and accuracy of these systems is largely unnecessary, as FLM structures are not usually created for the extremely small tolerances that such a system is able to provide. A potential advantage of applying robotic arms is the opportunity to increase the number of them to significantly increase productivity.

Portal frame type milling machines can be equipped with an attached printer head. A disadvantage of this solution is that these machines are not as fast and the functionality is limited compared to robotic solutions. But well-established standard post-processing software can be used, as the setup of these machines equals the Cartesian printer. The accuracy is normally good enough for all FLM printing processes. Another positive aspect is that a milling machine can be used for milling after changing the tool and removing the print bed.

Besides the machine setup, the printer head has a considerable influence on the accuracy, visual and haptic appearance of the product as well as on the process speed. The printer head is normally built out of three parts: the nozzle, the heater and the thermal insulator. The nozzle diameter determines the layer height, the heater is necessary to melt the thermoplastic filament and the thermal insulator is required to insulate the heater and the material supply system, as shown in fig. 4.

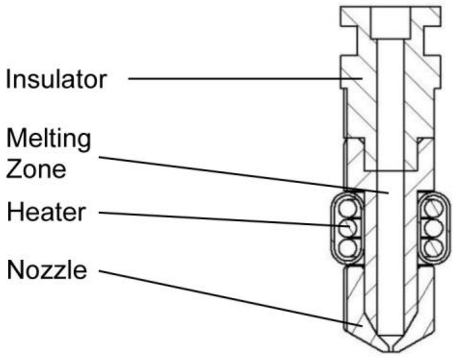

Figure 4: Printer head (hot end).

The choice of nozzle depends on the desired process result. If it is necessary to produce a part very fast but high accuracy is not required, a nozzle with a large diameter is useful as it creates thicker layers. If a high surface quality or dimensional accuracy is needed, it is more appropriate to use a nozzle with a smaller diameter, which will subsequently increase the process time.

Only two potential solutions are available as heating devices: a selective solution, as used with most home printers, or a professional one, which is wrapped around the whole heating device. The latter optimizes the melting process by equalizing the heat distribution in the thermoplastic material and enables a much faster heating-up time. The insulation must prevent heat transfer from the heater and internally works in a similar way to a hydraulic cylinder, by using the filament as a type of piston.

The material supply and feeding device also has an influence on the quality of the printing process, the two methods being direct drive and so-called Bowden extruders. In direct drive extruders, the material supply motor is positioned directly on top of the insulation, which makes it easy to control the parameters with standard control software. With Bowden extruders, the motor for the material supply is mounted outside of the build envelope and machine frame, and the material is fed through a **p**oly**t**etra**f**louro**e**thylene (PTFE) tube. The use of only one of these feeding systems for a large-scale machine causes problems as the material support may be interrupted due to the long travel for the printer head. A combination of both systems may solve this problem.

Another major influencing factor on material and part quality is the temperature inside the machine envelope. Most materials, particularly ABS, require a heated printer bed to aid adherence between bed and part. The part is connected to the bed only by adhesion forces. Internal stresses caused by temperature gradients inside the build chamber can cause part detachment. To prevent process failure, caused by cold air from outside, and to get a more even temperature distribution, it is beneficial to build a closed build chamber. Additionally, a controlled active heater for the build chamber can be used to achieve constant temperatures and to consequently solve the problem of uncontrolled part shrinkage.

Certain problems are not common with small-scale printers, but are very important to large-scale ones. An example of this is that material handling between the roll supplying the material and the printer head has to be guaranteed, and it must be ensured that the filament wire does not touch the part, or collide with any printer component. This can be solved by using a PTFE tube for carrying and protecting the material. All other components, for instance power cables and signal wires, must also be protected by tubes to avoid collision.

Furthermore, that the material remains inside a heated build chamber for a long time, before fusing in the printer head must also be taken into account. Emerging thermal material expansion can be avoided by a metal covered PTFE tube, which must have a slightly larger diameter than the filament itself. Further to this, bridging of long travel distances is an issue: if the material roll is positioned in the center of the machine, and at the top of the machine, the distances to all corners is the shortest possible, this is an optimal point. Small machines do not have long travel problems. However, with large-scale machines, the distance from the center to the corners is much greater and forces the material to be drawn out of the printer head. To prevent this, a brake device or a special command in the control program is necessary. The same problem occurs in reverse when the material is pressed through the printer head and forms little droplets at the tip of the nozzle, which will cause decreased part quality. The solutions presented above can also solve this problem.

Another challenge encountered by small printers, is thermal expansion of the heated printer bed and its extensive influence on the whole process. There are two areas of concern: Between the heater and the printer bed and between the printer bed and the part. The first problem can be minimized by using a thermally inactive material as a printer bed or by including heating elements inside the printer bed. The second problem is far more difficult to solve, because the challenge is that separate printer beds have to be used for each printing material, each having nearly the same coefficient of thermal expansion as the printing material. This causes a problem when using different materials for the support and the part, which may each have different thermal expansion coefficients. To overcome this difficulty, most of the larger machines use a 'raft' structure as the first layer. This structure can compensate for the tension between the materials and the heated bed.

The problem of thermal expansion has to be allowed for in the design and construction of all machine parts. One solution might be the use of an expansion joint between the machine parts.

3.3 Software

In general the same software application can be used for standard FLM machines and for large-scale printers, but professional solutions often cannot be used for printers of other sizes because the user cannot change the embedded settings. In contrast, open source solutions open up the opportunity to change every parameter, but they are often not capable of processing large data files sufficiently and may crash while slicing the part. The build and travel direction, and the process-parameters that are set in the machine postprocessor controller, also have significant influence on the mechanical properties of the part. Additionally the different part filling (infill) strategies can have a considerable influence on the strength and the process time, too. Finally, in order to solve all the problems mentioned above, the best approach is to program an individual software solution, customized to the systems being used.

3.4 Post-processing

After finishing the print process, the parts generally need to be reworked. With FLM, this is necessary due to the often unavoidable use of support structures. These structures are mainly to support the main geometry where there are gaps and free hanging structures. They can be made out of the same material as the main part, or a cheaper and easier to remove material. Some support structures are water-soluble, some are soluble in solvents, and some have to be removed mechanically. After removing the support structures, the parts must be cleaned of residue and they are then ready for use.

If a higher surface quality is needed, the parts can be reworked using traditional methods. Additionally, ABS has a particular reworking method to increase surface quality, if technical dimensional stability is not the main aim it can also be treated with acetone to raise the surface quality.

4 ECONOMIC APPROACH

To justify a large-scale 3D printer, the analysis of the economic effect of the whole system and the later use of the machine is necessary. It is important to mention here that the initial machine set-up requires significant time, heating up and cooling down periods must be accounted for, as well as a possible build time of more than 200 hours for very large parts. Due to the larger part size, a greater heat output is necessary, which increases the energy consumption. The cost of customized software has to be added to this calculation as well as the installation room required.
The use of industrial and professional printer head and all other machine components is also necessary, instead of the cheaper parts generally used in small printers, because parts for large-scale printers require durability and reliability, this is particularly true for industrial application. On closer inspection, these machines are predestined for large individual and seamlessly producible parts, where process time is not the most important factor.

5 CONCLUSION AND OUTLOOK

The practical applicability of large-scale FLM printers lies in the production of large, individualized parts. The main advantage of such printers is an inexpensive and uncomplicated functional principle, which is therefore widely used in the consumer and do-it-yourself sector. The wide variety of build-materials, which cover a wide range of applications, is also advantageous. On top of this, enlarged build envelopes are, in principle, easy to achieve only if low-level quality requirements are to be met. Taking into account the professional requirements identified and the appropriate solutions, a scaled-up, functioning FLM printer can be designed and built for industrial applications, but this requires much more than just scaling-up of smaller consumer type printers. Technically, almost all of the requirements can be fulfilled today, if the focus is on machine structure rigidity, printer bed and build chamber temperature control, the feeding and nozzle systems and the greater travel of most moving parts. Additional R&D will have to provide progress in available materials and their properties, to enable utilizing the advantages of FLM technology compared to other additive manufacturing technologies. The development of large-scale FLM printers, fulfilling industrial application requirements, enables new areas of application for

FLM parts, such as large, seamless models or final parts. Future research is required regarding process software to enlarge the field of application.
In future, the qualities this procedure offers will also enable completely individualized products in the most diverse overall sizes and from the most diverse materials in small serial production. This procedure also offers possibilities for use in the electronics industry for the production of multilayer printed circuit boards with integrated electronic components, and even in the construction industry for extremely fast and cheaply realizable buildings.

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ERGONOMIC DESIGN OF GRAPHICAL CONTROL ELEMENTS ON PRODUCTION MACHINES

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Abstract
The trend of increasing technological complexity of machines mainly correlates with the integration of additional functions in machines. Increasing functionality of the machines leads to an increased number of control elements, which limits the clarity of the machine operation and leads to higher cognitive demands in the machine operation.
Due to the growing functional range of production machines the demand of usability for the operating systems continues to grow. The selection and design of icons for the identification of controls contributes significantly to usability, especially for intuitive operation of production machines.
The aim of this study is to investigate the intuitive usability of production machines, to consider its use of graphical elements (icons) and to derive recommendations for a demand-oriented selection and design of icons. To achieve this goal, laboratory studies at five modern production machines (laser sintering machine, CNC universal lathe, plastic injection molding machine, laser processing machine, woodworking machine) - each with different operating concept - were performed.
The results of the study show that the used symbols in the examined machines are only limited self-explanatory and intuitive, and thus have significant deficits for easy and intuitive operation. Especially the combination of screens and electronic keys or switches was often criticized and leads to uncertainty in the operation. As a result, recommendations for the design of icons on production machines are given.

Keywords:
Usability, production machines, icons, usability, human-machine compatibility

1 BACKGROUND TO THE STUDY

The ergonomics of production machinery is becoming increasingly important, particularly in the context of Industry 4.0. The trend towards ever-increasing technological complexity and greater functional scope in machinery is accompanied by a greater number of operating elements, which in many cases limit the clarity of operation [1] and lead to greater cognitive demand during the operation of machinery [2]. As a consequence,

there are increasing requirements with regard to the usability of the operating system.
Graphical user interfaces on screens and symbols should assist the user in operating machinery and provide information independent of language [3]. The symbolic identification of operating elements clearly aids usability, particularly in terms of the intuitive operability of machinery.
It should be noted that understanding of icons inevitably changes over time [4] and may not be self-explanatory to the same degree for different target and age groups. An examination of icons on the operating interfaces of production machinery reveals that they have not been further developed with any urgency in the last ten years, as they have for example in smartphones or in the field of IT [1].
However, in practice, another challenge is posed by the fact that unskilled workers both at home and abroad are employed to operate production machinery, leading to increased difficulties in the interpretation of the icons used. A further complicating factor is that the ability of foreign workers to read cannot always be assumed, leading to an additional requirement to use only clear, self-explanatory icons.
International standard DIN ISO 7000:2008 provides an overview of more than 2,500 icons for technical equipment [3]. In the production machinery investigated in this study, only a small proportion of standardized symbols were identified. The majority of the symbols were designed by the machinery manufacturer.

2 APPROACH AND METHOD

In view of the problem as described, this study investigates the intuitive operability of production machines and their operating systems in respect of the icons used, and derives recommendations for action which will lead firstly to the user-friendly design of machine operating systems (user interfaces) and secondly to increased productivity. Another important aspect of improved usability is a reduction in training and teaching expenditure and increased acceptance of new machines and technologies by machine operators.
The investigation as carried out is divided into three case studies. The case studies include laboratory and field investigations on five modern production machines (laser sintering machine, CNC universal lathe, plastic injection molding machine, laser processing machine, woodworking machine), each with a different operating concept (fig. 1).

Case study	Production machine	Year of manufacture	Operating system	Number of test subjects
1	Laser sintering machine EOS FORMIGA P100 and P110	2006/2011	Display with touchscreen	11
2	CNC universal lathe DMG MORI SEIKI CTX alpha 300	2013	Button operation and graphic display	10
	Plastic injection molding machine Arburg Allrounder 420 C	2008	Button operation and graphic display with touchscreen	10
	Laser processing machine Laservorm LVS-909F	2011	Button operation and graphic display	10
3	Woodworking machine	2013	Button operation and graphic display with touchscreen	11

Figure 1: Information on the production machines investigated.

The first case study was conducted as a laboratory and field investigation at a major manufacturer of industrial joining technology as well as in the laboratory for development and design of the Ostwestfalen-Lippe University of Applied Sciences. In the second case study, usability tests were conducted in various laboratories at the Ostwestfalen-Lippe University of Applied Sciences. Case study 3 was conducted at a manufacturer of woodworking machines and two other production facilities in the timber industry.

The selected approach in all case studies included the conduct of usability tests in combination with video and speech recordings, the use of questionnaires and a final workshop in which measures were discussed and design recommendations extrapolated on the basis of the results of the analysis.

For the usability tests, test subjects were recruited from students and academic staff of various ages at the University of Applied Sciences Ostwestfalen-Lippe without any previous experience with the production machine in question. The test subjects received a short introduction to the production machine in question and were required to complete and comment on various tasks with minimal assistance from the investigator. Fig. 2 shows a section of the usability test at the CNC universal lathe.

Figure 2: Usability test at the CNC universal lathe.

After all tasks had been concluded, a questionnaire – based on the Compendium of Ergonomics from the Federal Institute for Occupational Health and Safety [5] and the software questionnaire ISONORM 9241/110-S /ISONORM 9241/10 [6] – was completed on the operation of the machine, in which various aspects of the operation and design of the production machine were evaluated.

In addition to basic functions - such as switching the machine on and off - tasks on the production machinery included a selection of typical work tasks carried out by machine operators during normal use. Each usability test lasted approximately 45 minutes per test subject.

3 RESULTS OF THE INVESTIGATION

The evaluation of the recordings and videos from the usability tests shows that the human-machine compatibility of the production machinery investigated in terms of the intuitiveness of the icons used could be improved.

In carrying out the tasks, so-called errors were frequently observed, the cause of which could be traced back to unsuitable representation of icons or their captions. Fig. 3 shows the observed errors, the nature of the errors and the causes identified. Thereafter a selection of examples of the errors observed is reproduced.

Actions (errors) observed	Type of action (error)		Root causes
Icon not found	Icons	Function of the icon not interpreted	Icon representation not comprehensible
		Icon assumed to be at another position	Unexpected arrangement
	Icon caption	Icon caption not legible	Incomprehensible abbreviation or writing too small
		Icon caption not comprehensible or not as expected	Imprecise, non-attributable choice of term or incomprehensible language
Operating error	Icons	Icon confused with another	Insufficient differentiation
			Representation in the wrong context
Additional and superfluous actions	Icons	Multiple choice or search for additional icons	Missing feedback on action
		Uncertainty and search for possible subsequent steps	Color representation or change of color not as expected

Figure 3: Errors observed and root causes.

1. Icon not found

For example, on the laser sintering machine, difficulties were observed among the test subjects in loading the construction task (7 of 11 test subjects), as the icon representation was not perceived as comprehensible and was criticized [7]. On the CNC universal lathe, icon no. 0983 with the title ‘Program with machine function’ (cf. [3]) was criticized by virtually all test subjects (9 of 10 test subjects) as not being self-explanatory, as it could only be found on the basis of its caption. On the woodworking machine, 7 of 11 test subjects could not find the icon to switch on the heating, as the abbreviated term ‘Auftragsei...’ (German) could not be interpreted and the icon representation was not self-explanatory.

2. Operating error

On the CNC universal lathe, all test subjects used the ‘SELECT’ button to select a program, despite the fact that this button was not relevant in this context. On the woodworking machine, six of the eight main function icons were either not recognized by the test subjects or were associated with other functions and selected accordingly.

3. Additional and superfluous actions

On the woodworking machine, for example, it was not clear to several test subjects whether a unit required for a particular process was switched on, as the yellow representation of the icon did not conform to the test subjects' expectations and was associated with an error. All 11 test subjects failed in the task of feeding in material for the process, as simply pressing the icon did not bring any response from the system or an instruction. Both mentioned examples led to uncertainty among the test subjects and a search for possible subsequent steps.

Overall, it was determined in the context of the whole study that self-designed icons appeared not to have been tested sufficiently or at all by the machine manufacturer during the development phase of the machine, and there were obvious weaknesses in the intuitiveness of individual icons. In addition, the results revealed that the use of standardized icons from DIN ISO 7000:2008 may be problematic, as the icon representations were not consistently perceived as intuitive by the test subjects. The errors set out in fig. 3 could significantly slow down operation, lead to operating errors and cause uncertainty in the operator.

4 REQUIREMENTS FOR THE DESIGN OF ICONS

In designing icons, recommendations for software ergonomic design should be taken into account. The basic principles of dialog design for human-system interaction set out in DIN EN ISO 9241-110 - such as suitability for the task, intuitiveness and conformity to user expectations - can be applied to the design of icons. The multi-part DIN EN 80416 series of standards

provides general principles and rules for the design of icons on machinery and equipment which also help icons to remain identifiable when they are greatly reduced in size during use [8].
Taken as a whole, these standards and series of standards require icons to be quickly and unambiguously identifiable, recognizable independent of language and culture, distinctively designed and compliant with the standards (e.g. icon in the form of a diskette for the ‘save’ function). Feedback from actions is important for the operator to identify the current processing progress, and to enable further actions to be extrapolated [9]. An appropriate color scheme assists in triggering the correct action in the operator. Icon captions must be designed to be comprehensible and easily legible to provide additional assistance in identifying the icon.
In addition, it should be noted that the intuitiveness of an icon can also be improved if it is only offered in a specific context [4]. With situation-based decision support, quick and reliable task processing can also be achieved [10]. Finally, it is recommended to test graphical operating elements in accordance with DIN EN ISO 9241-210:2011 during the development process of the machines.

5 CRITICAL EVALUATION

The results show that clear weaknesses exist in the intuitiveness of individual icons and that there is a potential for improvement in the intuitive operation of production machinery. The errors set out in fig. 3 could significantly slow down operation, lead to operating errors and cause uncertainty in the operator.
Overall it may be noted that the improvement of the intuitiveness of icons can make a clear contribution to improving the user-friendliness of production machinery, reducing the training and teaching expenditure and increasing the acceptance of these machines and technologies. The research methodology may be criticized for the fact that the test subjects came from only one cultural background and had a high level of education. However the production machinery investigated are occasionally operated in newly-industrialized countries by personnel who have a very low level of education. In addition, only a selection of the icons on the production machinery were investigated, so it may be assumed that there is further potential for improvement on these machines.
Further investigation with different groups of people and additional icons is recommended. Further findings could mean that a generally-applicable icon for a specific function cannot be designed, but that various cultural groups must be offered different symbol systems [11].

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EMISSIONS OF VOC AND ODORS FROM POLYURETHANE FOAMS

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Abstract
Main direction of this contribution is defined by a composition of quantitative and qualitative VOCs emissions and VOCs emitted by chosen materials used in upholstered furniture and mattresses such as polyurethane foam, bonded polyurethane foam and polyurethane foam with increased fire resistance. VOCs emissions are collected in a space chamber with pre-defined conditions. The assessment methodology of the VOCs emissions is described in the standard ČSN EN ISO 16 000-9. The air samples from the climate chamber, where a test sample is placed, after their collection the samples are analyzed by the gas chromatography (GC) method on a gas chromatograph with mass spectrometer and thermal desorption. Another part of this research is olfactometric assessment of odors emitted from tested materials, by the indirect olfactometry method. The relevance of the individual components on emissions of odor intensity and hedonic effect will be determined according to the chemical analyses of the achieved results.

Keywords:
VOC, odors, chromatography, olfactometry, polyurethane foam

1 INTRODUCTION

The increasing demands for comfort in life especially in the furniture production branch have great impacts on the quality of environment. So leading over from the user point of furniture to the quality of the indoor air. The quality of indoor air makes an impact on the decrease of volatile organic compound emissions. So odor criteria have become a key performance requirement in most applications. To address this issue, the entire supply chain, known as life cycle analysis, from producers to end-users attempts to find ways and means to identify, understand and reduce unexpected emissions and odors [1].
Indoor odors are usually mild and intermittent and the sources of indoor odor are varied and usually nonspecific; therefore, it increases the difficulty to characterize indoor odors and to identify the odor sources. Still, characterization of odors (qualitative and quantitative) can help to identify

pollution sources and plays an important role in evaluating indoor air quality due to greater human sensitivity to odor [2, 3].
The quantitative and qualitative content of VOCs emitted by the foam materials are based on polyurethane or latex, which have commonly great importance from the point of users using the upholstery products such as seats and wall paneling in cars and upholstery furniture. There exists little information about these materials in the scientific and technical literature in terms of VOCs emissions and odors. It is important to deepen this knowledge, because upholstered furniture surrounds us in each interior and car, used by any of us. It is clear that the entire indoor interiors and indoors of the cars affects the quality of indoor air in the houses, flats and cars.
The influence of the individual materials on indoor air quality is mainly characterized by the TVOC (total volatile organic compounds), which is used to describe the total amount of volatile organic compounds in indoor air. TVOC value indicates the level of indoor air pollution.
The aim of the research was to find the hedonic tone or odors and diversity of VOCs emitted from polyurethane foam, viscoelastic foam and latex foam depending on the time. This study examined the release of chemical substances from selected materials and their amounts, which are gradually released, versus time. Samples were prepared from a block of polyurethane foam from the vendor (not the manufacturer). Quantitative difference of entire emitted organic compounds showed the measured values of TVOC.

2 GOAL OF RESEARCH

This research describes the VOC emissions emitted by polyurethane foam, viscoelastic foam and latex foam. The study examined the release of chemical substances from selected materials and their amounts, which are gradually released versus time. The goal of the research was to find the hedonic tone and intensity of odors and individual representative of Volatile Organic Compounds emitted from polyurethane foam, viscoelastic foam and latex foam depending on the time. Samples were prepared from a block of polyurethane foam from the vendor (not the manufacturer). Quantitative difference of entire emitted organic compounds showed the measured values of TVOC.

3 MATERIALS, EQUIPMENT AND METHODS

The polyurethane foams (polyurethane foam N5063, Visco-elastic foam V5020 and Latex foam) were investigated.
Samples were taken from the normal manufacturing process, wrapped in aluminum foil and delivered to the tested laboratory. The polyurethane foam was cut into sizes of test sample (dimensions: 0.65m x 0.65m x 0.05m) and put into the test chamber. As emission rate of VOCs also depends on age,

the samples were put into the chamber as soon as possible after the delivery from the plant. In the present study, air samples were collected continuously onto the Tenax TA.

3.1 Tested materials

1. Polyurethane foam N5063, dimensions of one sample:
   0.65 m x 0.65 m x 0.05 m, size tested sample: S=0.98 m^2.
2. Visco-elastic foam V5020, dimensions of one sample:
   0.65 m x 0.65 m x 0.05 m, size tested sample: S=0.98 m^2.
3. Latex foam, dimensions of one sample:
   0.65 m x 0.65 m x 0.05 m, size tested sample: S=0.98 m^2.

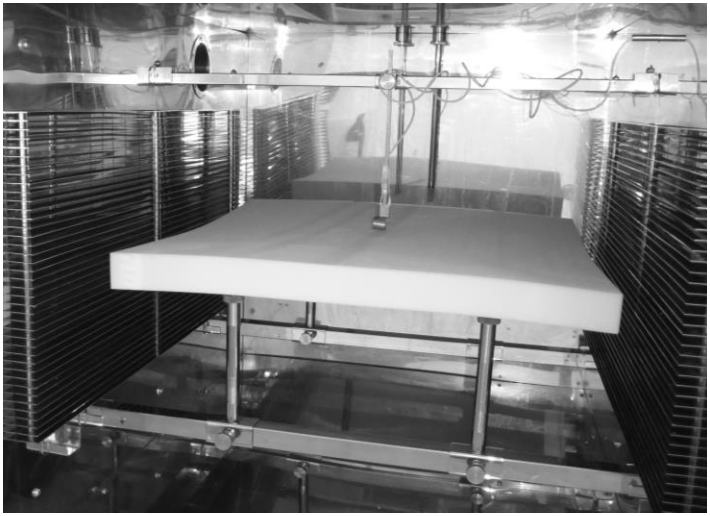

Figure 1: Small space chamber (VOC TEST 1000) with tested sample.

3.2 Equipment for determination VOC emissions and odors

- Short path thermal desorption tube, Silco trated Thermal Desorption Tube 786090-100, inner diameter 4 mm, fill in with 100 mg of Tenax TA (Scientific Instrument Services Company) for collection of VOCs emissions emitted from tested samples in to the air in chamber.
- Air sampler Gilian–LFS 113 SENSIDINE with air flow 6 l h^{-1} and 12 l h^{-1}.
- Gas chromatograph Agilent GC 6890 with MS (mass spectrometer) detector 5973 with cryofocusation, thermal desorption and library of spectra NIS 05, column type HP – 5 (AGILENT USA).
- VOC was tested in a small-space chamber with a volume of 1 m^3. Air temperature: 23 °C; relative humidity in the chamber: 50 %; air changing rate: 1 m^3 per 1 h; air speed over the tested samples: 0.1 to 0.3 m s^{-1}.

- Olfactory detector outlet Sniffer 9000 based on sensor techniques, one the most sensitive and intelligent detector.
- Gas chromatograph Agilent GC 4890 D, detector FID.

3.3 Methods

Methods of VOC and odors testing were set via standards:

ISO 16000: 2004	Indoor air
ISO 16000-1: 2004	General aspects of sampling strategy
ISO 16000-5: 2005	Measurement strategy for (VOCs) volatile organic compounds
ISO 16000-11: 2004	Determination of the emission of volatile organic compounds – sampling, storage of samples and preparation of test specimens
ISO 16000-6: 2005	Determination of volatile organic compounds indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and chromatography using MS/FID
ISO 16000-9: 2004	Determination of the emission of volatile organic compounds - Emission test chamber method
EN 13725: 2003	Air quality - Determination of odor concentration by dynamic olfactometry

3.4 Determination of hedonic tone for individual VOCs in the mixture

Hedonic tone of the each substance is determined by the equipment Sniffer 9000. The Assessor submits the assessment of individual substances at specified time intervals. Assessors determine hedonic tone of odor substances according the Hedonic scale. At the same time he writes data from the point of the character, odor and pleasantness. The data have been expressed signed / + /, or annoyance expressed signed / - /, made into tables. The output is a graph of sensations with retention times. Its overlap with the chromatogram assign to individual records identified substance.

4 RESULTS AND DISCUSSION

The results of measurements of TVOC emissions released from visco-elastic foam V5020 are shown in tab. 1. The results of measurements of TVOC emissions released from latex foam are listed in tab. 2. The results of measurements of TVOC emissions released from polyurethane foam N5063 are listed in tab. 3. Identified characteristic VOCs of the individual measured foam materials are listed in tab. 4. The results of odors olfactometric assessment are listed in tab. 5 and tab. 6. The samples of foams were evaluated by four reviewers (2 males, 2 females) of age from 27 to 34 years old.

Table 1: TVOC emitted from visco-elastic foam V 5020.

TVOC	*After 24 hours**	*After 48 hours**	*After 72 hours**	*After 672 hours**
Unit	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$
$TVOC_{MS}$	(303 ± 91)	(326 ± 98)	(323 ± 97)	(138 ± 41)

* Average of result ± expanded measurement uncertainty

Measured values of the emission of VOCs terpenes, aldehydes, aromatic hydrocarbons and benzene derivatives are negligible. The value TVOC in connection with the time characterizes a growing trend after 48 hours. After 72 hours, the TVOC value slightly decreased, but still significantly higher than the measured value TVOC after 24 hours. Even after 672 hours (28 days) TVOC value is relatively high in relation to the optimal value of around 100 $\mu g \cdot m^{-3}$.

Table 2: TVOC emitted from latex foam.

TVOC	*After 24 hours**	*After 48 hours**	*After 72 hours**	*After 672 hours**
Unit	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$
$TVOC_{MS}$	(379 ± 114)	(238 ± 71)	(211 ± 63)	(197 ± 57)

* Average of result ± expanded measurement uncertainty

Measured values of the emission of VOCs terpenes, aldehydes, aromatic hydrocarbons and benzene derivatives have negligible trend. The TVOC value in connection with the time characterizes a downward trend. Even after 672 hours (28 days) TVOC value is relatively high in relation to the optimal value of around 100 $\mu g \cdot m^{-3}$.

Table 3: TVOC emitted from polyurethane foam N5063.

TVOC	*After 24 hours**	*After 48 hours**	*After 72 hours**	*After 672 hours**
Unit	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\mu g \cdot m^{-3}$
$TVOC_{MS}$	(311 ± 93)	(192 ± 58]	(123 ± 37)	(97 ± 41)

* Average of result ± expanded measurement uncertainty

Measured values of the emission of VOCs terpenes, aldehydes, aromatic hydrocarbons and benzene derivatives are negligible. The TVOC value in connection with the time characterizes a downward trend.

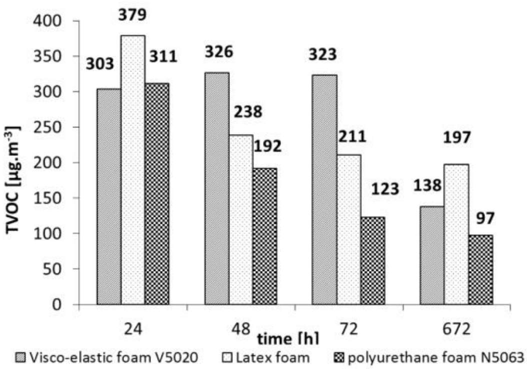

Figure 2: TVOC emitted by various kinds of foams in time.

Table 4: The characteristic of the substance VOC emissions with the significantly effect of TVOC concentration.

Identified substance	The range of percentages of the total value of TVOC from 24 hours to 672 hours [%]			
	Visco-elastic foam V5020	Latex foam	Polyurethane foam N5063	**R. T.***
Toluen	-	Insignificant – 4.635	Insignificant – 3.397	6.81
Piperazine, 1,4-dimethyl-	-	2.613 – 3.357	-	9.11
P-xylene	-	2.49 – 5.29	1.995 - 4.395	9.59
Morpholine, 4-ethyl	3.327 – 13.366	9.47 – 20.75	3.558 – 11.155	9.75
Triethylen diamine	9.710 – 20.189	-	-	13.15
Benzene-methanamine, N,N-dimethyl-	7.060 – 12.530	13.480 – 21.245	10.710 – 15.897	13.74
Undecane	10.41 – 26.676	3.56 – 4.11	1.443 – 4.842	14.84
Dodecane	2.003 – 7.157	3.50 – 6.33	7.612 – 10.110	16.86
Tridecane	2.003 – 7.157	3.16 – 4.95	6.710 – 12.148	18.71

* Retention time

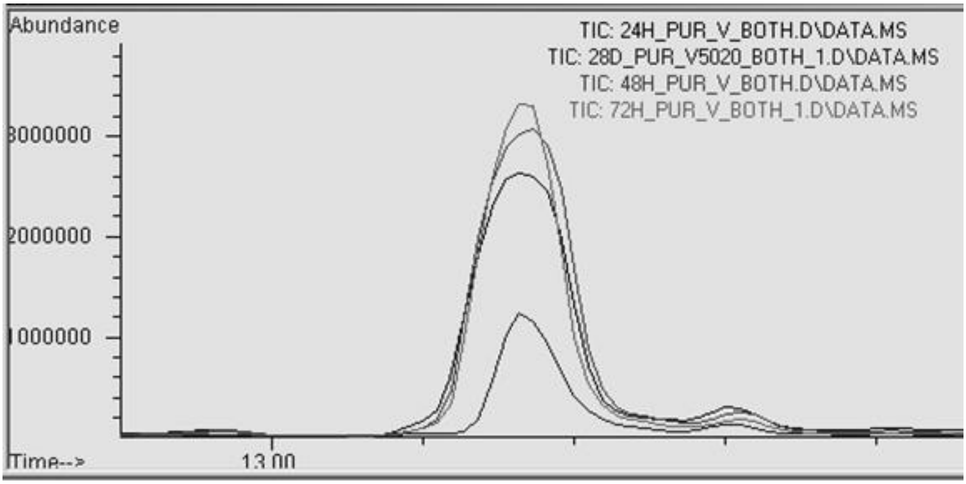

Figure 3: The dependence of the Triethylendiamine peak size on the time of its measurement.

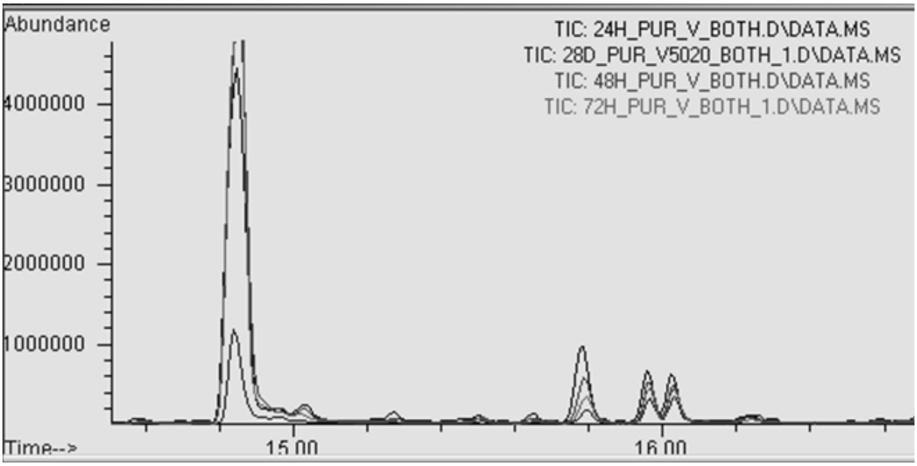

Figure 4: The dependence of the Undecane peak size on the time of its measurement.

For these published measured results, we can conclude the TVOC concentrations of latex foam and polyurethane foam N5063 gradually decreases over time. In contrast, the visco-elastic foam V5020 shows an increase of TVOC an increase after 48 hours. After 72 hours, the measured value is higher than the TVC was after 24 hours but less than 48 hours.

Increasing concentrations of VOCs is caused by the emissions of Triethylenediamine and Undecane and the decreasing concentration in time are listed in fig. 2 and 3. On the contrary, the concentration increases after 48 and 72 hours. Some of the VOCs concentrations that have an effect on TVOC were found in our selected materials in big amount. It can be said these substances are characteristic for the foam materials. The individual VOCs are listed in tab. 4.

By comparing individual foams, we found that the material composition affects the hedonic tone and intensity of an odor. For the same substance VOCs changes either the intensity of the odor but also changes the Hedonic tone. In essence, this means that evaluation e.g. hedonic effect of toluen by individual foams is different are listed in tab. 5 and 6. VOCs that have been evaluated by assessors over time and may vary so that the foam material will not be recorded after 72 hours, but will be examined after 672 hours. For example such a substance is Nonan in visco-elastic foam V5020. These VOCs were possible to identify. Further measurement will complement other VOCs regarding to hedonic tone and intensity of the odor, which could not be identified.

Table 5: Identified values of Hedonic tone and intensity of odor emitted by the foams after 72 hours.

VOC	Retention time	*Hedonic tone and intensity of odor*		
	s	Visco-elastic foam V 5020	Latex foam	Polyurethane foam N5063
Toluene	5.7	-2	-2	-
Styrene	9.5	-3	-2	-3
Nonan	10.3	-	-4	-2
Benzaldehyd	11.7	-3	-3	-3
Limonene	13.5	-3	-3	-3
Nonanal	15.0	-4	-3	-4
Dekanal	17.2	-	-2	-

Table 6: Identified values of Hedonic tone and intensity of odor emitted by the foams after 672 hours.

VOC	Retention time	Hedonic tone and intensity of odor		
		Visco-elastic foam V 5020	Latex foam	Polyurethane foam N5063
Toluene	5.7	-3	-1	-2
Styrene	9.5	-	-3	-3
Nonan	10.3	-4	-4	-
Benzaldehyd	11.7	-3	-4	-4
Limonene	13.5	-	-5	-
Nonanal	15.0	-5	-4	-4
Dekanal	17.2	-2	-4	-3

6 CONCLUSION

The aim was to assess the initial measurement of materials used in the manufacturing of upholstered furniture, especially mattresses, by the method called olfactometry indirect. At the same time, the determination of the effect of the emission load of volatile organic compounds (VOCs) including parameter TVOC took place.
From point of the measured values of the VOCs emissions that were emitted from individual test foams, it can be concluded that the influence of time on the amount of volatile organic substances has been shown. This phenomenon is not visible by the amount of the individual concentrations of VOCs, as the concentration itself was too low, but the effect on the TVOC value it is much more significant. TVOC evaporated by latex foam and polyurethane foam decreased with time. TVOC emitted by visco-elastic foam on the contrary, increased with time. Increased level of TVOC was caused by VOC Triethylenediamine and Undecane which are contained in the largest percentage of the TVOC value.
The method of olfactometric assessment revealed that the foams exhibit negative hedonic tone (odor) and their intensity reaches in some cases grades - 5 (extremely unpleasant). By the performed measurements of Olfactometric assessment, it was found that the foams exhibit significantly in connection with odors.

7 RECOMMENDATION

- To deepen the problematic of emission of VOC and odors in foam materials
- To determine the increasing climatic conditions of VOC emissions and odors effect
- To determine the effect of foam mechanical load on VOC emissions and odors
- To extend the portfolio of measured foam materials

ACKNOWLEDGMENTS

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VOC EMISSIONS FROM HEAT TREATED WOOD

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Abstract
This paper describes the VOC emissions emitted by massive spruce wood treated at 180°C and 200°C. The heat-treated wood has been considered as an ecological alternative to impregnated wood material and it can also be used for several purposes, e.g. for garden, kitchen and sauna furniture, floors, ceilings, inner and outer bricks, doors and windows and for musical instruments. The focus was on the influence of heat treated process, on the quality and quantity of volatile organic compounds, especially on the amount of emitted phenol and furfural. The emission was analyzed as function of time after heat-treatment. The influence of the finishing with UV curing lacquer on VOC emissions was also investigated. The VOC emissions were collected in columns with absorbent Tenax Ta. We analyzed the columns with the VOC emissions by analytical method, used as follows: the gas chromatography in conjunction with mass spectrometer and direct thermal desorption. The methodology of sampling samples of VOC emissions from heat treated wood was done according to standard ČSN EN ISO 16000 part 1, 5, 9.

Keywords:
VOC emissions, heat treated wood, spruce, gas chromatography, water borne lacquer

1 INTRODUCTION

Heat-treatment of timber is used to modify the properties of wood to resist dimensional changes in different humidity [1, 2], to achieve better heat insulation, improved decay and weather resistance, reduced moisture deformation and new shades of color as an alternative to tropical hardwood. All these changes are achieved with heat treatment process without any added chemicals.

Wood darkens during thermal modification, and similar color formation of wood from Scots pine and Norway spruce was found for the two types of processes, even though the treatment under saturated conditions was performed at a treatment temperature that was 40°C lower than used in superheated conditions [3]. Moreover, birch gave a darker material than pine and spruce in both treatment processes [4]. We have reported that higher

acid content could be found in wood thermally modified under saturated steam conditions than under superheated steam conditions, and birch was found to give more acid than pine and spruce [4]. It is also striking that the strongest smell was obtained for birch treated under saturated steam conditions. This indicates that degradation reactions of wood components are more prominent under saturated conditions than under superheated conditions and that the extent of degradation is also related to wood species.
Thermal modification of wood leads to a material that is less hygroscopic and more dimensionally stable. This has been attributed to degradation of hemicellulose and to condensation reactions that hinder uptake of moisture by forming new bonds between wood polymers such as lignin [5, 6, 7, 8]. Degradation of hemicellulose may take place via formation of soluble carbohydrates, and formation of such products during thermal modification conditions has been presented [5, 9]. Further degradation of polyoses without formation of monosaccharides during heat treatment of wood has been proposed [10]. Furans can be degradation products from carbohydrates and furfural and 5-(hydroxymethyl) furfural (HMF) have been found during thermal treatments of wood [5, 11, 12].

2 GOAL OF RESEARCH

This research describes the VOC emissions emitted by solid spruce wood treated at 180°C and 200°C. The focus was on the influence of temperature, on the quality and quantity of volatile organic compounds, especially on the amount of emitted phenol and furfural. The emissions were analyzed as function of time after heat-treatment. Also the influence of the finishing with water borne lacquer on VOC emissions was investigated.

3 MATERIALS, EQUIPMENT AND METHODS

The tested wood (spruce [*Picea abies*]) obtained from KATRES company Ltd., Czech producer of heat-treatment chambers, was investigated. The pre-dried wood samples were modified at 180°C and 200°C in a heat treatment process.
Samples were taken from the normal manufacturing process, wrapped in aluminum foil and delivered to the test laboratory. The wood was cut into pieces (sizes: 740 mm x 40 mm x 1 mm) and put into the test chamber. As emission rate of VOCs also depends on age, the samples were put into the chamber as soon as possible after the delivery from the plant. The chosen heat treated wood in 180°C and 200°C was finished by water borne lacquers. In the present study, air samples were collected continuously onto the Tenax TA.

3.1 Tested materials

1. 10 pieces of lamellas made from native spruce wood, each of tested lamellas has these dimensions:
   0.74 m x 0.04 m x 0.001 m, size tested sample: S=0.6 m^2.
2. 10 pieces of lamellas made from heat-treated spruce wood at the temperature of 200°C, dimensions of one lamella:
   0.74 m x 0.04 m x 0.001 m, size tested sample: S=0.6 m^2.
3. 10 pieces of lamellas made from heat-treated spruce wood at the temperature of 180°C, dimensions of one lamella:
   0.74 m x 0.04 m x 0.001 m, size tested sample: S=0.6 m^2.
4. 10 pieces of lamellas made from heat-treated spruce wood at the temperature of 200°C, finished surfaces by waterborne lacquers, dimensions of one lamella:
   0.74 m x 0.04 m x 0.001 m, size tested sample: S=0.6 m^2.

Figure 5: Small space chamber (VOC TEST 1000) with tested sample.

3.2 Equipment for determination VOC emissions

- Short path thermal desorption tube, Silco trated Thermal Desorption Tube 786090-100, inner diameter 4 mm, fill in with 100 mg of Tenax TA (Scientific Instrument Services company) for collection of VOCs emissions emitted from tested samples in to the air in chamber
- Air sampler Gilian–LFS 113 SENSIDINE with air flow 6 l h^{-1} and 12 l h^{-1}
- Gas chromatograph Agilent GC 6890 with MS (mass spectrometer) detector 5973 with cryofocusation, thermal desorption and library of spectra NIS 05, column type HP – 5 (AGILENT USA)

- VOC was tested in a small-space chamber with a volume of 1 m^3. Air temperature: 23°C; relative humidity in the chamber: 50%; air changing rate: 1 m^3 per 1 h; air speed over the tested samples: 0.1 to 0.3 $m.s^{-1}$

3.3 Methods

Methods of VOC testing were set via standards:

ISO 16000: 2004	Indoor air
ISO 16000-1: 2004	General aspects of sampling strategy
ISO 16000-5: 2005	Measurement strategy for (VOCs) volatile organic compounds
ISO 16000-11: 2004	Determination of the emission of volatile organic compounds - sampling, storage of samples and preparation of test specimens
ISO 16000-6: 2005	Determination of volatile organic compounds indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and chromatography using MS/FID
ISO 16000-9: 2004	Determination of the emission of volatile organic compounds - Emission test chamber method

4 RESULTS

Based on the obtained results (fig. 2, 3, 4) it is concluded that the heat-treatment of wood increases the quantity of VOC emissions emitted by tested samples. The main difference was found in the amount of emitted furfural and phenol in the blend of gaseous evaporated by heat-treated spruce in normal conditions. The temperature of heat-treatment has a great influence on the amount of emitted furfural by tested heat-treated wood. That means the higher the temperature during the spruce heat-treatment the higher the furfural emissions. Furfural and phenol are typical chemicals, which are resulting in thermal degradation of wood components.
The finished surface by the water borne lacquer does not decrease the amount of emissions escaping from heat-treated spruce wood. Surprisingly, water borne lacquers even elevated the amount of VOCs.
Fig. 2 shows the influence of the temperature of the wood modification and of the time between the VOC measurement and wood modification on the amount of VOC emissions. The amount of VOC emissions decreases with the decreasing temperature of wood modification. The amount of emitted VOC declines with the increasing time between the modification of wood and the measurement of VOC emissions emitted by tested samples.
Fig. 3 shows the comparison of TVOC from heat-treatment (Picea abies) in

the temperature 200°C and 180°C and untreated wood in dependence on time. The highest concentration of TVOC was emitted by heat-treatment wood in temperature 200°C.

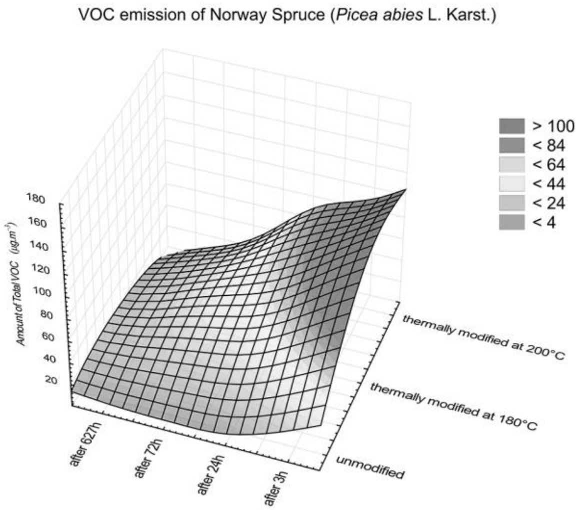

Figure 2: Amount of VOC emitted by heat-treated spruce wood after 3, 24, 72 and 672 h.

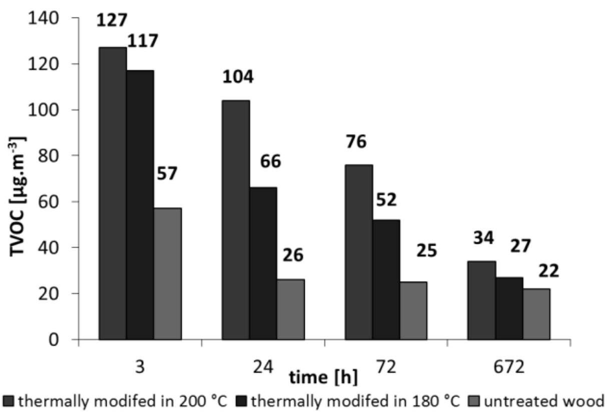

Figure 3: Comparison of TVOC emitted from thermally treated of Norway spruce, the temperature of thermally treated wood in the temperature 200°C and 180°C and untreated wood.

Fig. 4 shows a comparison of VOC emissions from Norway spruce heat-treatment in 180°C and 200°C after finishing by water borne lacquer. We can see very high concentration of buthoxy ethanol, while this compound is obtained in water borne lacquer. Furfural and phenol are substances resulting from thermal decomposition of lignin. Concentration of furfural is moved in the hundreds of $\mu g \cdot m^{-3}$, while concentration of phenol is moved only to units of $\mu g \cdot m^{-3}$.

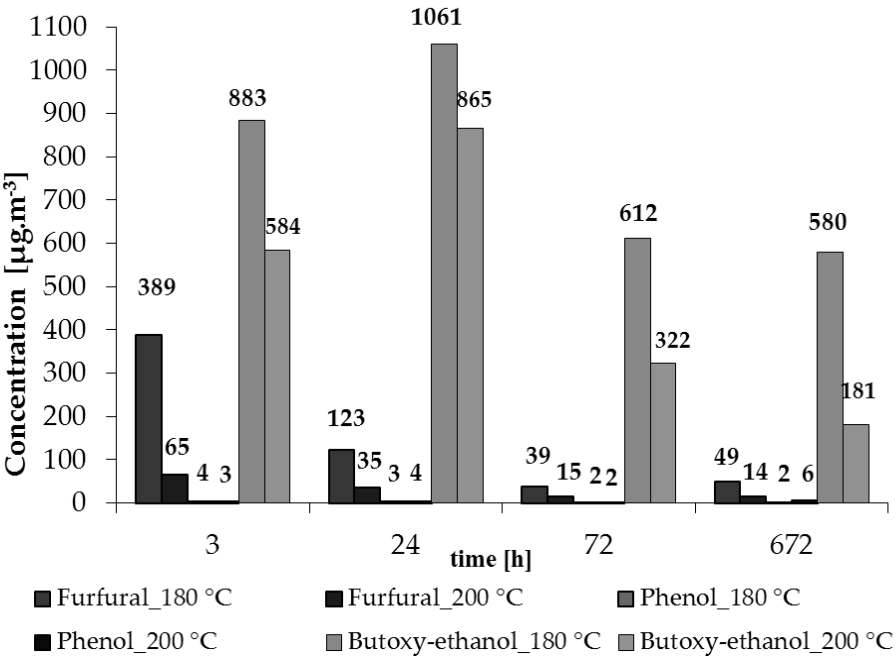

Figure 6: Comparison of VOC emissions from Norway spruce heat-treatment wood in 180°C and 200°C after finishing by water borne lacquer.

5 DISCUSSION

Main difference consists in the amount of emitted furfural and phenol in the blend of gaseous evaporated by heat-treatment Spruce in normal conditions. The great influence of emitted furfural amount has the temperature of heat-treatment. The higher temperature during the spruce treatment means the higher amount of furfural emissions. TVOC, the indicator of indoor air quality depends on the temperature of the modification, it is possible to state.

Furfural and phenol are typical chemicals, which are resulting in degradation of wood components. The finished surface by the water borne lacquer not only decreases the emissions escaping from heat-treatment Beech wood but even doesn't increase the quantity of evaporated VOC emissions from these samples.
The next step of this research will investigate the influence of heat-treatment on the amount of VOC emissions emitted by different kinds of wood, and it will study the influence of heat-treatment on wood finished surfaces, especially to find the correlation between the kind of the surface finishing and VOC emissions. Eventually, the relation of the quality and quantity of VOC emitted by the heat-treated wood on the way of finishing of the heat-treated wood surfaces will be investigated.

6 CONCLUSION

- Heat-treated wood from Norway spruce emitted more VOC components of furfural and phenol than untreated wood (natural wood).
- Heat-treated wood form Norway spruce emitted more concentrations of furfural and phenol before finishing than after finishing.
- Heat-treatment wood after the finishing (water born lacquer) emitted very high concentration of buthoxy-ethanol.
- After finishing wood modified by heat treated process in 180°C emitted more concentration of VOC emissions than that processed in 200°C.

7 RECOMMENDATION

The modified - heat treated wood (spruce) is suitable for use in external environment (doors, floors, terraces). Heat-treated wood is not suitable for interior, especially from the perspective of the negative effect of chemicals on human health. This research has demonstrated the long-term effects of VOC emissions in the interior, so it is recommended that the heat-treated wood (furniture, floors, doors etc.) be exposed at least for six months after production and before its use in the interior.

ACKNOWLEDGMENTS

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SESSION C

Product Life-Cycle – from Concept to Market and Use

THE APPLICATION OF THE QFD METHOD TO DESIGN A NEW TYPE OF EVAPORATOR

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Abstract
Veolia Water Technologies Italia S.p.A. is the Italian branch of Veolia Environment, a multinational group active in the energy, water and waste management sectors.
The Italian branch is mainly focused on water management and reuse, and within the company the operative headquarter of Zoppola (PN), that is the 'Solutions Division', is specialized in design and production of plug and play plants and machines for treating wastewater.
The idea to design the new units using the Quality Function Deployment techniques came from a top management commitment in order to innovate the way to think, design and realize the new products.
With the same aim, a new organization has been created consequently to support this new process: a bottom-up driven structure that works in team and in a multidisciplinary way.
The application of the Quality Function Deployment has enabled to introduce, even in a small-medium size company, the different ideas and points of view coming from the customer's needs already in the first phases of the definition of the concept idea.
Then the management of these evidences in a scientific and proven way, and through a lean and multidisciplinary organization, has helped to realize an innovative and high competitive product design already from the very first phases of its market launch.
A type of product that can meet the customer's expectations, even the ones that are not yet recognized by themselves.
To concentrate the efforts and the resources on a real case, the company has identified in the new RVN 3 evaporator the trailblazer of this new way to design.

Keywords:
Evaporation, product innovation, organization, multidisciplinarity, customer centered design, product-system design

1 VEOLIA WATER TECHNOLOGIES ITALIA S.P.A.

Veolia Water Technologies Italia S.p.A. is the Italian subsidiary of Veolia Water Technologies, that is the branch of Veolia Group specialized in technological solutions to provide a complete range of services required to design, build, maintain and upgrade water and wastewater treatment facilities for industrial clients and public authorities.
The company uses the most advanced technologies to design and realize standardized machines to treat liquids. Within this context, the Italian subsidiary is the one defined as competency center for the evaporation technology.
Veolia Water Technologies S.p.A. is organized in three divisions, each focused on a specific business:

- The design & build division, for the realization of water treatment plans for the municipal as well as industrial market, both in Italy and abroad
- The services division, for the management and the maintenance of the water treatment plants in Italy
- The solutions division that is specialized in the design, production and installation of standard machines for water treatment. The main products of this division are the evaporators, whose commercial brand is EVALED™

2 THE EVALED™ EVAPORATORS

2.1 General description

EVALED™ are industrial systems accelerating the natural evaporation process with low energy consumption and low CO2 footprint. They were first manufactured thirty-five years ago and were designed with a far-sighted intuition, which proved that the acceleration of this phenomenon, through the use of package-modular standard units, would have represented a ‘clean system’ to separate water from any pollutant component with a higher boiling temperature than water’s.
EVALED™ treat industrial wastewater with capacity from 1 to 200 tons/day, and to fit at best clients’ water treatment needs, the range of the products is made up by three different evaporation technologies:

- Heat pump (fig. 1): which benefits are flexibility, low energy consumption and reliability
- Hot/cold water: in the cases in which heat surplus is available (cogeneration)
- Mechanical vapor recompression (MVR): for large flow rates and operational costs minimization

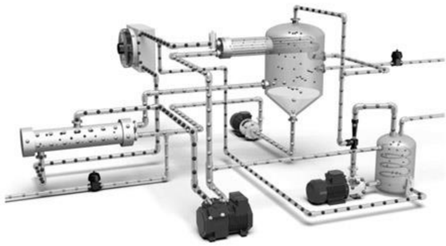

Figure 1: The functioning of the EVALED™ heat pump evaporator.

How a mechanical vapor recompression evaporator works
The vapor generated within the boiling chamber is adiabatically compressed (energy consumption depends on the compressor operation), temperature level increases and condensation takes place into the main heat exchanger that transfers latent heat to the fluid to be evaporated (fig. 2). An auxiliary heat recovery system offers the opportunity for a significant low energy consumption (about 30 W/liter water, 25 times lower than atmospheric evaporation).

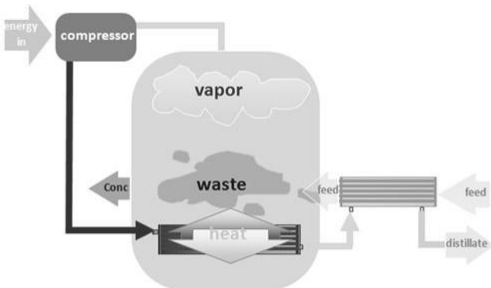

Figure 2: The functioning of a vapor recompression evaporator.

2.2 The EVALED™ RV
The RV (‘Ricompressione Vapore’, means vapor recompression) is the EVALED™ higher capacity range of evaporators that can treat up to 200 ton of wastewater per day and are ideal when large quantity of waste which can cause fouling, precipitation and crystal formation has to be treated.
The low running costs due to minimal electrical energy consumption enable installation in a plant with a return on investment that can often be measured in months.

This type of evaporators can use different heat transfer technologies, and are consequently available in three different series:

- **F series**: a new generation of forced circulation MVR evaporators, with innovative technical choices to improve performances
- **N series**: the natural circulation evaporators, focus on the specific treatment needs of oily wastewater
- **C series**: the falling film evaporators, with a very low specific energy consumption of only 30 kWh/ton

EVALED™ RV N series
EVALED™ RV N is the most energy efficient new line of MVR natural circulation evaporators dedicated to oily wastewater minimization and water recycling.
The benefits of the technologies exploited in this product are:

- High quality of recovered water suitable for reuse
- Very low energy consumption
- Modular and flexible
- Short delivery time
- Skid mounted (small footprint) and ready to use (plug & play unit)
- Fully automatic, minimal manpower
- Complete control panel and necessary instrumentation
- User-friendly (intuitive HMI)
- Reduced maintenance
- Low running costs enable installation of plants whose return on investment can often be measured in months
- Environmental impact reduction: CO2 emissions = 15 $kgCO_2eq/m^3$ liquid waste treated, means -97.6% the percentage of emissions avoided with respect to incineration of the liquid waste

The EVALED™ RV N has a high efficiency heat transfer thanks to the use of vertical tubes and natural circulation (fig. 3). Low energy consumption is guaranteed by the operating in batch mode: wastewater is constantly treated with water being continually separated, as soon as the final concentration is reached, the residue is completely discharged, wastewater is refilled and a new cycle starts.

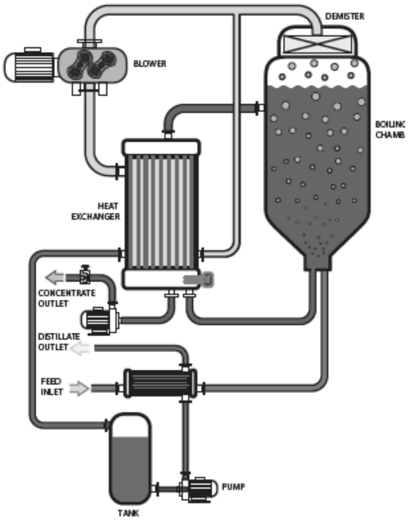

Figure 3: The functioning of an EVALED™ RV N.

As the EVALED™ RV N series is the most innovative and the most promising one within the Veolia Water Technologies Italia's products range, the general management has decided that the project of application of the Quality Function Deployment (QFD) method be focused on this type of machine. Then the unit RV N 3 has been chosen because a prototype of this machine was already been realized, so it would also have been possible to compare the different results of the design with and without the application of this method.

3 DESIGN THE NEW EVALED™ RV N 3 THROUGH THE QFD METHOD

3.1 Why the QFD

The evaporators for the water treatment are highly technological products with a niche market. In fact the overall number of evaporators that the world market can require per year is no more than few thousands, and the context is the one in which emotionally or self fulfilling purchases are missing or reduced to the minimum.

Consequently, the challenge of Veolia Water Technologies Italia was to develop a new type of evaporator that can maintain its technological leadership on the market, and at the same time offer to the clients something new that can greatly change their approach to how an evaporator can facilitate and improve their activities.

Therefore, the new project must have the chance to embody, from the very first steps, the requests of the market and the actual needs of the clients (even the needs that they have not recognized by themselves yet): its aim has to be the realization of an innovative product that satisfies the expectations of the market even in an unexpected way.
The management of the company wants to seize the opportunity to change dramatically the process to conceive and design a new product, with the purpose of innovate it and trace new rules on the market of the evaporators, in a way that can greatly improve the expectations of the clients to what an evaporator has to be.
A great part of the quality expressed by a product or service is due to the product's definition and the design process. Every product or service can be considered like a complex system of entities, such as clients, users and stakeholders, and their mutual relations, each one potentially very important in terms of contribution to the overall quality of the product.
At the first place, in terms of importance, can be placed the customer, but every human involved in the product life is a potential driver for product quality and innovation.
That is the reason why it is so important to apply a methodology able to take into account all the needs and variables belonging to the many stakeholders involved in the product definition, starting from the internal team, and including the organization, the society, and obviously, the customers.
One of the most appropriate methods to reach this goal is the Quality Function Deployment method, which can lead the understanding of the customer's need to a new product that can set a new standard on the market.
Carrying out a comprehensive version of the QFD requires an important effort that in a small-medium company, as the solution division of Veolia Water Technologies Italia is, can divert many resources from the ordinary activities in a way that could damage the business. Therefore, the choice of the top management was to ask for support to a senior consultant already expert in the sector and in industrial design. Such support was given by professor Giuseppe Mincolelli and the design consultancy company Lineaguida S.r.l.

3.2 A new way of designing

The first step of the introduction of this new process was to create a multidisciplinary team of nine experts, representing all the competencies and the skills involved in the project. Thus, the team covers nearly all the departments into the company, and in particular:

- Engineering
- Purchasing
- Chemical process evaluation
- Marketing

- Sales
- Production
- Service and after-sales
- Quality and safety

Nonetheless, working in team with people with different languages, skills and points of view is not an automatic mechanism and it takes time to create a good and positive ‘climate’ in order to see some results. Prof. Giuseppe Mincolelli and Lineaguida team operated as mentors and ‘boosters’ to facilitate this process and keep each department aware about the direction and progresses of the project.
The first innovation introduced to the design process has been not to follow the traditional function-based approach (from the marketing idea to the production), but keep all the participants continuously involved in the evolution of the project, even if with different engagement along the different phases.
As fig. 4 shows, every functional department is in fact seamlessly involved in every phase of the design process, with different intensity according to the opportunity.

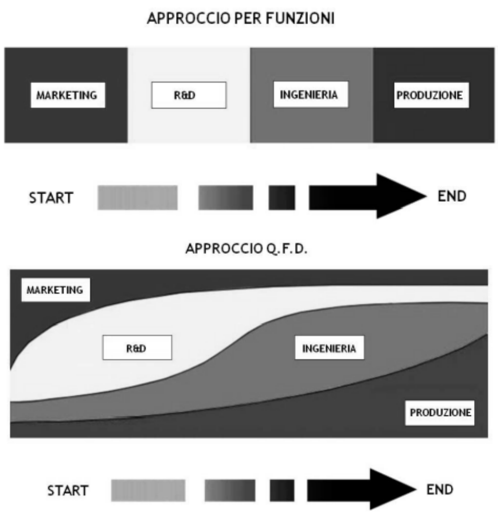

Figure 4: The new approach.

3.3 System layout and project analysis

As remarked in section 2.2, the EVALED™ RV N has been chosen as the series to which apply the QFD method because of its importance within the

product range, and also because the prototype already built up of a N 3 version was designed with a traditional approach and it did not match all the performances expected. Thus, the challenge has become to redesign this product with the aim to strongly improve its quality in terms of what make the difference in the client’s choice.
To obtain this result, the team started to draw a simple system layout to visualize a first picture of the complex environment, in terms of stakeholders and their relations (fluxes, hierarchies, etc.) within which the product has intended to ‘live’ (fig. 5).

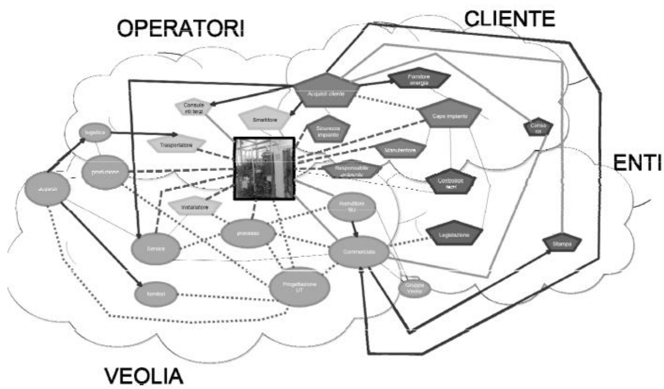

Figure 5: The external system layout.

The next step was to draw the unit system lay out, which means to ideally divide the product into sections in order to better clarify its functions and features. Afterwards, all the defined functions and characteristics have been classified either as a project invariant (something that is out of the perimeter of action of the project, such as the available technologies, the general context of the company, the social environment, etc.) or as a project variable (something that can be changed or questioned to find alternatives or different solutions). An example of the unit system lay out of the RV N 3 unit is shown in fig. 6.

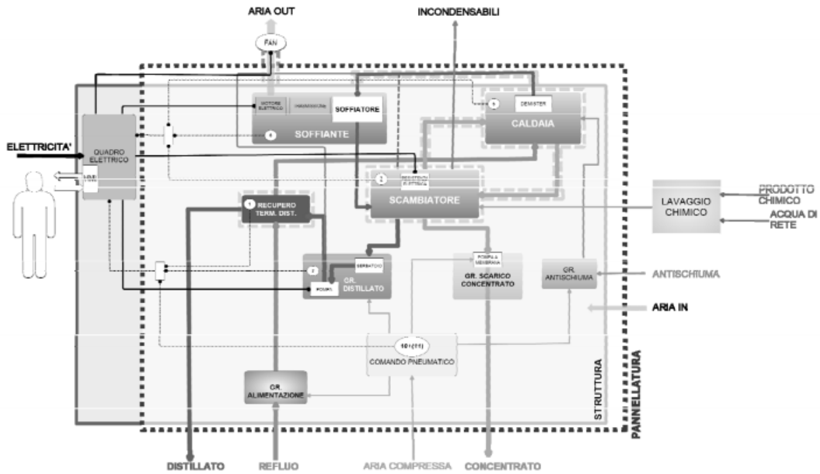

Figure 6: The unit system layout.

3.4 Clients and needs

The core of the QFD activity, from which all the other actions will start, is to identify every stakeholder involved in the overall project, even the ones not usually considered as interested in conceiving the product (e.g. the workers of the assembly department).
After the identification of all stakeholders, they have been classified as internal clients (for example, in the RV N 3 case, the internal operators that have to deal with this product such as blue collars, service technicians, sales managers, etc.) or external clients (buyers, people in charge of transportation, functioning, maintenance, the waste water treatment plant chief, and so on).
The result of this step was a list of sentences expressed with the same words that could be used by the considered people in order to be as much as possible close to the clients' goals and to avoid their frustrations. Here below there are some examples of this list of sentences:

- Client's goals:
    - 'I want to control the unit from a remote site.'
    - 'I don't want to become dirty when I clean the unit.'
    - 'I don't want to pay too much the electricity for the running of the unit.'
    - 'I need that the unit has to be reliable.'
    - 'I want to reach a clean water for discharging it.'
    - 'I need a good pay-back of the investment.'

- Client’s possible frustrations:
    - ‘I have not enough instructions for the maintenance.’
    - ‘I’m having unexpected costs and expenses.’
    - ‘I can’t easily move and transport the unit.’
    - ‘The spare parts are always available too late.’
    - ‘The requested maintenance tools aren’t easy to find.’

To have a scientific and objective result of this activity, each identified requirement has been ranked in relation to the following indicators:

- Relative weight of the need
- Absolute weight of the need
- Strengths of the new model
- Way to satisfied the need in the current model (RV N 3 prototype)
- Way to satisfied the need in the new model (RV N 3 new version)
- Degree of improvement of the new model with respect to current model

Furthermore, the same list of needs was used to compare how the competitors already in the market satisfy these needs, in order to have a clear picture of the benchmarking context. The result was a complex matrix which however helped to prioritize the final list (fig. 7).

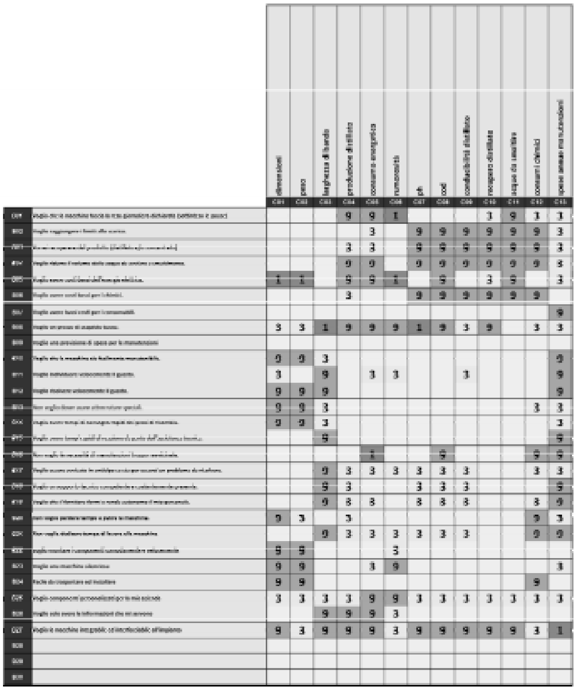

Figure 7: The final matrix.

3.5 Technical requirements and features specifications

The last step of the work was to interrelate the characteristics defined for the new model with the needs highlighted in the previous part of the QFD method application.
Therefore, every characteristic has been associated to a quantitative size (expressed by a number) to assign a precise value to the expected performances, as for instance:

- Dimensions
- Weight
- Yield of evaporation;
- Distillate production
- Corrosion resistance
- Noise level
- Quantity of chemical products needed for the running
- Number of hours requested for the assembly

The team determined the quantitative value for each analyzed characteristics by taking into account the results of the applications of a QFD algorithm.
This algorithm creates a hierarchy of the characteristics, through computing its level of correlation with needs, the importance of needs, the performance benchmarking and other parameters related to marketing and brand values.
The final stage of the activity was the creation of a document containing detailed specifications about all the design aspects related to the unit (mechanical, thermo-hydraulic, chemical process, electrical, electronic, logistic, purchasing, components customization, treatment customization, assembling, interface, remote control, selling method, maintenance and after sales). These specifications are conceived to be usable by all the different developers and designers that will participate in the design process. The document so defined follows the same criteria of the methodology that has been applied for its creation, so it is organized in chapters, ordered according to the importance of needs: high, medium or low priority and, for each of them, submits a list of technical proposals and some considerations about the characteristics related to its satisfaction.

4 FINAL CONSIDERATIONS

Above all the considerations about the quality and usability of the final specification document, that will be eventually proven at the end of the design process, we can observe some effective results that the application of QFD methodology has already allowed to achieve.

- **Team building and awareness**: For the first time, an interdisciplinary group of people coming from different working areas has been obliged to cooperate since from the very first step of the design process. They had to discuss and evaluate various points of views to get to a shared unanimous result. Beyond the current work, this allowed to create awareness about the different methods, competences, skills, difficulties, resources that are present inside the organization.
- **Shared objectives and aims**: The QFD method leads to a common list of aims, defined through the contribution of every member of the team, belonging to all business functions. It aims to ensure consistency in the various stages of development, avoiding possible lack of communication between different competences.
- **Customer oriented project objectives**: It allows to focus all the design resources to produce useful innovation, clarifying the reason of design choices, reducing the risk of virtuosities or technology-centered solutions, making it possible to enhance the level of perceived quality of the product.

DATA MINING: A POTENTIAL DETECTOR TO FIND FAILURE IN COMPLEX COMPONENTS

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Abstract
This paper is aimed to discuss current research using data mining techniques and industry statistics in production environments. The general research approach is based on the idea of using data mining processes and techniques of industry statistics to find rare and hidden patterns behind failures of complex components. A case study will be applied to illustrate how the technique is carried out and where the limits of this approach occur. The case study deals with a component supplier of printing machines, which received an increasing number of client complaints, all related to one distinct problem. The observed failures seem to occur only among clients with very high quality standards. The affected component undergoes a very complex production process with several steps in different departments. Every single production unit records data information from multiple process variables and at different points in time. In the beginning there was no understanding of the failure causes in production at all. Therefore a huge amount of production data had to be analyzed to find the pattern that discloses the failure.
The data mining process starts with a first step in which the given data sets are prepared and then cleaned. Followed up by building a prediction model. The aim is to detect the root causes for failures and to predict potential failures in affected components. This paper shows how to use data mining to get the answer on pressing production failures.

Keywords:
Data mining, production failure, multi-variant analysis, multivariate process control, predictive modelling, case study

1 PROBLEM BACKGROUND

A product of a printing components manufacturer shows an increasing number of client complaints in recent years, all related to one distinct problem. The nonconforming component leads to more insufficient print quality. Depending on the client´s individual quality standard the failure causes complaints. The different quality standards result in the fact that the

peculiar problem occurs among clients who need a very high print quality for their products or respectively these clients notice the reduced output due to their sensitive products much earlier.
The occurring reduced output causes subsequently extreme abbreviated service time of the component in the machine and consequently induces down time for the clients.
At the moment the insufficient components are sent to the manufacturer for amendment. Up to the present claimed parts were completely revised and sent back to the client. This shows that some components are fully operational and some again hold the reduced output, which leads to another client’s complaints.
On the part of the manufacturer it is not clear yet which work steps and production parameters in his fabrication release the reduced output and thus the client complaints. During manufacturing, the affected component undergoes a very complex production process with several steps and several production parameters. Another aggravating factor is that the products are manufactured in different departments in shift operation.
So far, the manufacturer has not detected any assessment criteria for avoiding the failure and recognizing the reduced output before delivery in time.
The aim of this study is to detect hints regarding these criteria with the help of statistical analysis, especially data mining methods.
Data mining methods have a long success story in areas of marketing, financial service, fraud detection and health. Health monitoring during operation, anomaly detection on running machines (for example aircrafts) are often done with the machine learning method [1].
In production environments data mining is still not a common tool to detect production failure. Using prediction methods of data mining to find assessment criteria for avoiding the failure is also not widely distributed. But the needed theories and methods are well known and solutions can be adapted from the named areas above [2] [3] [4].
This work deals with an existing production problem, how data mining can help to solve it.
The overall project is divided into two phases:

1. Phase: analysis of the components geometry
2. Phase: analysis of the production unit records of the component and data collected during the application of the component in the production environment until the failure occurs

From the manufacturer´s point of view it is important if there is a special significance to find out and to solve possible in-house reasons for the reduced output of the components.
The present paper is dealing solely with the first phase. It is structured by the following topics:

- Data
- Analysis
- Findings
- Future prospects

2 INPUT DATA

2.1 Required data

The company is recording a lot of data during the production process. These datasets deal with the geometry, material and information of used semi finished parts of the components. We have also access to some data out of the manufacturing process itself, like information on which production line the component is built, how long it takes, at which time in the year and which person has done special manufacturing processes. Actually there is no access to production process variables like grinding speed.

For this survey we got access to a dataset that covers two years of production and repair details. All build components of the concerned type are listed and the data contain the information, if the problem (failure) occurs or not. The file contains about 100521 datasets and 65 variables. It includes components with no failures and components with failures as well. The data were delivered in a format that needs some preparation to get ready for analytics.

2.2 Data preparation

Having obtained useful data, it now needs to be prepared for analysis. It is not useful to have the data stored at quite a detailed level in the data mart. But to get relevant results out of the analyses, transformation and aggregation of the data is necessary. It is unlikely that data mining algorithms will find hidden patterns without prior data preparation.

Preparation time is expected to be at least 70% of the total time required to do the data mining.

In every data preparation step the time constraints during the production have to be considered. This is essential in order to use the results to predict potential failure for the individual component before this is delivered to the client. Therefore, only data that are recorded before the component leaves the company can be used in any kind of prediction. This sounds obvious, but it is based on the fact that the file also contains repairing data: it is important to pay attention to this.

If we the study is not limited to descriptive analyze and it is planned to develop a prediction model, a target variable is needed. In our case the target variable will be created as a binary variable. If the failure comes up or not this has to be transformed in just two values such 0 / 1. ‘1’ indicates the component has a failure ‘0’ means everything is fine with the component.

In general: the data must be screened for empty areas and it must be decided how to handle them. Depending on the individual situation we use one out of three options:

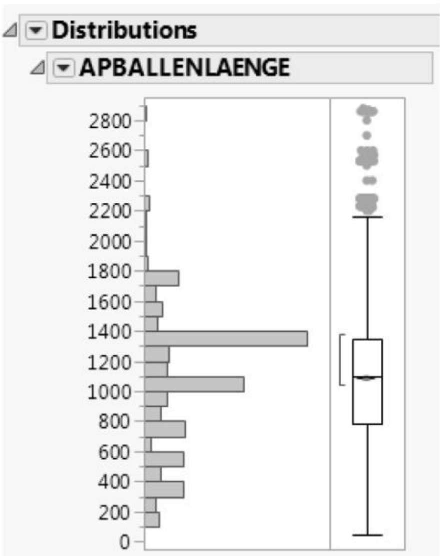
- To exclude that dataset
- Input a potential good estimator for the missing value
- Do nothing because empty means nothing happened

Several further data cleaning steps have to happen. Columns in which text is written have to be cleaned such that similar meaning is shown in one equal string. For example, an additional blank changes the string: for the analytical tool the strings then are different.
After all steps of transformation and aggregation, one row for every built component with all the variables inside is needed. Our data file includes now '7966' datasets and 13 variables.

3 ANALYTICS

3.1 Pre-analytics

As a first step, a descriptive analysis was done over all variables. Examining those results, first valuable hints on the data are collected. Fig. 1 gives a typical picture and it gives also good impression on the data we like to use for further analytical steps.



Quantiles

100.0 %	maximum	2880
99.5 %		2530
97.5 %		1880
90.0 %		1630
75.0 %	quartile	1346
50.0 %	median	1096
25.0 %	quartile	786
10.0 %		344
2.5 %		180
0.5 %		165,0835
0.0 %	minimum	48

Summary Statistics

Mean	1089,1211
Std Dev	462,20255
Std Err Mean	5,1785978
Upper 95% Mean	1099,2725
Lower 95% Mean	1078,9697
N	7966

Figure 1: Histogram of geometry parameter length.

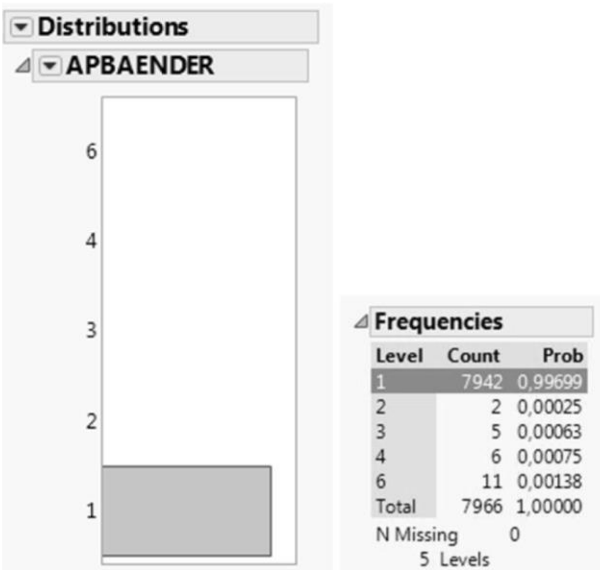


Figure 2: Histogram of geometry parameter ‘APBAENDER’.

Comparing the distribution given in fig. 1 and 2, it is obvious that it might be more likely that the plotted ‘ABBALLENLAENGE’ might have any impact compared with the ‘APBAENDER’ plotted in fig. 2 that shows no variance.

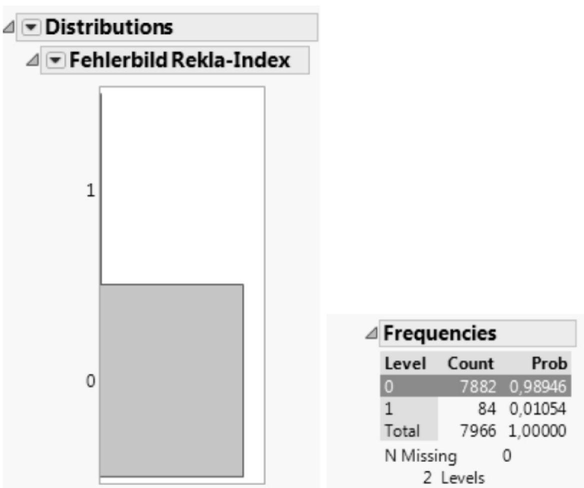


Figure 3: Histogram of target variable ‘REKLA-INDEX’.

One of the most important things is to find out how many failures occur in the data base. In this case 7966 data sets and 84 targets (FEHLERBILD REKLA-INDEX) with 1 mean that the failure is inside. Nearly one percent of the produced components are defective.

From a production point of view, 1% is much too high. But under analytical aspect it might be too low. How to handle this will be described in chapter 4.
The pre-analysis of the failure distribution to the clients, shows that only a small number of clients reclaims failure. Fig. 4 shows the distribution of FEHLERBILD REKLA-INDEX 1 over clients.
The client 11611.001 bought 15 components and made claims for all components (100% error rate). This overview indicates the risk that the target variable 'FEHLERBILD REKLA-INDEX' failure or no failure was not answered from all clients with the same quality standards. It seems that the claims are strongly depending on the individual quality standard to the client itself. That means that the estimated number of unreported cases of the failure is much higher.
An error rate of 100% leads to suspicion that the detailed terms of use at the clients affects the specific problem. These will be investigated in the second phase of the project.

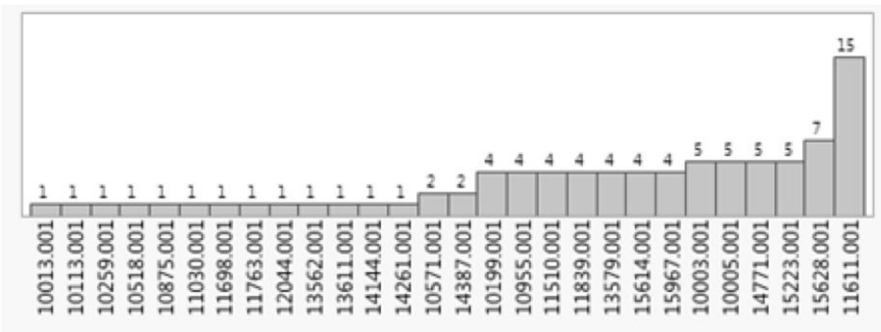


Figure 4: Histogram customer distribution to 'FEHLERBILD REKLA-INDEX' 1 (failure).

Beside the fact that there is one client with an error rate of 100%, there are several customers (with several components bought) who have not reported any failures.

3.2 Multi variate analysis

After finishing the descriptive analysis, a multi variate analysis is done with the main focus on variables containing geometry information. It is expected to find any kind of relationship (correlation, collinearity) between the

different parameters. Some of these relations are pretty obvious and easy to detect by the use of domain knowledge, but others are quite astonishing. To see not only the relations between the variables, the statistics are also grouped by the target Variable (FEHLERBILD REKLA-INDEX).
The scattering matrix of a multi way analysis contains scatter diagrams for each combination of the variables. On the diagonal the histogram of each variable is shown. The left part of fig. 5 shows the scattering matrix for the 'FEHLERBILD REKLA-INDEX' value 0 (no failure), the right part of fig. 5 'FEHLERBILD REKLA-INDEX' value 1 (failure).

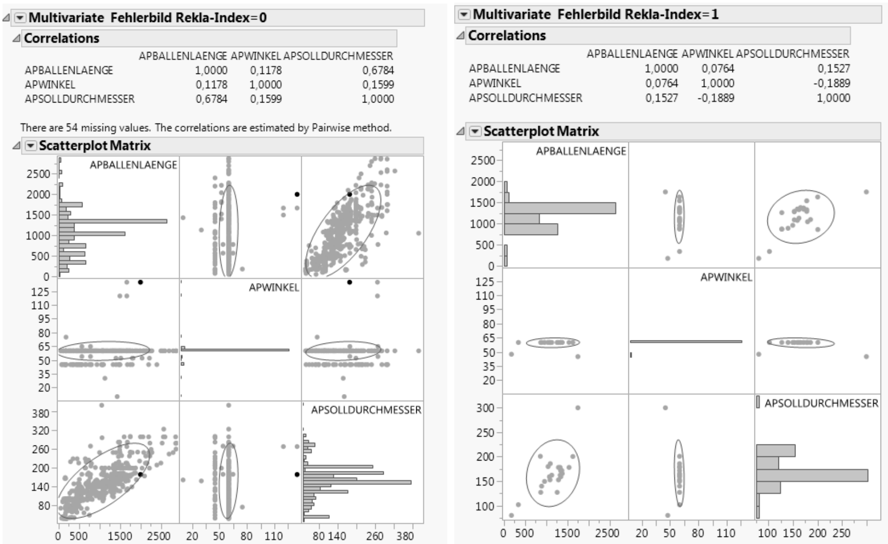


Figure 5: Multivariate correlations geometry for target value 0 / 1.

Comparing both parts of the figure, it is obvious that there are different patterns for 'FEHLERBILD REKLA-INDEX' 1 and 'FEHLERBILD REKLA-INDEX' 0. For example, for the combination 'APBALLENLAENGE' / 'APSOLLDURCHMESSER', it can be seen that the failure are likely to appear on components with 130-225mm 'APSOLLDURCHMESSER' and a 'APBALLENLAENGE' of 750mm to 1750mm. For the no failure case a very different pattern is shown.
With the help of contingency tables and chi-square testing the individual power of a variable to explain the target variable is detected. An example is the contingency table of 'APBAUART' versus 'FEHLERBILD REKLA-INDEX' (Fig. 6, left part) and 'PRODUKTIONSLINIE' versus 'FEHLERBILD REKLA-INDEX' (Fig. 6, right part). The variable 'APBAUART' is an example of a potential explanatory variable and the variable 'PRODUKTIONSLINIE'

(production line) is an example of a variable with no single impact on the failure.

It can be easily seen that both contingency table and the result of the chi-square testing give clear hints about which variables are potentially good explanation factors to detect failure. Although the software indicates invalidity of the chi square test for 'APBAUART', due to many cells occupied too less, these overall results are very obvious.

'APBAUART' 210 is a clear candidate to indicate potential failure.

Contingency Table

APBAUART

Fehlerbild Rekla-Index	Count / Total % / Col % / Row %	10	20	210	220	30	40	60	Total
0	Count	2248	270	3577	83	1366	240	98	7882
	Total %	28,22	3,39	44,90	1,04	17,15	3,01	1,23	98,95
	Col %	99,56	100,00	98,08	100,00	99,78	99,59	100,00	
	Row %	28,52	3,43	45,38	1,05	17,33	3,04	1,24	
1	Count	10	0	70	0	3	1	0	84
	Total %	0,13	0,00	0,88	0,00	0,04	0,01	0,00	1,05
	Col %	0,44	0,00	1,92	0,00	0,22	0,41	0,00	
	Row %	11,90	0,00	83,33	0,00	3,57	1,19	0,00	
Total	Count	2258	270	3647	83	1369	241	98	7966
	Total %	28,35	3,39	45,78	1,04	17,19	3,03	1,23	

Tests

N	DF	-LogLike	RSquare (U)
7966	6	27,864871	0,0026

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	55,730	<,0001*
Pearson	49,150	<,0001*

Warning: 20% of cells have expected count less than 5, ChiSquare suspect.

Contingency Table

PRODUKTIONSLINIE

Fehlerbild Rekla-Index	Count / Total % / Col % / Row %	Ker_S_W2	Ker_S_W4	Total
0	Count	9020	4314	13334
	Total %	66,85	31,97	98,83
	Col %	98,89	98,70	
	Row %	67,65	32,35	
1	Count	101	57	158
	Total %	0,75	0,42	1,17
	Col %	1,11	1,30	
	Row %	63,92	36,08	
Total	Count	9121	4371	13492
	Total %	67,60	32,40	

Tests

N	DF	-LogLike	RSquare (U)
13492	1	0,48512089	0,0001

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0,970	0,3246
Pearson	0,988	0,3202

Figure 6: Contingency table APBAUART / FEHLERBILD REKLA-INDEX.

As a result of the analytics done in this chapter we are able to do some feature reduction and to find potential good interaction to be used in a predictive model (Section 4).

4 PREDICTIVE MODEL

Based on the pre-analytics results above, it is planned to develop a predictive model that can be used to forecast whether a module is likely to fail or not. As a side aspect the model also generates clear hints of how to avoid future failure during the ongoing production. The modelling process follows a general data mining process (fig. 7).

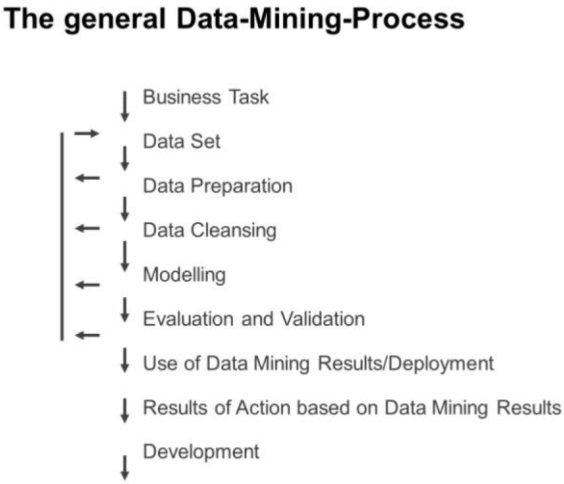


Figure 7: General data-mining-process [2].

As described above, all steps until modelling are already done. We are now focusing on the modelling part.

To ensure good and reliable model quality to work with a train and test approach on one hand or to use cross validation on the other hand is indicated. This ensures overfitting of the model as well. Based on the fact that just 1% of all datasets are 'FEHLERBILD REKLA-INDEX' =1. It was decided to use cross validation as evaluation and validation technique. Details can be found in [3].

As modelling technique decision trees are chosen. The main drivers behind this decision are the facts that in most cases they come up with robust results, a good graphical representation and the opportunity to translate the model itself in actionable rules [2] [3] [4].

Best results are produced by the C4.5 algorithm. The C4.5 algorithm is a decision tree algorithm that is a further development of the ID3 [5]. The main advantages of C4.5 algorithm are the use of categories and numeric values and an error based pruning. C4.5 is in use and described in detail in several data mining text book for the last 20 years. Apart from the paper by Quinlan [5], an applied description of C4.5 is also given in [6].

Confusion Matrix		**To (predicted Target)**		
		1	**0**	**all**
from (real Target)	**1**	**35**	49	84
	0	93	**7789**	7882
	all	128	7838	7966

Figure 7: Confusion matrix.

The confusion matrix above (fig. 7) means, that if the model provides a list of 128 components, 27.3% (35 components out of 128) of them are genuinely positive and 41.6% of genuine positives (35 out of 84 components) do appear on the list. In contrast, randomly choosing 128 components from 7966 would yield only 1.6% of positives on average, and 98.4% of actual positives would be missed.
It is obvious that it is not likely to find a model that predicts 100% of all failures correctly. But the found model is a good starting point to reduce the amount and the percentage of components that failed.

5 RESULTS

In general the project shows the power of data mining techniques to solve quality problems in production areas. Differently from traditional quality management techniques, like e.g. statistical process control (SPC) –charts [7], a model was worked out under a data mining process [8]. This Data mining model enables the company to optimize their production and to predict potential failures before they are delivered to the client side, even when a certain overestimation will waste efforts in additional quality control on those that are wrongly estimated as potential failures. But under the bottom line it saves money, because the cost of reclamation, after the component is part of the clients' production line, is much higher. Client's satisfaction and the related increased likelihood of future purchases are another monetary value as well.
Based on some detailed findings in phase 1, the manufacturer also started technical investigation of the problem. The first finding indicates a waviness on the surface with very low amplitudes [9].

6 FUTURE

As indicated in the beginning, based on the experience of this first project phase we will conclude with the second phase. The major drivers of the second phase are:

- To develop a 'standard' quality measurement tool kit to ensure that the amount of today's undetected failures will be reduced and to make failure quotes comparable;
- To get more detailed production unit record. Actual there are some hints that the failure pattern can be caused by special dynamic behavior;
- Data/detailed information on the environment and the circumstance of how the component is embedded in the customer production line;
- Results of the physical findings will be included as well.

At the end of phase 2 we expect an improved and more precise model that helps to detect potential failures as soon as possible and that reduces the amount of reclamation.

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THE ROLE OF TECHNOLOGICAL AND GEOMETRICAL PARAMETERS IN THE CONSTRUCTION OF WOOD MILLING TOOLS

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Abstract
In the research, the influence of the blade rake angle, chip thickness and angle of wood tissue on the quality of the machined surface of beech wood was studied. Cutting was carried out in the direction of 0° - 90°, which means that the edge of the blade was parallel to the direction of the tissue and the feed direction was perpendicular to direction of the tissue, as is typical in conventional turning. Rake angle ranged from 10° to 50°, and the orientation of the tissue ranged from 0° to 90°, where 0° means tangential surface and 90° the radial surface. Chip thickness was 0.05 mm, 0.1 mm and 0.15 mm. Roughness parameters were measured for each combination. The results showed strong dependence of surface quality on individual technological and geometrical parameters of cutting. The best quality of cut was achieved at the highest rake angle and minimum chip thickness at the radial surface. The results of this research can greatly help in the construction of milling tools for wood where better surface quality can be obtained with cutting tools with greater rake angles as compared to the conventional tools for longitudinal milling.

Keywords:
Cutting tool, surface quality, wood, beech

1 INTRODUCTION

In the manufacturing of round wooden elements, turning (fig. 1a) is a common technological process where the work piece is rotating and the blade is stationary. Since in the initial stage the work piece is not circular, larger centrifugal force due to the imbalance of work piece may occur, so the rotation and thus the cutting speed of the work piece is usually lower than cutting speed in the conventional milling where the work piece rests and the tool rotates. The result is a higher feed per tooth and thickness of the chip, and consequently poorer quality of the resulting surface.

Alternative is circumferential milling (fig. 1b) where a slowly rotating piece is milled with a milling cutter. The quality is better but grinding is still necessary due to sub-optimal geometry of the cutting blade, which is usually used for longitudinal milling.

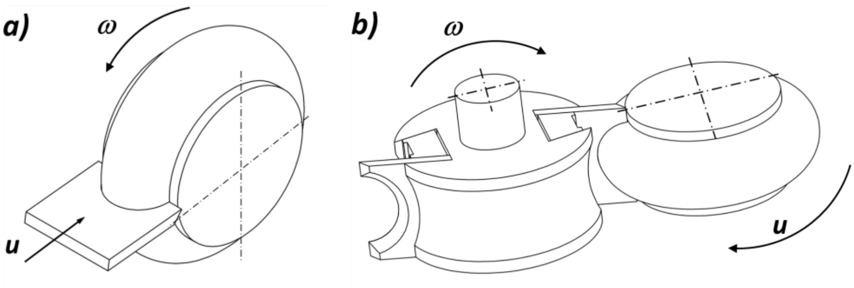

Figure 1: a) Turning and b) circumferential milling; *u* – feeding speed, ω - rotational speed.

In the case of longitudinal orthogonal cutting of solid wood in the direction of 90°-0°, (fig. 2) chips can be divided, according to their shape, into three groups, namely type I, II and III [1]. The type I chip shown in fig. 3a is generated by cutting when the rake angles are greater than 25°. From the viewpoint of material flow which passes into the chip, it can be said that the chip is discontinuous [2]. When the cutting tool comes in contact with wood it first indents the uncut part of wood and the energy accumulates. When the accumulated energy in material in front of the advanced cutting tool is sufficiently large and small material discontinuity is presented, the energy is suddenly released and the crack propagates rapidly to some equilibrium length at which the accumulated elastic energy is spent. Subsequently, the blade lifts the chip; the crack propagates when the stress intensity factor at the crack tip equals critical stress intensity factor and when bending stress in the chip is smaller than the bending strength. With increasing crack length the bending stress increases and the chip breaks when it reaches the ultimate value. The chip still has some rigidity that the blade must overcome with some force. When the blade reaches the area of chip break, the cycle repeats.
The type II chip is shown in fig. 3b. It is formed by cutting when the rake angle ranges between 5° and 25°. There is usually no cracking and splitting of wood tissue in front of the tip, but the tissue fails under compression and/or shear. The type III chip is formed by cutting with rake angles of less than 5°. The tissue in front of the tip of the blade is failed because of the compression. Since the low rake angle makes lifting and removal of the chip difficult, the tissue is often bulged on buckling and then removed.

The process described is typical for longitudinal wood cutting in the direction of 90°-0°, where the direction of cleavage of the tissue in chip formation depends on the direction of wood tissue. Therefore the basic rule is to try to avoid the occurrence of chip type I by using rake angles between 15° and 25°.

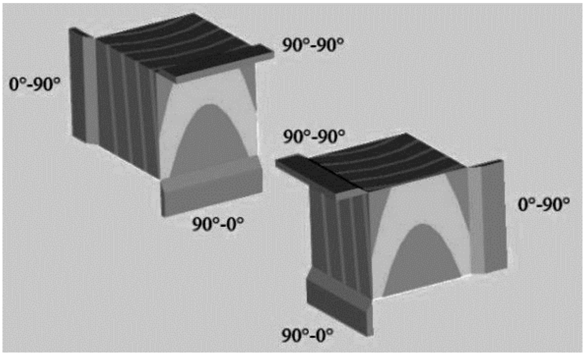

Figure 2: Basic directions of orthogonal wood cutting [1].

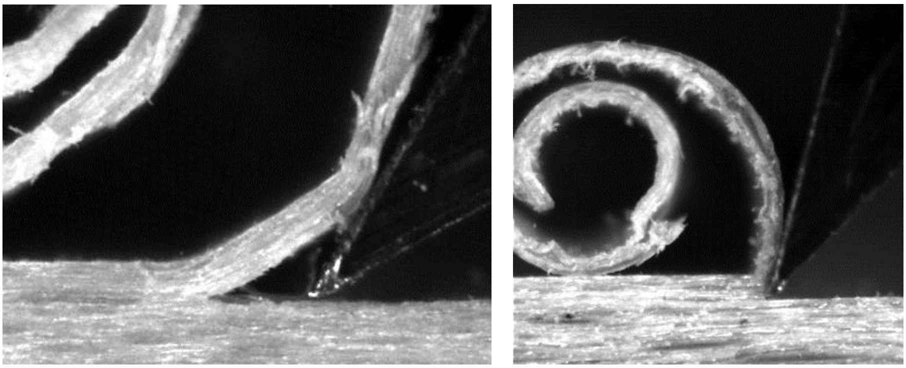

Figure 3: Longitudinal cutting in the direction of 90°-0°,
chip thickness 0.3 mm.
a) Type I chip, rake angle 31°; b) Type II chip , rake angle 16°.

The above description gives rise to the question whether the tools, i.e. blades with smaller rake angles that are optimal for longitudinal cutting of wood tissue, are also suitable for cutting wood tissue in the perpendicular direction, i.e. 0°-90° (fig. 2).

2 MATERIALS AND METHODS

Beech wood (*Fagus silvatica* L.) was cut. Two 60 mm thick boards were glued together, and then the samples 10 mm thick were cut as shown in fig. 4a. Equilibrium moisture content was 9 ± 0.5%.
Cutting was carried out in the direction of 0°-90° (the edge of the blade and the feed direction were parallel and perpendicular to direction of the tissue, respectively) as it is typical in conventional turning. Rake angles were 10°, 20°, 30°, 40° and 50° and the orientation of the tissue was 0°, 30°, 60° and 90°, where 0° means tangential surface and 90° radial surface (fig. 4b). Chip thickness was 0.05 mm, 0.1 mm and 0.15 mm.

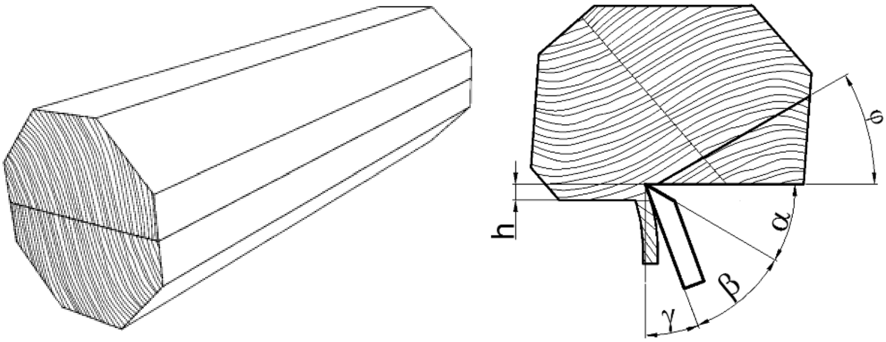

Figure 4: Specimen preparation and geometrical parameters: α - clearance angle, β – tool angle, γ - rake angle, φ - angle of tissue orientation.

Cutting was performed by a sharp HSS blade with a tool angle of 30° (fig. 4). The blade was placed on a trolley with guides, which was fed by hydraulic cylinder at 0.2 m/s. Two cuts were made for each combination of parameters and each cut surface profile was measured in three places. Each measurement was 20 mm long, that is, a total of 60 mm for each cut. The profile was measured with a cone travelling along the surface while measuring the cone oscillation by a laser. From each profile measurement the following profile roughness parameters [3] (fig. 5) were calculated:

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

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

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

$$R_z = \frac{Z_1 + Z_2 + Z_3 + Z_4 + Z_5}{5} \tag{2}$$

- R_t - maximum height of the profile:

$$R_t = R_p - R_v \tag{3}$$

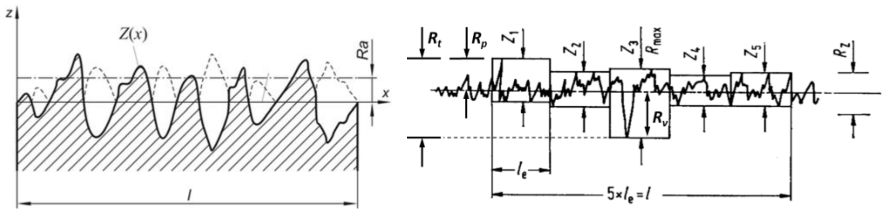

Figure 5: Profile roughness parameters R_a, R_z *and* R_t [3].

3 RESULTS AND DISCUSSION

Fig. 6 shows average values of the profile roughness parameter R_a for chip thickness of 0.15 mm, where the values are decreasing with increasing rake angle. It can be seen from this figure that the minimum values and thus the best surface is produced at tissue orientation angle of 90°, that is, at the radial surface while the angle of 30° produces the highest value. However, it should be noted that in turning as well as in the circumferential milling where the slowly rotating piece is milled with a milling cutter, a specific orientation angle cannot be avoided, i.e., the work piece has to be milled from all sides.

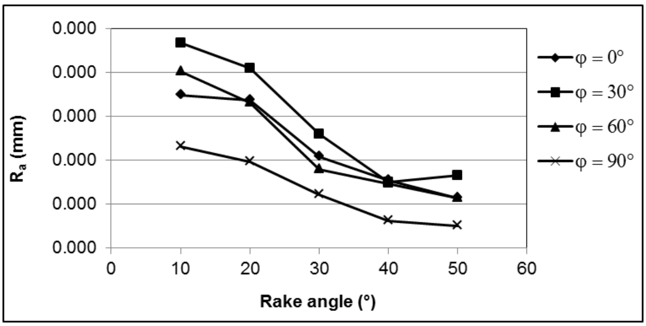

Figure 6: The profile roughness parameter R_a for the chip thickness of 0.15 mm, different rake angles and wood tissue orientations (φ).

The same trend as for R_a also applies to the profile roughness parameter R_z (fig. 7): that is, the values are decreasing with increasing rake angle, and are the lowest at the rake angle of 50°.

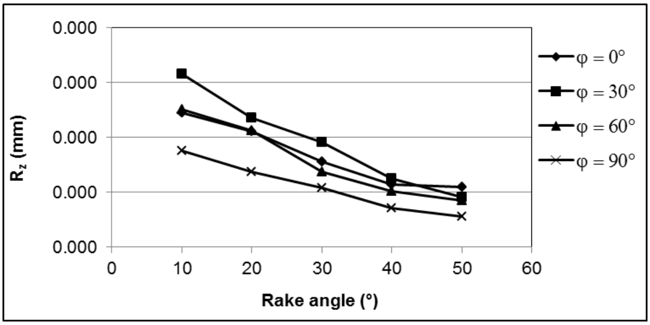

Figure 7: The profile roughness parameter R_z for chip thickness of 0.15 mm, different rake angles and wood tissue orientations (φ).

In wood machining process it often happens that the otherwise high-quality machined surface has torn grain, which means that such a surface is useless. Fig. 8 shows parameter R_t, which tells us the maximum distance between the highest peak and the lowest valley, which in our case corresponds to chip torn or grain surface. It can be seen in the figure that the values are the lowest at the greatest rake angle, i.e., the surface has the best quality.

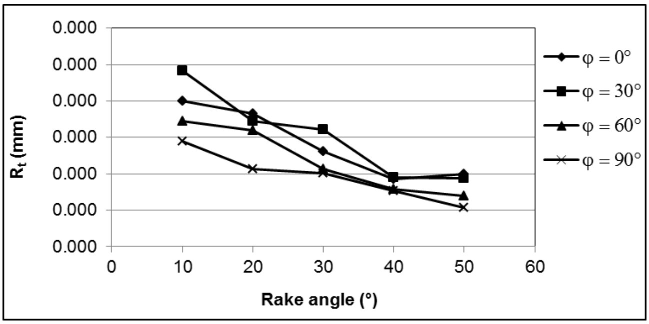

Figure 8: Profile roughness parameter R_t for chip thickness of 0.15 mm, different rake angles and wood tissue orientations (φ).

But a distinction has to be made between cutting in the directions of 90°-0° and 0°-90°. In the first case, cutting with greater rake angles can result in the cleavage of the tissue in front of the tip of the blade bellow the cutting plane as described in the introduction. On the contrary in our case (0°-90°), cutting at low rake angle results in tearing wood because the tip of the blade does not cut the tissue, but it pushes it in front of the blade which can lead to torn grain below the cutting plane. Such a profile can be seen in fig. 9a, where the cut was made at the rake angle of 10°, tissue orientation angle of 30° and chip thickness of 0.15 mm, whereas fig. 9b shows a profile for the rake angle of 40°.

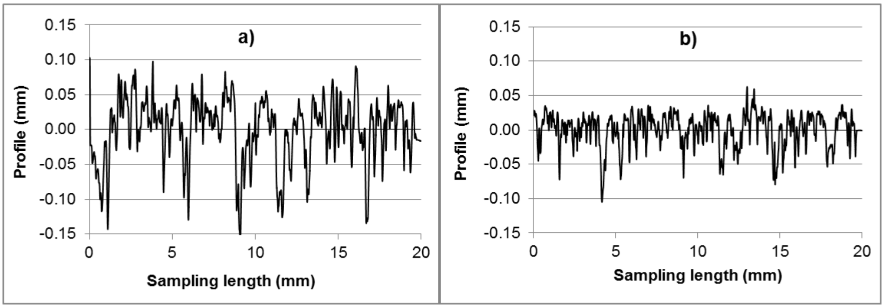

Figure 9: Profile roughness measurement, chip thickness 0.15 mm, wood tissue orientation 30°; a) rake angle of 10° and b) rake angle of 40°.

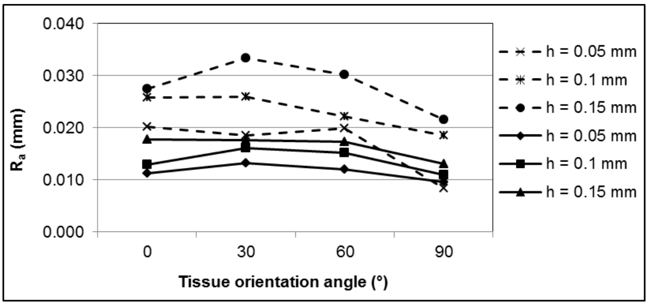

Figure 10: Profile roughness parameter R_a at rake angles of 10° (dashed line) and 40° (solid line) for different wood tissue orientations and chip thicknesses (h).

Fig. 10 shows parameter R_a for different tissue orientations and chip thicknesses cutting at the rake angles of 10° and 40°. The rake angle of 40° was chosen because in the case of the cutting knife made from the tungsten carbide the minimum tool angle of 45° is required, which means that only 5° remains for the clearance angle. The picture shows the fact that was already highlighted in fig. 6, i.e., the worst quality surface results at the tissue orientation angle of 30°. In addition, the figure clearly shows that the surface quality increases with decreasing chip thickness. This was expected and is in line with common practice, and shows that the surface quality is better at smaller chip thicknesses. This is particularly true for cutting at the rake angle of 10°, while cutting at the rake angle of 40° R_a is less sensitive to tissue orientation and chip thickness.

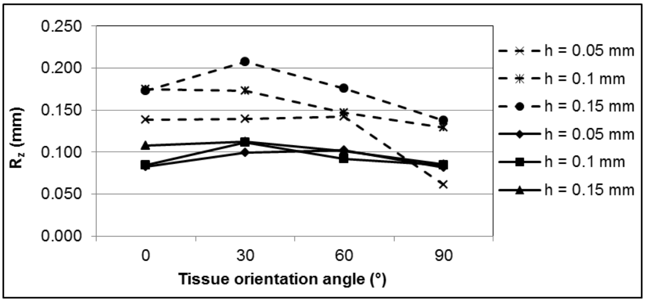

Figure 11: Profile roughness parameter R_z at rake angles of 10° (dashed line) and 40° (solid line) for different wood tissue orientations and chip thicknesses (*h*).

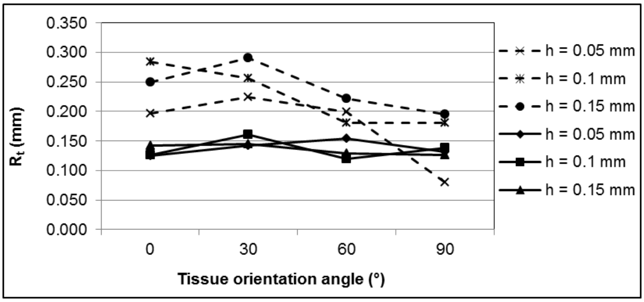

Figure 12: Profile roughness parameter R_t at rake angles of 10° (dashed line) and 40° (solid line) for different wood tissue orientations and chip thicknesses (*h*).

Fig. 11 and fig. 12 show R_z and R_t respectively for the same cutting conditions as shown in fig. 10. Both figures show practical no dependence of profile roughness parameter on chip thickness at the rake angle of 40°. This means that cutting with rake angle of 40° makes the surface smoother at smaller chip thicknesses since R_a is smaller (fig. 10), but the amount of torn grain is the same, i.e., there is no torn grain at any chip thickness (fig. 11 and 12).

4 CONCLUSION

Within this research, the influence of rake angle, chip thickness and orientation of tissue in the orthogonal cutting in the direction of 0°-90° were investigated. The research has shown that the best surface quality can be achieved by cutting at large rake angles where the surface quality slightly fluctuates with wood tissue orientation angle, being the worst and the best at the angles of 30° and 90° respectively, where 90° correspond to the radial surface. However, it should be noted that normally different tissue orientation angles cannot be avoided, since the work piece has to be milled from all sides.

The research has also shown that at the rake angle of 40° parameter R_a increases with chip thickness while R_z stays the same, which means that at a smaller chip thickness the surface is otherwise smoother as compared to a greater chip thickness, but there is the same amount of grained surface. A quite different situation is in cutting with rake angle of 10° where parameters R_z and R_a increase with chip thicknesses, which means rougher surface with a greater amount of grained surface. It should be noted that in case of a rougher surface the surface can be grinded. If, however, the surface is highly grained with a great amount of torn chips the surface cannot be grinded because too much material has to be removed. It follows from the research conducted that the use of tools which are normally used for cutting in the longitudinal direction, i.e., in the direction of 90°-0°, is not optimal for cutting in the direction of 0°-90°. Due to the chip formation process, described in the introductory part, the rake angle in a longitudinal milling (in the direction of 90°-0°) has to be around 20°. At greater rake angles the chip is formed by the cleavage of tissue in front of the tip of the knife. If the cut is made against the grain, the tissue can split below the cutting plane in front of the tip of the blade which produces a chipped surface.

However, when cutting in 0°-90° direction, the stiffness of the tissue in the lateral direction is lower than in longitudinal direction, and thus the chipped surface cannot occur when greater rake angles are used, while there may be tissue tear-offs below the cutting plane when small rake angles are used where greater compressive stresses are present.

ACKNOWLEDGMENTS
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DEVELOPMENT AND LIFE CYCLE ASSESSMENT OF FURNITURE FOR THE ELDERLY

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Abstract
Today, production of environmentally friendly products for the elderly is a priority of numerous development, research, and policy initiatives. The prototype furniture concepts for the elderly community with minimal environmental impacts by taking into account the 'cradle to cradle' design paradigm was designed. In parallel with the furniture design process the environmental friendliness of materials was evaluated and prediction of their decomposition was considered. The elderly population was involved throughout the design process. The furniture prototypes selected for analysis were a customized bed and nightstand. And three prototype versions were constructed with varying materials (solid wood, veneered particleboard, plywood) and compared. Carbon footprint calculations were used as the basis of comparison for the three furniture prototypes. The bed and nightstand set with the lowest carbon footprint was made of solid beech wood. Accounting for CO_2 stored in the material the carbon footprint of solid wood reduced further, increasing the advantage it held over its composite wood counterparts. Replacing metal fasteners and connectors with wooden counterparts would further decrease the carbon footprint of the furniture prototypes.

Keywords:
Life-cycle, product design, furniture

1 INTRODUCTION

As sustainability becomes a greater concern, the environmental impact of construction and furnishing materials should be included in planning by considering the life cycle and embodied energy of the materials used. Therefore, life cycle assessment (LCA) should be used to reveal the environmental and energy performances of the used materials throughout their whole life cycle. The common LCA methodology is defined in ISO 14040 [1] and ISO 14044 [2]. Since the 1980s, when LCA analysis was first developed, numerous methodologies to classify, characterize, and normalize environmental effects have been developed. LCA is performed for various stages of a product's life span.

A product life cycle starts with procuring the raw material, and follows the product through primary processing, secondary processing or manufacturing, packaging, shipping and handling, installation, in-use energy consumption, maintenance, and end-of-life scenarios. LCA analyses products over specific periods of a products life cycle, for example, cradle-to-gate refers to life cycle assessment from raw material stage to the point directly before the product is shipped. Similarly, cradle-to-grave involves LCA of all stages of the product or the material, starting from raw material procurement to its end-of-life. For wood products, the life cycle generally starts with extraction of raw resources from the natural environment or recovery of materials from a previous use. The raw resources are then manufactured into useable products. The finished products are shipped to a site, consuming energy in the process. During the service life of the product, it may consume energy based on its use (e.g., energy used to maintain the product). Over time, renovations or retrofitting may be performed on the products, which may require additional materials and energy. Finally, the product is removed/demolished and its materials disposed of, either as construction waste or recycled for reuse. Each of these steps consumes energy and materials and produces waste. The purpose of LCA is to quantify how a product or system affects the environment during each phase of its life. Examples of parameters that may be quantified include: energy consumption, resource use, greenhouse gas production, solid waste generation, and pollution generation.

With regard to greenhouse gas emissions, wood is a better alternative than other materials. Werner and Richter [3] reviewed the results of approximately 20 years of international research on the environmental impact of the life cycle of wood products compared to functionally equivalent products from other materials. Furthermore, wood causes less emissions of SO_2 and generates less waste compared to the alternative materials [4]. However, treated wood, adhesively bonded wood and coated wood might have toxicological impacts on human health and ecosystems.

The number of LCA studies of wood-based composites is relatively limited, geographically distributed, uses a variety of databases, and impacts ssessment protocols. Kutnar and Hill [5] used a cradle-to-gate analysis to present the carbon footprint of 14 different primary wood products.

The largest source of emissions for all sawn timber products is removing the timber from the forest, while for kiln dried sawn timber the drying process follows closely behind. For fiber composites (MDF and HDF) the extra energy required to convert the raw material into fibers, in addition to the energy required to apply pressure and heat to the products is responsible for the bulk of the emissions from these products. The adhesives used in particleboard, plywood, and OSB are responsible for the largest fraction of emissions from these products. This is especially significant considering the low total volume they represent in the final products. Glulam emissions

derive mostly from the harvest and initial production of the softwood, but also from the extra energy required to apply pressure and set the adhesives used. Altering the system boundaries would yield different results. Furthermore, results would have been modified if the carbon footprint calculation accounted for carbon sequestration of wood, the use of recycled wood products, and other similar issues pertinent to LCA.
Furthermore, the results would have been different if a full life cycle of products, cradle to grave or cradle to cradle, would be considered. In fig. 1 carbon footprints of selected primary wood products are presented, calculated with IPCC 2007 GWP 100a V1.02 method, which was developed by the Intergovernmental Panel on Climate Change [6]. The method contains the climate change factors of IPCC with a timeframe of 100 years.

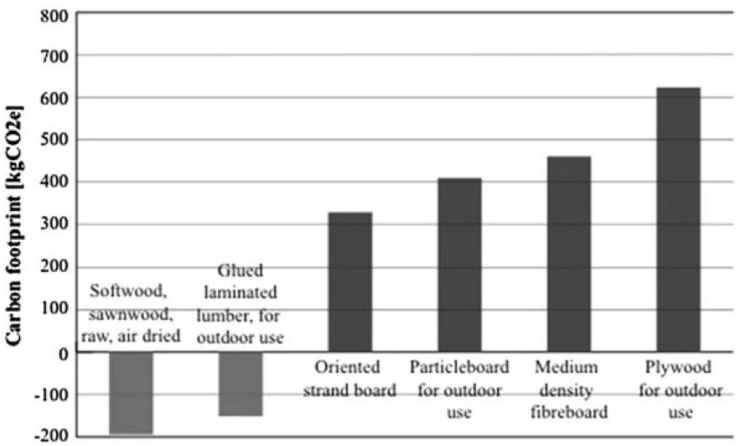

Figure 1: Carbon footprint of 1 m^3 of selected primary wood products from Ecoinvent 3.0 [7].

The products with the lowest carbon footprints are air-dried sawn timber and glued laminated timber. The glued laminated timber has higher carbon footprint due to adhesives, but is still negative. Wood has a negative footprint because of the carbon dioxide fixed by the original living tree. The emissions associated with harvesting, transporting, and processing sawnwood products are small compared to the total amount of carbon stored in the wood. This means that even when energy use for harvesting, transport, and processing are taken into account, sawnwood still has a negative footprint. Wood-based composite production requires additional energy inputs to process raw materials, manufacturing byproducts, and recycled wood into the desired form, as well as adhesives and other additives to form the composite matrices, which considerably increases the

carbon footprint of these wood products. The highest carbon footprint among the compared products has plywood for outdoor use, followed by MDF and particleboard. Among compared wood-based composites, oriented strand board has the lowest carbon footprint [8].
Besides environmental impacts of raw material, the products should be evaluated for their environmental impacts and at the same time serve the target users. One of the examples is furniture for elderly. The production of environmentally friendly products for the elderly is a priority of numerous development, research, and policy initiatives (fig.2). The share of people who have poor eyesight, hearing, memory; impaired motor abilities and who perceive information with difficulty due to their old age is increasing.
Nowadays the majority of products are designed for healthy, young, active and agile people. According to research, such products form up to 90% of the market.

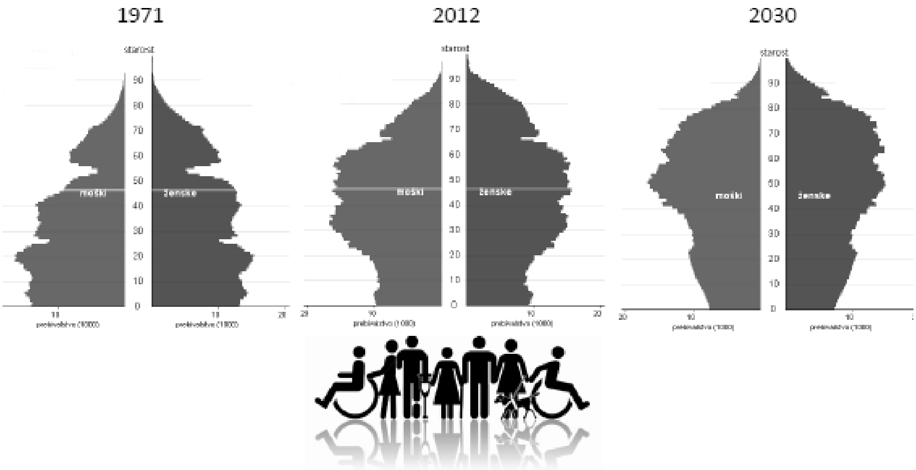

Figure 2: The demographic of aging - the percentage of elderly people grows enormously from one year to another.

Many elderly and disabled people no longer have the ability to fully use them; therefore, domestic chores cause more stress and consequently malaise. In this paper we present a study, in which customized bed and nightstand for elderly was developed following the C2C paradigm.

2 MATERIALS AND METHOD

2.1 Goal and scope of the carbon footprint calculation

Following the common life cycle assessment (LCA) methodology [1] the goal of the study was to objectively prove environmental impact from 'cradle to gate', an assessment of a partial product life cycle from manufacture ('cradle') to the factory gate (i.e., before it is transported to the consumer), of designed bed for elderly people. The main focus was given to the carbon footprint. The functional unit was chosen to be the whole bed. The use phase and disposal phase of the product were omitted. Analysis included carbon emissions of raw materials and waste resulting from product production, while transportation of materials to the factory, electricity and other energy sources in product production were not included in the calculation.

The scope and goal of the study was to compare the environmental impact of beds produced with different primary wood products. The carbon footprint was chosen as indicator of environmental impact, since the sequestered carbon and its impact on LCA results were aimed to be determined. Other indicators could also be used. However, the aim of this study limited to carbon footprint.

2.2 Analyzed product and data collection

The bed was designed keeping in mind the comfort and needs of old and ailing people. The conflict between designing for an individual and designing for a population was faced: a product that suits one person may be inconvenient to another. The ergonomic approach to home design may develop an integrated strategy aimed at the well-being and satisfaction of ageing people [9]. In bed, ageing people are liable to risks of falls and impacts. Furthermore, the mobility and physical ability of elderly people are changing over time. Therefore, the simple multifunctional bed that gives warm feeling of familiarity and orientation with the environment was designed. The design included the following requirements: the option to adjust height, maintaining person position, moving and turning part of bed, raising head and legs, bed rail, vertical grab pole, bed accessories should enable eating and other activities in bed, while all the appliances should be easy to use involving simple commands. The designed bed (width 90 cm, length 200 cm, and height 45 cm) that included the above requirements is shown in fig. 3.

The selected construction material was beech (*Fagus sylvatica*). The elements of the designed bed, their dimensions, and needed volume of wood for each element, accounting also the yield, are given in tab. 1.

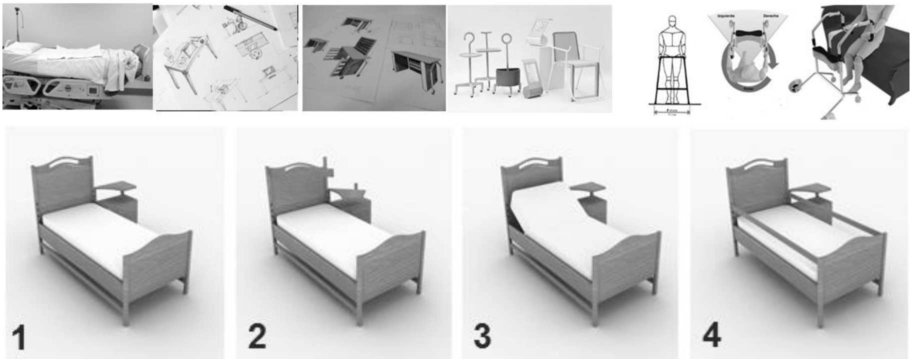

Figure 3: Bed for elderly people designed following the C2C concept. Different function of bed and nightstands: 1-basic, 2-adjustable bed trapezes and table, 3-raising the head of the bed, safety bad realis.

Table 1: List of solid wood elements, their dimensions, and amount of material needed for designed bed.

Elements	**Dimensions**			**Number of pieces**	**Volume (net)**	**Yield**	**Needed volume accounting yield**
	Length [mm]	Width [mm]	Height [mm]		[m^3]	[%]	[m^3]
Leg - headboard	1200	40	40	2	0.0038	60	0.0064
Leg -footboard	750	40	40	2	0.0024	60	0.0040
Headboard	900	900	20	1	0.0162	60	0.0270
Trapeze bar	900	170	25	1	0.0038	60	0.0064
Food board	900	570	20	1	0.0103	60	0.0171
Board	2030	200	20	2	0.0162	60	0.0271
Side rail	1950	30	30	2	0.0035	60	0.0059
Rail	2030	70	20	2	0.0057	60	0.0095

Table 2: List of input materials for calculation of carbon footprint and their quantities for the designed bed for elderly people.

Input materials	
Solid wood	0.103 m^3
Metal connecting elements	128 g
Metal swivel clamp	70 g
Adhesive PVA	200 g
Water based coating	1,450 g

Following the elements given in table 1, the list of materials needed for production of designed bed was determined. The amounts of materials were assessed and used for carbon footprint and net carbon foot print calculation (tab. 2).
Based on the determined goal and scope of the study, the life cycle inventory of input/output data for the carbon footprint calculations was performed. Data of energy inputs, raw materials, products, co-products, waste, and releases to air, water and soil were assessed. The upstream life cycle impacts of input materials were not analyzed specifically for this project. Instead, sound secondary life cycle data (emission factors) were sourced from Ecoinvent database 3.0. [7].

2.3 Modeling and impact assessment

The data collected were modeled in Simapro [10]. Emissions and consumptions were translated into environmental effects, which were grouped and weighed. The biotic carbon sequestration was considered in the calculation. Carbon footprint was calculated with methodology IPCC 2001 GWP 100a V1.02 (Climate Change, 2001). IPCC 2007 contains the climate change factors of IPCC with a timeframe of 100 years. IPCC characterization factors for the direct (except CH_4) global warming potential of air emissions. They do not include indirect formation of dinitrogen monoxide from nitrogen emissions, do not account for radiative forcing due to emissions of NOx, water, sulphate, etc. in the lower stratosphere + upper troposphere, do not consider the range of indirect effects given by IPCC, and do not include indirect effects of CO emissions.

3 RESULTS

Carbon footprint calculates the amount of greenhouse gas (GHG) emissions caused by a particular activity or entity, commonly also referred to as global warming potential (GWP). It is measured in tones (or kilograms) of carbon dioxide equivalent (CO_2eq.). Approximately 50% of dry timber is elemental carbon; thus, 1 kg of wood contains approximately 0.5 kg of carbon, which equates to 1.83 kg of CO_2. When calculating a carbon footprint, whether to include this stored carbon in timber (and, to a far lesser extent, small amounts of stored carbon in other materials) is a much debated issue. In this study, the carbon footprint and NET carbon footprint were calculated. The carbon footprint of the designed bed analyzed product was 10.4 kg CO_2e, while the NET carbon footprint was – 107.4 kg CO_2e due to carbon storage (sequestration) in the product, which was 117.8 kg CO_2e (tab. 3).
In tab. 4 and fig.4, the contributions of input materials to carbon footprint are given.

Table 3: Carbon footprint, CO_2eq sequestered in the product, and NET carbon footprint of designed bed for elderly people.

	Carbon footprint [kg CO_2e]	CO_2eq. sequestered in the product [kg CO_2e]	NET carbon footprint* [kg CO_2e]
Bed for elderly	10.4	117.8	- 107.4

* includes carbon storage (sequestration)

Table 4: Carbon footprint of emission sources and their contribution to the total carbon footprint of designed bed for elderly people.

Input materials	**kg CO_2e**	**%**
Sawn timber, hardwood, raw, air / kiln dried, u=10%	6.65	
Polyvinyl chloride resin	0.359	
Steel, converter, unalloyed,	0.317	
Acrylic dispersion, 65% in H2O	3.07	
Total	10.4	

Although the water-based coating presented low contribution to the weight of the whole product (2.2%), it contributed a significant 29.5% to the carbon footprint. On the other hand, the timber presented high contribution to the weight of the product (97.2%), but it contributed only 63.9% to the carbon footprint of the designed bed for elderly people.

Furthermore, metal parts and adhesive contributed 3% to the carbon footprint of the designed bed for elderly people.

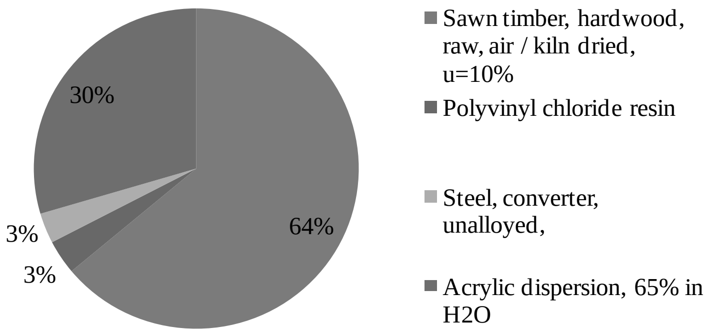

Figure 4: Contribution of emission sources to carbon footprint of the ‘bed for elderly people’.

4 CONCLUSION

The study showed that coatings and adhesives considerably contribute to the carbon footprint, although they have low contribution to the weight of the whole product; therefore, coatings and adhesives from renewable resources should be used to reduce the environmental impact of the designed bed for elderly people. The study demonstrated that the LCA is a rational, quantified approach to determining specific environmental impacts of a product. As solutions are sought to reduce the impacts of products, LCA is seen as an objective measure for comparing products designs. LCA clearly has an important role to play in assessing the sustainability of green products and it is a valuable tool [8]. The adoption of life-cycle approach to design, where not only current energy concerns are accounted for, but also long-term energy, environmental, and social impacts, should lead to an integrated approach to design. Future research will investigate the bed for elderly people made out of a solid beech wood in combination with veneered particleboard, and out of a solid beech wood in combination with beech plywood with the aim to determine the best solution, when the environmental impact is the measure of a material selection process, including the energy use of the production process.

Before starting to design furniture (the bed and nightstand) for the elderly people, the following rules should be taken into consideration: appropriate materials (considering the configuration), safety, cleaning and manipulation of the furniture; incorporate the intelligent technology as much as possible; the organization of bed and nightstand elements has to be adapted with the requirements of the senior users in mind. Future furniture design has to include robots, computer regulation, advanced mechanisms and modern nano films on surfaces to simplify everyday chores and ensure better hygiene standards.

ACKNOWLEDGMENTS

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THE IMPACT OF ADDITIVE MANUFACTURING ON FIRMS' COMPETITIVENESS: AN EMPIRICAL INVESTIGATION

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Abstract
The purpose of this research is to study in depth the adoption of additive manufacturing (AM) inside industrial processes and its impact on firms' competitiveness and performances. We conducted an explorative investigation among eight innovative B2B Italian firms that adopted AM technologies in order to enhance their capacity of designing and producing prototypes and components. In this paper, the impacts of this emerging technology in the manufacturing process and in their market strategy classifying them in: business strategy, customer, products, process and costs are examined. Then, based on the accordance and discrepancies arisen from the empirical research, some fundamental factors influencing firms' competitiveness and performances have been found.

Keywords:
Additive manufacturing, competitiveness, SWOT analysis

1 INTRODUCTION

Additive manufacturing (AM) is a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing technologies [1], such as traditional machining. The general process of AM is clearly shown in fig. 1 where has been indicated how a 3D object is made from a 3D CAD model.

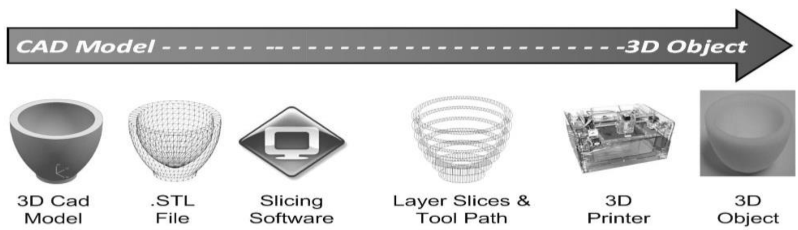

Figure 1: Generalized additive manufacturing process.

Selective Laser Sintering (SLS) and Fused Layer Manufacturing (FLM) of plastic and metal are part of these 'layer by layer' based AM techniques, which are well known as the next industrial revolution [5]. AM is a developing technology that has been launched in the 1980s [6]; however, as regard to practical application, AM is currently an upcoming forefront of manufacturing, medicine, art, and so on.

The paper is organized in five sections. The section 2 proposes a literature overview, which helped us to identify research gaps and to formulate research questions. The section 3 describes the research methodology and the selected case studies. The analysis of the results is presented in section 4 and some hypothesis emerged from case studies is formulated. Finally, we discuss results.

2 LITERATURE OVERVIEW

According to Berman [3] additive technologies have gone through three evolution phases in recent years. In the first phase, product designers employed AM technologies to make only prototypes of new designs, the second evolutionary phase of AM includes the application in creating finished parts (this step is referred to as 'direct digital manufacturing' or 'rapid manufacturing'), the third phase involves 3-D printers which will be used by final consumers, like desktop printers.

With rapid, customized, and low-cost products, 3D printing (3DP) is presumably to have a huge and far-reaching impact on the industrial world. Due to the significant benefits that AM brings to manufacturing and market, this disruptive technology has attracted several researchers in business strategy and technology management.

AM technologies are creating a world of possibilities that can take an organization in an entirely new direction and help launch new businesses and business models [12]. By enabling companies to cover unstable demand, sharing the design, individualizing products, and effectively producing of low volume or single part [5, 8, 9, 10], AM provides accessing to new markets, demand growth and competitive advantages for the firms. These impacts lead to change of business strategies and business models.

From customers' point of view, AM leads to a time-to-market reduction and to full-customized products. The customer requirements can be met by creating products, which fit in color, form and function. AM can enable the required level of individualization for high-tech equipment, for which the customers are willing to pay high prices.

Some researchers demonstrated with means of various case studies AM's advantages such as product customization of complex parts, and better functionality and aesthetic [5, 8] that can be integrated into individual products. In addition, AM has some impacts on the production process. Since AM does not require tools, changeover, molds or punches, also multifunctional team-based labors and multiple raw materials, simpler production cycle is provided in comparison with conventional manufacturing techniques [3, 5]. Some other researches demonstrated that AM leads to minimum material waste and maximum degree of flexibility in design and production [3, 5, 8, 9].

Another important factor to be considered in the technology adoption is the cost of products and operations. Current limitations of AM include high material costs, and high machine costs [3, 11]. In addition, some studies compared the energy consumption between AM technologies, and conventional manufacturing methods [e.g., 2, 7, 13]. Although the conventional manufacturing methods consume less energy according to the results of Yoon *et al.* [13]; the study of Baumers *et al.* [2] approves the efficient energy consumption of AM technologies, considering the feasible design optimization.

The previously mentioned literature investigates the impacts of AM in different industries and markets. Accordingly, we categorized them in five clusters: (1) business strategy, (2) customer, (3) product, (4) process and (5) costs. Some of these impacts are in consensus, while in some cases there are differences, based on the company and product specific characteristics, as discussed in the energy consumption issue. To the best of our knowledge, the lack of an explicit link between the impacts of AM and companies and products' characteristics exist. Consequently, the first research question is:

'*How will AM technologies influence firms' competitiveness and performances?'*, and in order to link these effects with companies' features the second research question is *'How do the effects of AM on manufacturing and markets performances relate to the specific characteristics of companies and of the products?*'.

3 RESEARCH METHODOLOGY

Due to the exploratory nature of this study, it was decided to adopt a multiple case study research strategy. The multiple case study methodology offers the possibility to provide in-depth understanding and identification of the patterns that link different explaining variables. Eight cases of Italian firms have been selected, which work with Rapid Prototyping and Rapid Manufacturing (RP/M) technologies to produce prototypes or component parts for external customers, considering the potential differences of companies in terms of design/production processes, strategy and technological choices. Authors interviewed companies' managers using a set of predetermined questions supported by literature. The questions are categorized based on the five micro-areas: (1) business strategies, (2) customers, (3) products, (4) process and (5) costs. The informants at the companies were executive or production managers.

3.1 Companies' background

The introduction of additive manufacturing in Italy, mostly in RP, goes back about two decades of history, installing the first additive technologies at the end of the nineties. However, as regards to practical application, AM is currently an upcoming forefront of the manufacturing. Consequently, firms that have used additive processes are facing increasingly aggressive competitors.

Our sample includes eight firms situated in northern Italy. All these firms produce prototypes and components for client firms operating in aeronautic, motor racing and biomedical sectors.

Despite the applications of AM in producing finished products, the production of prototypes and components are still older and more widespread. Therefore, we choose this sector of industry (producing prototypes or component parts) to reach confident results. The representativeness of the sample is guaranteed by the heterogeneity of the firms in terms of revenue, year of introduction of AM, type of AM activities, AM technology, and materials usage (see tab. 1).

Table 1: Sample companies information.

Cases	**AM Activity**	**AM Technology**	**Material**	**Introduction of AM**	***Transition from traditional process to AM***	***Size***
Company A	RP	SLS, DMLS	Metal	Consolidated	YES	SME
Company B	RP	FDM	Plastic	Recent	NO	SME
Company C	RM	SLA, DMLS, FDM	Plastic, metal	Recent	YES	Large
Company D	RP	SLA, SLS, FDM	Plastic	Consolidated	NO	SME
Company E	RP	SLS	Metal	Recent	YES	Large
Company F	RM	DMLS, SLA, SLS, EBM	Plastic, metal	Consolidated	NO	SME
Company G	RM	SLA, SLS, FDM, 3DP	Plastic, metal	Consolidated	YES	SME
Company H	RM	FDM, SLS, DLP, SLA, DMLS	Plastic, metal	Consolidated	YES	SME

Types of AM activities are Rapid Prototyping (RP) and Rapid Manufacturing (RM). Types of AM technologies are Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Fused Deposition Modeling (FDM), Stereolithography (SLA), Electron Beam Melting (EBM), 3 Dimensional Printing (3DP), Digital Light Processing (DLP). In the introduction of AM, Such firms with more than 10 years of experience in AM were considered as 'consolidated' while such with less than 10 years as 'recent'.

4 ANALYSIS OF THE RESULTS

4.1 Differentiating factors

On one hand, our case studies differ for some factors such as revenue, year of introduction, type of AM activities, AM technology, and material usage as seen in tab. 1. On the other hand, some discrepancies in the opinions of the firms have been arisen (see tab. 3). Therefore, it is reasonable to explain these discrepancies by factors differentiating the firms in the sample. In other words, the main objective is to identify the links, where they exist, between the discriminating factors and the different managers' opinions that emerged for some concepts. In the following paragraphs, there are some concepts where discrepancies in the firms' opinions have emerged; therefore, this study attempted to link these aspects with discriminating factors.

4.1.1 Competitiveness

It has been concluded that, in the opinion of the research sample, competitiveness obtained by AM, is influenced by companies' size or revenue, year of introduction of AM and types of AM activities. As seen in fig. 2, large companies that entered in AM more than 10 years ago (consolidated), with the objective of rapid manufacturing, claim that AM is an efficient technology for competitiveness. They trust in these technologies because their characteristics have allowed the firms to serve customers and satisfy them, bringing an increase of income and the possibility of expansion. Concerning competitiveness, the analysis of the case studies allows us to formulate the following hypothesis:

> *H1: Gaining competitiveness in using AM is influenced by companies' size, year of introduction of AM and type of AM activity.*

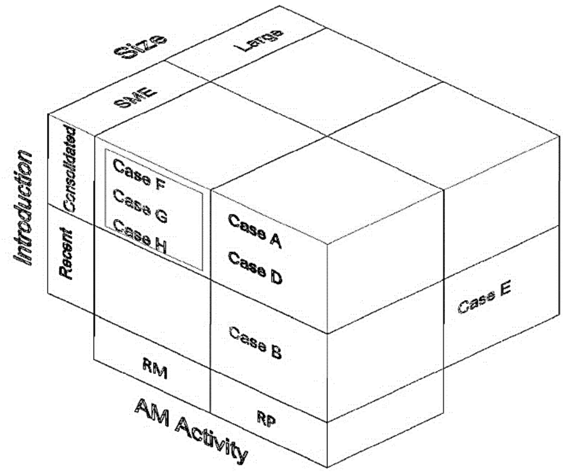

Figure 2: Dimension of competitiveness in sample firms.

4.1.2 Energy consumption

It has been concluded that, in the opinion of the research sample, energy consumption of AM is influenced by material, year of entry in AM and types of AM activities. Fig. 3 shows that companies, using metal as a raw material that entered AM more than 10 years (consolidated), with the objective of the rapid manufacturing, claim that AM has less energy consumption compared with the formerly used conventional manufacturing.

The adoption and familiarity with the new technology is a key to achieve a high layer of efficiency. As with any other innovative technology, gaining experience is the way of earning total benefits from its features. Probably 'learning by doing' allowed firms that introduced AM recently, to improve the application of AM in their processes. Concerning energy consumption, the analysis of the case studies allows us to formulate the following hypothesis:

> *H2: Reaching an efficient energy consumption of AM in comparison with conventional manufacturing is influenced by material, year of introduction of AM and type of AM activity.*

4.1.3 Return on investment (ROI)

It has been concluded that, in the opinion of the research sample, ROI is influenced by material, and types of AM activities. As shown in tab. 2, companies using plastic as a raw material, with the objective of the rapid prototyping, claim that the ROI of AM is longer than with conventional manufacturing.

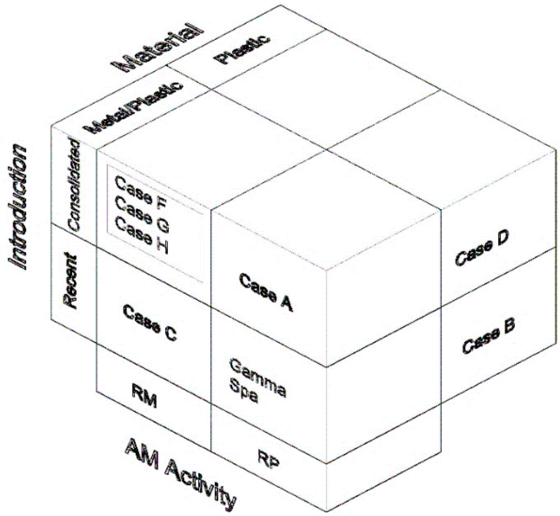

Figure 3: Dimension of energy consumption in sample firms.

Due to the higher value of the parts made in metal by AM, there is the possibility to sell them at a higher price, influencing revenues in a positive way. This allows a shorter return time on the investment of the AM, even if the number of parts is less than those produced by traditional manufacturing. Prototypes made out of plastic are sold with an inferior price than the price of the same pieces made out of metal and so the margins obtained are less, implying a longer ROI. Concerning ROI, the analysis of the case studies allows us to formulate the following hypothesis:

> *H3: Longer return on investment (ROI), while using AM, is influenced by material and type of AM activity.*

Table 2: Return on investment.

AM Activity	Plastic	Metal/Plastic
RP	Case D 'Longer' Case B 'Longer'	Case A '*Shorter*'
RM		Case G *'Shorter'* Case F '*Shorter'*

Table 3: Concepts emerged from interviews.

	Business strategy				Customer		Products			Process				Cost			
Cases	**Access to new market**	**Demand growth**	**Material Supplier**	**Competitiveness**	**Time to market**	**Disposability to pay**	**Aesthetic**	**Functionality**	**Customization**	**Production cycle**	**Flexibility**	**Material waste**	**Part size**	**Machine**	**Return on Investment**	**Material**	**Energy consumption**
Company A	Yes	Likely	Shortage	Depends	Reduced	More	Better	More	High	Simplified	High	Low	-	High	Shorter	High	Lower
Company B	-	Likely	Shortage	Early to say	-	More	Better	More	High	-	High	-	-	-	Longer	-	Higher
Company C	Yes	Likely	Shortage	Early to say	Reduced	More	Better	More	High	Simplified	High	Low	Medium	Same	-	High	Higher
Company D	-	-	Shortage	-	Reduced	More	-	-	-	Simplified	High	Low	Small-Medium	-	Longer	High	-
Company E	Yes	-	Shortage	-	Reduced	-	-	-	High	Simplified	High	Low	Small-Medium	High	-	High	Higher
Company F	Yes	Grown	Shortage	Goods for …	Reduced	More	Better	More	High	Simplified	High	Low	Small-Medium	Same	Shorter	High	Lower
Company G	Yes	Grown	-	Goods for …	Reduced	More	Better	More	High	Simplified	High	Low	-	-	Shorter	High	Lower
Company H	-	Grown	-	Goods for …	Reduced	-	Better	More	High	Simplified	High	Low	-	High	-	High	Lower

4.2 Strategic analysis

As mentioned before, after analyzing the data, some findings were reached agreed by all of the research samples. In the following paragraphs, the same effects of AM in all cases, in spite of differences in company and product features, are discussed. Findings analyzed respectively in terms of strength, weakness, opportunities and threats (SWOT analysis). The results are summarized in fig. 4.

4.2.1 Strength

The first evidence, supported by most of the research samples, is related to the notion of agility. When a company is developing its new products, one can rarely assume that the market will wait. Therefore, time-to-market reduction is a key requirement for business success that AM provided for the companies. Another aspect that should be considered as a strength is dealing with the better aesthetic and functionality of products. In production process perspective, AM leads to simpler production cycle, minimum material waste and more importantly full flexibility in design and process.

4.2.2 Weaknesses

In the AM production process, the materials require sophisticated atomizers to be usable; and this implies the higher prices of raw material. One of the firms claimed for example, 1 kg of metal powder (like titanium) could reach the price of 300-400 Euro.
Another interesting observation made by one of the sample's firms is the presence of hidden costs. One of these costs concerns the disposal of the filters used in AM machines, which work without oxygen. Another important aspect deals with the potential toxicity of materials, for example, the metal powder can represent a health hazard. The particles can provoke abrasions and eye irritations. In addition, AM can economically produce small and medium product size, so producing large parts is not economically justified until now.

4.2.3 Opportunities

The first empirical evidence, supported by all research samples, is the possibility of accessing new demanding markets where products or services have to be tailor-made for customers. The digitalization of manufacturing allowed the business functions of the firms to expand and become active in the market of consultancy, designing the part in collaboration with customer. The demand for customized products are increasing in this sector, consequently AM is becoming a production method essential for competitiveness. Thanks to the possibility of obtaining customized products there is a willingness of consumers to pay higher prices, therefore the income will increase.

4.2.4 Threats

AM technologies are still in their embryonic stage and so many attempts are needed to infer how to gain full use of them. The lack of technical standards, which allow reaching the maximum qualitative level of the machines, represents an obstacle for the competitiveness of the company. In addition, most of the machines are still patented and are, according to this, exclusive, which hinder the reduction of prices. In the raw material supplying perspective, the materials cost is significant because they have new shapes that require expensive operations to realize them, furthermore the shortage of suppliers leads to a high negotiating power for AM materials suppliers.

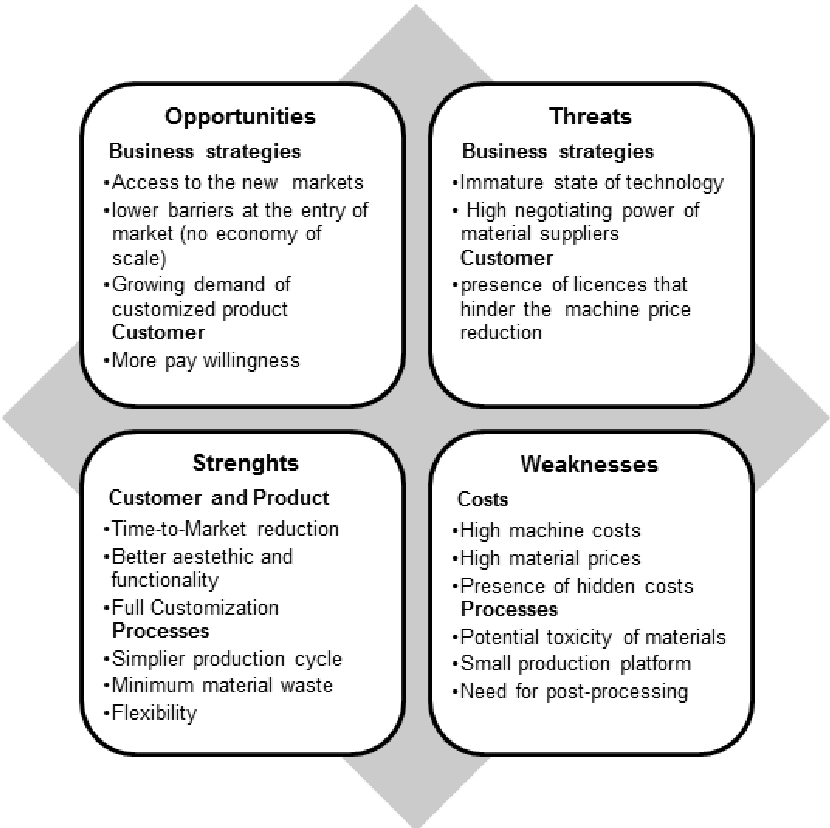

Figure 4: SWOT analysis.

5 CONCLUSION

The research has underlined some fundamental impacts of AM on firms' competitiveness and performances. Then, considering the potential differences of the firms in the one hand, and some discrepancies arisen from firms' opinions in the other hand, some explicit links are depicted. The data has been gathered from eight Italian firms that provided the opportunity to study in-depth AM in order to understand and identify the patterns that link variables.

We highlighted how the structure of this sector's market is in favor of the introduction of AM because it needs low production volume, high customization, more aesthetic and functionality of the product. The competitiveness of this kind of technology can be found in the fulfilment of all these requirements; it is cheaper than traditional techniques, bringing benefits not only to firms, but also to clients.

So we can affirm that AM has brought not only a process innovation (production mode in layers that increases flexibility, simplified production cycle, less material waste), but also product innovation that allows free form fabrication, which is impossible to fabricate with traditional techniques. Besides introducing new products, AM leads to new markets. Therefore, it is reasonable to expect a growing demand as some firms of the sample have found, and an increasing willingness of consumers to pay more due to the higher value offered. This higher value is influenced also by the improvement of service to customers in terms of time-to-market reduction and full customization. This higher value provides the possibility to apply higher prices, especially for parts made in metal; therefore, it influences revenue in a positive way.

In contrast, AM technologies have some disadvantages that should be considered. In terms of operational costs, some additional expenses such as depreciation of machines, maintenance and more significantly high prices for material and machines, need to be compressed. In the processing point of view, potential toxicity of materials, small production platform, need for post-processing are the most challenging ahead.

The findings emerged from this analysis allow to answer the research question. AM improves performances and competitiveness of the large companies that entered in AM more than 10 years ago (consolidated), with the objective of the rapid manufacturing. In addition, energy consumption of AM technologies is less than conventional manufacturing methods, mostly in companies using metal as a raw material that entered in AM more than 10 years ago (consolidated), with the objective of the rapid manufacturing. In terms of return on investment, only companies using plastic as a raw material with the objective of the rapid prototyping have longer ROI.

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HYBRID MANUFACTURING MACHINES: COMBINING ADDITIVE AND SUBTRACTIVE MANUFACTURING TECHNOLOGIES

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Abstract
Since its advent in the late eighties, additive manufacturing (AM) has become a well-established manufacturing technology. A number of distinct technological principles and processible materials are available today. Freedom of design is seen as a main advantage of AM, but production of finished parts, which fulfill specifications, is frequently difficult to achieve with AM alone. Over the last couple of months, major machine manufacturers have presented several hybrid machines and possibilities have also been developed to enable hybrid manufacturing with conventional CNC machines. All these solutions work using a powder based laser cladding system that is combined with a traditional CNC machine.
The combination of these different manufacturing technologies shows the potential to overcome some of the current shortcomings in AM processes, such as high surface roughness or limited dimensional accuracy. Nevertheless, for the successful integration of additive and subtractive processes into one machine, a number of challenges arise from the mechanical, thermal, process, software, and other areas. The aim of this paper is to analyze the existing solutions and main challenges.

Keywords:
Additive manufacturing, subtractive manufacturing, hybrid approaches, finished parts quality, build envelopes

1 INTRODUCTION

Every manufacturing company currently faces the challenge of producing increasingly complex products, in combination with most often decreasing lot sizes, in order to provide products with large variant diversity [1]. Furthermore, customers demand high flexibility regarding delivered quantity and delivery dates, as well as changes to product design.
Additive manufacturing (AM) can contribute to meeting these requirements by enabling the fabrication of individual products, even those with complex geometry, directly from three-dimensional CAD data [2]. This allows cost effective manufacturing of small lot sizes or single parts, a high level of resource efficiency due to lower material usage compared to subtractive

technologies and the design of load, stress and strain optimized or function integrated parts.

Despite of all these possibilities, AM technologies currently show some limitations, particularly regarding part quality. The dimensional accuracy that can be achieved using AM is low compared to conventional technologies, such as turning, milling and of course, EDM, grinding, sanding or polishing. Moreover the surface quality is also low, exhibiting high surface roughness and the so-called staircase effect caused by the layers, which build the part up. Tab. 1 gives some examples for achievable AM part quality.

Table 1: Achievable part qualities for AM processes for metal.

production technique	**dimensional accuracy**	**minimum depth of roughness R_z**
laser beam melting	≥ 0.05 mm [3]	20 µm [3]
electron beam melting	≥ 0.20 mm [4]	35 µm [4]
laser generating	≥ 0.25 mm [5]	25 µm [5]

Improved dimensional accuracy and surface quality can be identified as two of the main advancements specifically required for AM of finished parts [6]. Using current technology AM parts do not usually meet the requirements for functional surfaces or operating parts and thus necessitate the application of an additional subtractive process.

One possible solution is to apply the subtractive machining as a post-processing step after completing the AM process. This course of action includes a lot of manual work and is thus difficult to automate. Furthermore, the subtractive machining is more or less limited to the outer surfaces of the AM part as, depending on its geometry, inner surfaces may not be reachable.

Another approach is to integrate subtractive and additive manufacturing into one single machine. Thereby a hybrid manufacturing process is created, incorporating specific challenges, opportunities and constraints.

2 HYBRID MANUFACTURING PROCESSES

2.1 Classification of manufacturing processes

Manufacturing processes can be classified according to their intended effect, or their working principle. One possible classification system is described by

the German standard DIN 8580 [7] distinguishing six main groups, based on working principles, depending on their intended effect, as shown in fig. 1.
Contrary to this very detailed classification, differentiation between formative, subtractive, and additive manufacturing processes is also common. Applying this classification to the main groups according to DIN 8580 (2003) [7], primary shaping and material forming can generally be seen as formative, dividing as subtractive, and joining and coating as additive processes.

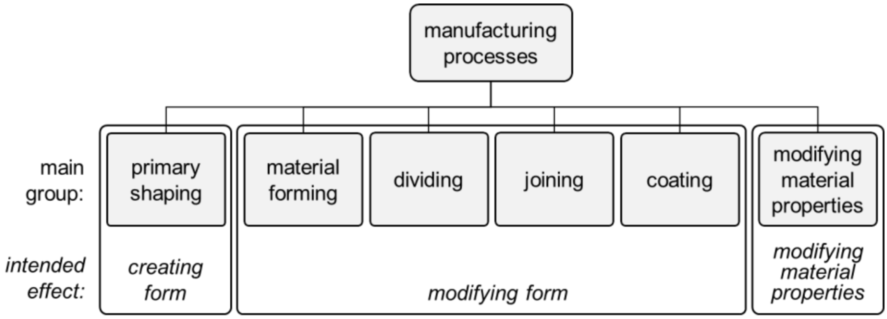

Figure 1: Classification of manufacturing processes, according to [7].

Admittedly this rough assignment does not work for all processes perfectly, as additive manufacturing technologies in particular would rather be classified as primary shaping according to the German classification.
While conventional manufacturing processes, such as milling, casting or welding, can be classified according to these main groups, the classification is not necessarily applicable to hybrid processes, which may combine processes from various groups.

2.2 Definition of hybrid manufacturing processes

Hybrid manufacturing systems aim to increase productivity and production effectiveness by combining different processes or technologies into one single process [8]. According to [9] this combination can be achieved by

- Combining process steps, which are usually separated, for example casting of multi material parts.
- Combining processes with different physical operating principles, for example laser assisted turning.
- Combining processes with different operations into one machine, for example combination of extrusion and bending in curved profile extrusion.

These combination principles make clear that a hybrid process can either combine two or more processes from the same main group or from different main groups. Laser assisted turning is one example for combining processes from one group, in this case cutting by use of laser and cutting tool. In contrast, curved profile extrusion combines extrusion as a primary shaping process with bending as a material forming process. Generally, in hybrid processes the combined manufacturing processes can either take place simultaneously or alternately.

What the hybrid manufacturing processes all have in common is that they aim to create an advantage by combining different processes, which means that the hybrid process should show increased positive effects compared to the serial application of the single process steps.

3 ADDITIVE AND SUBTRACTIVE HYBRID PROCESSES

3.1 Process description

The additive and subtractive hybrid process can be classified as a process combining different operations, in this case an additive and a subtractive one, into one machine.

The additive process applied here is laser generating (sometimes also called laser cladding or laser deposition), which can be briefly described as three-dimensional laser deposition welding. For laser generating, a processing head consists of the laser optics, a material feeder, and a supply of inert gas. The most common material used in this case is powder, but the use of wire is also possible. Fig. 2 depicts the schematic of a processing head for laser generating with powder.

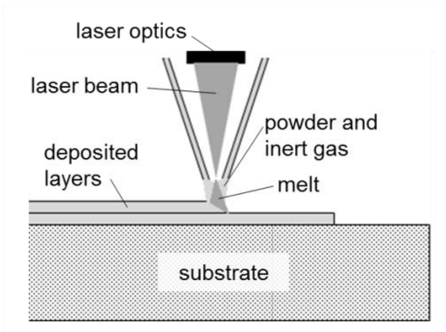

Figure 2: Processing head for laser generating with powder, according to [10].

The laser energy creates a local melt pool on the substrate surface into which the powder particles are being fed. When the laser moves on, the melt pool cools down and solidifies, leaving a solid welding path. The relative movement between processing head and substrate enables the formation of welding paths on the substrate surface [11].
Geometric elements are built up by generating basic elements such as layers and walls from these paths. In order to form layers, several paths are generated next to each other, whereas a wall consists of single paths deposited on top of each other, as illustrated in fig. 3. To enable the generation of complex structures, these basic elements are combined, and the part is built up by three-dimensional movement of the processing head, which is usually carried out on a 5-axis CNC (computerized numerical control) machining center. The high kinetic energy of the powder particles enables non-vertical deposition of material that is as effective as vertical deposition [11].

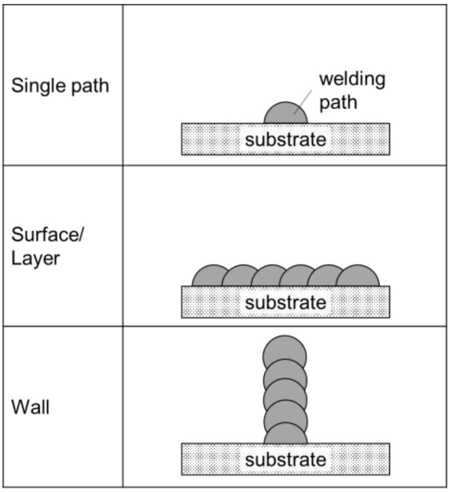

Figure 3: Basic elements in laser generating, according to [10].

Subtractive processes in this hybrid system are common hard machining processes such as milling, turning or drilling. The additive and subtractive processes are integrated into one CNC machine and take place alternately. First a certain part of the product is generated and in the next step this is machined to achieve the final shape and surface. Thereafter, the next part is generated and machined until the product is completed.
This approach enables manufacturing products with high geometrical accuracy and surface quality, which are common with traditional subtractive processes, without the material waste that is caused by machining parts

from a block of material. Furthermore it enables the three-dimensional generation of complex structures and, compared to a serial application of additive and subtractive processes, it allows the processing of surfaces that might not be accessible after the part production is completed.

3.2 Process requirements

In the additive and subtractive hybrid process, laser generating and machining are integrated into one machine. To enable complete three-dimensional processing, a 5-axis CNC machine is commonly used as the basis for this integration. Whilst machining, and often even laser based cutting processes, are standard equipment in such a machine, the integration of the three-dimensional laser generating tool is one of the most demanding steps in the development of an additive subtractive hybrid process.

To enable an automatic workflow, the laser generating head has to be adapted to the machine tool holder or magazine. This includes the mechanical adaption, as well as ensuring the transmission of all the necessary process data, which are not only the data for the laser beam control (tool path), but also data for the amount of inert gas and material supplied. All of the necessary data has to be integrated into the machine control, including communication between the different components.

As the process of laser generating requires the supply of filler material as well as that of inert gas, these also have to be integrated into the machine. It is, however, necessary to keep the weight sufficiently low to enable fast travel, precise positioning of the working head and also to ensure that no pipe or hose lines can interfere with the tool in its working area.

The geometry of the final machined product is limited by the form and position of the single welding paths, as is shown in figure 4.

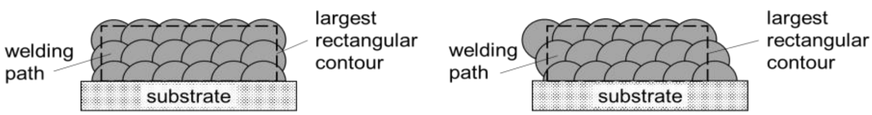

Figure 4: Influence of welding paths on product geometry.

Thus, correct calculation of the required material allowance of the laser generated product and the placement of the single welding paths must be based on extensive knowledge of the process parameters and their influence on the welding path. As the form and size of the welding path are influenced by a large number of process parameters, such as laser power or the beam power density, feeding speed or material mass flow, it is necessary to consider these parameters when defining the contour and volume of the generated part [5].

The cutting of the newly deposited material takes place alternately with the laser generating. This requires dry processing, as the use of cooling medium would contaminate the material and cause failures in the next generating step. In this case, it is important to consider the temperature of the tool as well as of the product and the heat conduction mechanism. These parameters are not only significant during the cutting processes, but also in the switch from generating to cutting, as the deposited material has to cool down to a defined solid state before subtractive processes can be applied. To ensure sufficient heat conduction from the melt pool, a substrate with high thermal conductivity is required. This substrate can either be a base part, on top of which the additional geometry is generated or a build platform.

The hybrid process is influenced by a large number of parameters. An overview of process parameters influencing the laser generating process is given in tab. 2.

Table 2: Parameters influencing laser generating, according to [12].

influencing parameters	**laser**	**beam properties:** power, power density, wavelength
		beam formation: beam diameter, power density distribution
	machine	**relative movement:** feed speed, path overlapping, interaction time
	filler material	**material properties:** thermo-physical properties, fractionation, absorption
		material supply: direction, nozzle diameter, angle and distance, mass flow, properties of transport and inert gas
	substrate material	**material properties:** melting temperature, thermal conductivity, absorption
		part properties: geometry, heat-dissipating mass, initial temperature

The large number of parameters demands a complex system of process control. A host computer has to process the machining center data, as well as all of the additional components, such as the laser source, laser optics and material and inert gas supply, and must deliver the necessary data for the operation of all these components [12].

Furthermore, the large number of parameters and the alternating application of cutting and laser generating processes bring a high risk of failures, which may also be caused by interaction between the two processes and do not exist in stand-alone additive or subtractive processes [5].

3.3 Current systems and applications

Recently the additive and subtractive hybrid process was commercialized by a number of machine manufacturers. Some examples are presented hereafter, without aiming to be comprehensive.

The LASRETEC 65 3D from DMG Mori was amongst the first additive and subtractive hybrid machines on the market and was presented at trade fairs in the US and Europe in 2014. The machine setup is based on a standard 5-axis milling machine and includes a system for laser deposition welding with powder filler material (laser generating), applying a 2 kW diode laser. It enables the generation of three-dimensional geometries without the need for support structures. Wall thicknesses of 0.1 mm to 5 mm can be achieved, depending on the nozzle geometry. According to the manufacturer, the generating process is up to ten times faster than that of powder bed fusion processes. [13]

With this system, products can be designed with special three-dimensional CAD (computer aided design) software, additional software modules support programming the CNC data for laser generating and milling. The laser processing head is not included in the standard tool changer magazine but is stored separately; from there it is clamped onto a special adapter of the tool spindle. [13]

With the INTEGREX i-400AM, the machine manufacturer Yamazaki Mazak Corporation offers another hybrid system based on a 5-axis machining center. Besides milling, this system also includes a turning spindle. Programming is done by standard NC code. [14]

The German company HAMUEL Maschinenbau GmbH & Co. KG offers a hybrid machine that is optimized for the application of additive and subtractive processes for the repair of turbine blades and turbo compressors. It combines laser generating, turning and milling in one machining center. In order to enable the correct material build up on existing base parts, it also employs a three-dimensional measurement with a stylus in the machine setup. [15]

Hermle Maschinenbau GmbH pursues a different approach; the company developed a hybrid machine that does not apply laser generating but a thermal spraying process, which was developed exclusively for this application. In this process metal powder is heated and accelerated to supersonic speed. The high kinetic energy causes high forces and high local temperatures when the powder particles impact on the surface, thus a bond between the powder and the substrate is formed. [16]

These examples show that with the latest development of hybrid systems companies that have, until now, been focused on conventional machines are entering the additive manufacturing technologies market. This is a major change in a market that has, so far, been dominated by startups coming, to a greater or lesser extent, from the technological research area.

A different approach is the AMBIT™ multi-task system by Hybrid Manufacturing Technologies. The system provides the opportunity to add a laser generating head, including powder and inert gas supply, to almost any CNC machine or robotic platform, thus enabling the integration of hybrid manufacturing into new machines as well as into existing ones. This system has a laser generating head that is adapted to the machine tool changer, and allows completely automated operating. [17] This concept was also presented with the first International Additive Manufacturing Award, by The Association for Manufacturing Technology (AMT) and the German Association Verein Deutscher Werkzeugmaschinenfabriken (VDW) in 2015 [18].

All of these hybrid systems were launched during the last few years and are not yet well established in manufacturing companies. Thus application examples are currently more or less limited to industrial case studies, presenting solely the possibilities offered by hybrid technology.

One application possibility for additive and subtractive hybrid technology is the repair of complex parts, e.g. blades that are subject to high wear. For this, the worn out contours of the blade are first milled to a defined shape, after which material is added by laser generating and then machined to reach the final shape [15].

Another example can be the fabrication of complete molds or mold inserts by use of hybrid manufacturing [19]. This enables the integration of conformal cooling, a benefit of additive technologies, while at the same time finished part surfaces can be produced by milling.

3.4 Advantages of additive and subtractive hybrid processes

The advantage of additive and subtractive hybrid processes are mainly based on the processes itself, their productivity, the product's material properties and dimensional and surface qualities. The main advantage of such combined processes is enabling the combination of additive technologies benefits, such as geometric freedom or building inner structures, with the high surface quality and dimensional accuracy of conventional subtractive processes [19]. While this can also be achieved by performing serial additive and subtractive processes, the hybrid manufacturing also enables the processing of inner surfaces during the part build-up.

Compared to powder bed fusion processes, laser generating is up to ten times faster, according to manufacturer's specifications [13]. This data probably includes time for post processing, as the deposition rates do not vary much. Typical deposition rates, according to [3], are up to 30 or 40 cm^3/h for Selective Laser Melting under high efficiency conditions, up to 80 cm^3/h for Electron Beam Melting, which is currently recognized as the powder bed process with the highest productivity, and about 0.5 kg/h for laser generating, which would equal about 60 cm^3/h for unalloyed steel with a density of 7.85 g/cm^3.

The shortcomings of the laser generating process, with regard to surface quality and dimensional accuracy, are compensated by the subtractive process. Furthermore the manual unpacking and post processing, which are necessary in powder bed fusion processes, are not required in the hybrid process.
Density and microstructure of laser generated parts are similar to those of powder bed fusion processes. They gain a high density with almost no porosity or micro cracks and a fine-grained microstructure [12], resulting in high tensile strength.
The three-dimensional, five axes movement of the laser generating head and the possibility for non-vertical deposition enable the generation of three-dimensional structures without the need for support structures. This also enables building up material on existing three-dimensional surfaces. With powder bed fusion processes, this is only possible for planar surfaces.
The material efficiency of the additive and subtractive hybrid process is higher than it is for conventional subtractive processes alone, as laser generating can operate near net shape and only minor material allowance is generated.

3.5 Disadvantages of additive and subtractive hybrid processes

The fine-grained microstructure, caused by melting and cooling during the generating process may result in material properties different to those that the same material may show after conventional primary shaping processes. Depending on the particular material, it can not only influence mechanical properties like strength or ductility, but could also make machining more difficult. The latter may result in the need for special optimized machine settings during the subtractive processes.
As dry processing is required to keep the substrate clean, cutting and feed speed are limited in order to minimize the influence of heat on tool wear, as well as on the material structure. If the use of a liquid cooling medium is inevitable, additional cleaning processes have to be applied between the subtractive and additive process steps.
Another disadvantage can be identified in the high acquisition cost of a hybrid machining center. Furthermore, compared to an exclusively subtractive machining, the essential operation time of the tools is much lower as the additive and subtractive process steps are not performed in parallel [8].
Despite general advantage of material efficiency, the degree of metal powder utilization is due to overspray not greater than 85% [12]. This over-sprayed material is more difficult to recycle than it is in powder bed fusion processes, as it can be spread over the entire working area of the machine and is contaminated by chips and possibly also cooling medium. Besides this, the properties of the metal powder make a closed build envelope and air extraction and filtering necessary.

4 CONCLUSION

The development of additive and subtractive hybrid processes enables a number of interesting new applications. The use of this technology, particularly in the repair of complex parts as well as the possibility of building large products increases the additive manufacturing application field
Nevertheless, the applicability of this technology is not yet sufficiently proven. On the one hand, a number of case studies show the potential for industrial applications. On the other hand, only few practical values exist. Currently single scientific studies regarding the technological and mechanical properties of the parts from hybrid processes are available, but a lot more research on this topic is required to get a full picture of its strengths and weaknesses.
Research should include the influence of different process parameters on the part properties as well as possibilities for process control during production. Besides gaining a more precise knowledge of the process itself, improving its efficiency will be an important field of research. Regarding efficiency, it might be interesting to increase the degree of raw material utilization especially when considering the difficulties entailed in the recycling of unused powder. Another way to enhance the hybrid process productivity and efficiency would be to enable parallel processing, as this would increase the essential operating time of each process.
A further development of the additive and subtractive hybrid technology can be the buildup of multi material parts by modifying the raw material composition. This is not possible using powder bed fusion processes and may increase the opportunities for generating load-optimized structures.
Besides the opportunities presented by the technology itself, the entrance of well-established conventional machine manufacturers into the additive manufacturing market has the potential to initiate change within the market. This includes not only the structure of the companies in the market sector but also the technologies, for example, the application of CNC programming to additive technologies.
Overall the additive and subtractive hybrid processes seem to be an interesting new technology that is not yet fully mature and will probably reveal their full potential in combining the best of the two worlds with the further development of this technology.

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LIFETIME BENEFITS OF A TOPOLOGY OPTIMIZED AEROSPACE PART APPLYING ADDITIVE MANUFACTURING

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Abstract
The aerospace sector is characterized by long product life cycles and a need for lightweight design. Additive manufacturing is a technology that produces parts layer by layer and thus enables the manufacturing of any complex parts at nearly no extra costs. A topology optimization enhances the part's performance for their special purpose. The results are often complex bionic structures that cannot be produced with conventional manufacturing technologies. The paper analyzes how the high potential of this technology can be applied to aerospace parts. A topology optimization will be conducted for an aircraft part explaining the crucial points and a life cycle analysis examines the achieved sustainable improvements for the aircraft's life cycle.

Keywords:
Additive manufacturing, topology optimization, aerospace, life cycle costs

1 INTRODUCTION

The aerospace industry is characterized by a long product life cycle and the need for a lightweight design. Aircrafts usually operate around 30 years with up to 60,000 flights while the time between the developments start and the decommissioning of the last aircraft sums up to 70 years [1]. Due to the high acquisition costs for aircrafts the utilization rate has to be maximized while minimizing the operation costs. Decreasing fuel consumption with a lightweight design of aircraft parts is one way to do so. [1] [2] [3]
Additive manufacturing offers the ability to flexibly produce even complex parts at nearly no extra costs due to the layer-based production method. Thus, the potential to design optimized and lightweight parts for aerospace to save costs during the product life cycle is high [4].
The reduction of the fuel consumption is a major development focus in aeronautics. The lighter an aircraft is, the lower is the fuel consumption and thus its carbon dioxide emmissions. Applying new technology and material developments can improve the performance.
One of these new technologies is additive manufacturing. In combination with a topology optimization this technology is promising to enhance different

parts and thus reducing the aircrafts weight. Therefore, it is mandatory to select the right parts as proposed by Lindemann et. Al. [5].
In this paper the goal is to show the potential of additive manufacturing in aerospace with a topology optimization of a sample part and to quantify the economic life time benefits that can be achieved by that.

2 FUNDAMENTALS

2.1 Topology optimization

One of the driving forces in aircraft design is the lightweight design of structure elements. The limit of using the less material fulfilling all requirements is pushed further with an increasing speed over the last years. Using material best in loaded areas and saving it where not needed often results in high complex structures, the more for complex loading and limited space conditions. Over the last years, especially with increasing computing power and algorithms, the analysis of burdened structures with the finite element method is used on more and more parts [6]. In addition to the pure analysis of structures, the topology optimization (TO) offers an automatic way to find the optimal material distribution in a limited space (design space). Depending on the loads and constraints influencing this space the stresses and strains on each element are calculated and low burdened elements get a lower density or ‘importance’ and will no longer be considered in the next iterations [7] [8]. The results are often very high complex structures hard to manufacture by conventional machining. In this case AM is the way to get the digital design into real parts.

2.2 Product life cycle

The idea of a lifecycle costing is based on the follow-up costs of an investment. The operation costs over the complete product lifecycle are often higher than the acquisition price and thus should be considered in order to get to a holistic economical overview. Costs for the operation, repair and overhaul as well as the disposal have to be taken into account [9].
This approach is not only product specific but also takes into account all periods of a product. [10] This enables a long-term strategic decision based on expected costs to be for a specific product and not on data from the past. Thus, the lifecycle costing can be applied to optimize the use of resources and supports the decision process of an investment considering long-term accruing expenses. [10] This is why one has to be aware that the calculation is based on predicted future cash flows and thus is subject to uncertainties.

2.3 Sample part

The lever is a conventional milling part made of stainless steel (316L) with a buy-to-fly ratio of 7.9. The final part weighs 750 g with a volume of 95 cm³. A major cost driver of the current manufacturing method is the need for switching the orientation of the part during milling.

This part has been chosen as it serves a similar function as the one analyzed in the project but is not subject to be published. It is assumed that the sample part is used for the luggage rack in an aircraft similar to the Boeing 737-800 with 30 seat rows [11]. Each seat row has one luggage rack so that two levers are required for every row. Thus, in total 60 levers have to be installed for every newly produceded aircraft. A further demand is generated by the spare part supply.

3 TOPOLOGY OPTIMIZATION FOR ADDITIVE MANUFACTURING

The result of a topology optimization is a weighted distribution of small, sharp tetrahedral elements. This result has to be interpreted on which 'density' or 'importance' of elements should be used in the latter part and is mostly not directly usable for manufacturing [5]. On the one hand the results are very complex including undercuts and hollows making it impossible to manufacture conventionally. On the other hand, depending on the mesh size, the resulting shapes do not fit mechanically exactly. Connection bridges could have disconnections and rough surfaces are typical. Therefore the topology optimization results have to be revised, adapted and corrected according to manufacturing process and obvious force fluxes.

The solver interprets the appearing stress and strain in each element and thereby sets the density or 'importance' for each element. In post processing the user defines a threshold value for the density to decide which elements shall be shown for export and which not. This procedure sometimes leads to difficulties as shown in fig. 1. All three examples show the necessity of additional interpretation and work for the designer. The color of the elements shows the density or importance of each element. High loaded elements with high stress and strain are shown red (dark) and the lower it is burdened the color changes over yellow and green to blue (pale). These are three of the most common failures and problems of topology optimization results.

First there is an area questionably loaded and filled with an undefined amount of material. This is a thrust plane stiffening the upper strut. The resulting shape is not clearly describable by either a thin plate or defined struts. In this case for conventional machining a plate with a thickness easy to manufacture but not perfect for lightweight design would be used. Additive manufacturing gives the possibility to use 'low dense structures' such as very small lattices or sponge-like structures.

The second one shows gaps in connection struts due to insufficient resolution. Depending on the mesh quality there are bigger and smaller elements inside one strut. The stress and strain inside these elements as well are not homogenous distributed. Thereby for a specific threshold some elements are not shown and by that not part of the result and of the latter part.

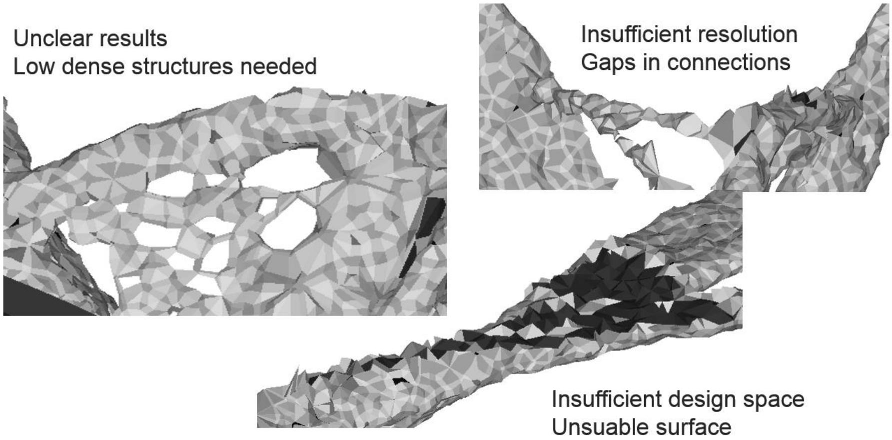

Figure 1: Examples for shape difficulties in topology optimization results.

The third main problem is an insufficient design space due to limitations resulting from adjacent parts or due to model manipulation by user. A strut under tension load is shown where typically the inner elements are very important and thereby red (black) and the outer ones are less important and thereby green (pale) or even blue. In this case black elements can be seen as there is need for more elements and the force flux of tension crosses an area without material. If this is due to the lack of space for this part one have to check if the assembly could be built in another way. In the shown case the design space was reduced after meshing to reduce the computing effort, based on earlier calculation results. Nevertheless such a wavy unusable surface may also appear with sufficient design space and, with a differing mechanical influence, for smaller and bigger mesh sizes.
Common topology optimization tools already have integrated rudimental algorithms for smoothing the surface and exporting of IGES or step files. These algorithms are not made for direct printing. Manual work has to be put in often.

3.1 Part analysis

The FE-model for analyzing the sample part is set up as shown in fig. 2 with rigid elements for bolt, dowelling and inside the bearing. The connection towards the other side is modeled with RBE3 elements distributing the forces on both arms. Each force for the two load cases – opening and closing – affecting the middle between both arms as shown in fig. 2.

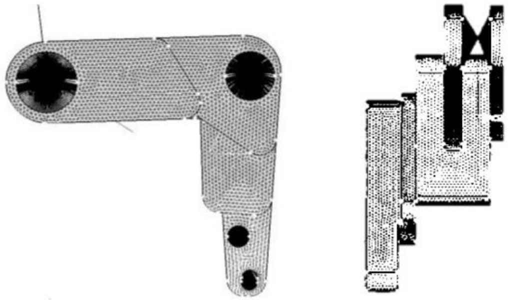

Figure 2: FE-model for analysis with force transmission.

The results show a maximum displacement of 0.106 mm and a maximum stress of about 162 MPa. While these high stresses mainly appear at sharp edges and in the middle of the lever, there are big areas with only low or no stresses. By a topology optimization the unused material should be moved in the high burdened areas as allowed by design space and thereby lead to a more homogenous stress distribution while less material is used.
In the next step the design space giving the material available for optimization is defined. Due to the attached parts the design space here is limited and only 350 g can be added so that the overall mass is 1098 grams. The optimization should reduce the material where it is not needed and reallocate it to get to a most homogenous stress distribution using least material. Beside the design space the non-design space is defined. This is the material that must not be reduced, like around the screws and interfaces where the force is brought in.

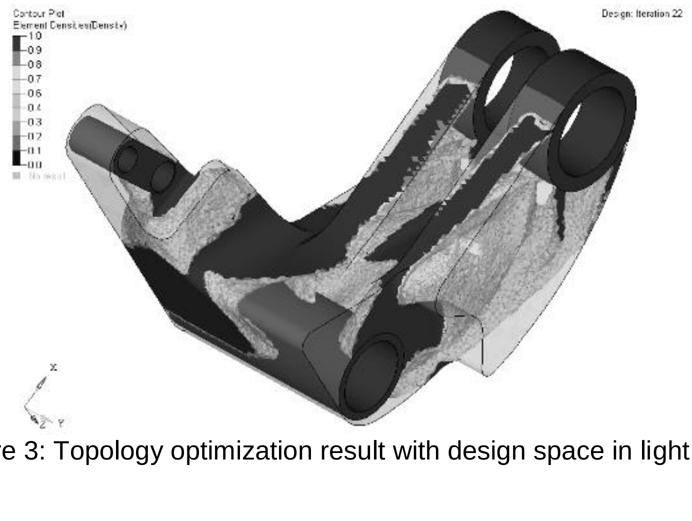

Figure 3: Topology optimization result with design space in light grey.

First a mass reduction optimization is made only with a displacement constraint at the force transmission point with a minimum of 0.1 mm. With the determined minimum mass a new optimization regarding high stiffness is conducted. In this case the overall stiffness of the part is optimized with a limited mass and the displacement constraint. The result is shown in fig. 3. Beside the result including the original geometry in transparent the result for a threshold of 0.5 is shown. Functionally relevant elements are shown red (black). The less important the lighter the elements are marked.

3.2 Methodology of ragaining TO-shapes for AM

As described above the results cannot be printed directly as the results still have to be revised and adapted. Especially if the part is still in design process and the exact shape of interfaces or transmission points have to get updated, it is mandatory that conventional CAD-tools can interact with the data of the optimized part. If transmission points or interface shapes depend on the attached parts or vice versa, an interoperability is needed.
Standard CAD-tools often are based on the kernels ACIS or Parasolid and originally are made for the use of B-REP and CSG features. Though they are already updated with some freeform tools for design of NURBS, they still have some problem with organic shapes [12]. One way out of these problems is to think about the underlying representation methodology. Especially due to the mandatory change from B-Rep / CSG / NURBS into a polygon model for a FE-analysis and for TO this is necessary anyway.

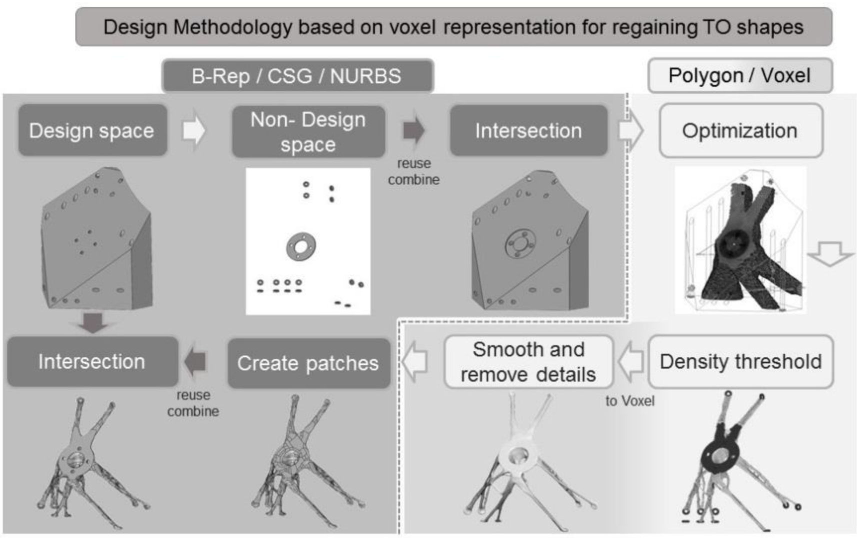

Figure 4: Design methodology based on voxel representation for regaining TO shapes.

A typical design procedure after TO now would be a retransformation to NURBS based on all elements by complex algorithms or by designer's interpretation. Both ways would not lead to perfect surfaces as automatic surfaces often keep bulkiness and as difficulties with unclear results appearing as explained in fig. 1. A designer though may equalize result issues but is not capable of redesigning all complex details.
A proper way to keep all desired details and remove unwished details or waviness is to stay one step longer in the alternative representation level as shown in fig. 4. The polygon model is transformed into a voxel representation. This enables an even more freeform design, as the voxels can be moved, removed and added completely free. Thereby it is as easy as in no other representation to smooth surfaces, add material where needed and design surfaces perfect for stress distribution [13]. Low notch factors are possible as one is not restricted to circular notch forms and may design notch forms as propagated by C. Mattheck [14].

3.3 Results of topology optimization of sample parts

The topology optimization of the sample part was carried out and the result plots are shown in fig. 5.
It can be seen that the maximum displacement still is the same with 0.106 mm. The resulting stress distribution shows two main improvements: on the one hand the stresses are distributed much better and only the non-design material shows very low stresses. On the other hand still two stress risings, one due to the force transmission at the small end, and one in the middle of the lever can be seen. Conditioned by insufficient design space in this high burdened area still a stress rising can be seen. The adjacent parts should be checked if a bigger design space is possible.

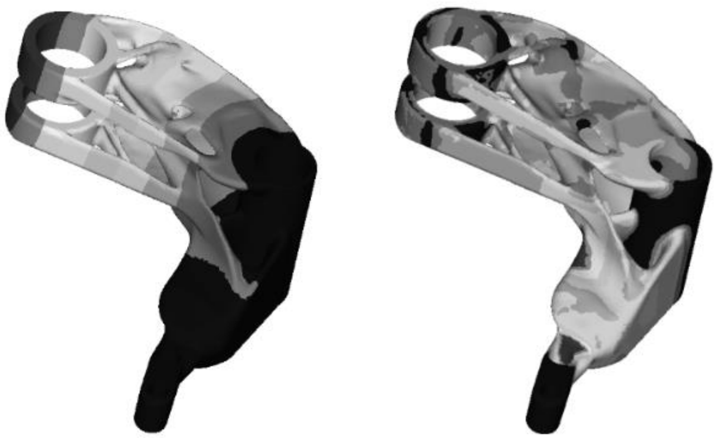

Figure 5: a) Displacement plot for conventional design with max. 0.1 mm.
b) Stress plot for conventional design with max. 100 MPa.

The overall results are shown in fig. 6. While the weight was reduced nearly by 50%, the maximum stress rises only a little bit but still stays way under the yield strength of about 550 ± 39 MPa [15] and the fatigue performance of additive manufactured 316L without surface treatment of about 200 MPa [16]. The maximum displacement stays at 0.01 mm as this was the constraint for optimization, as well.

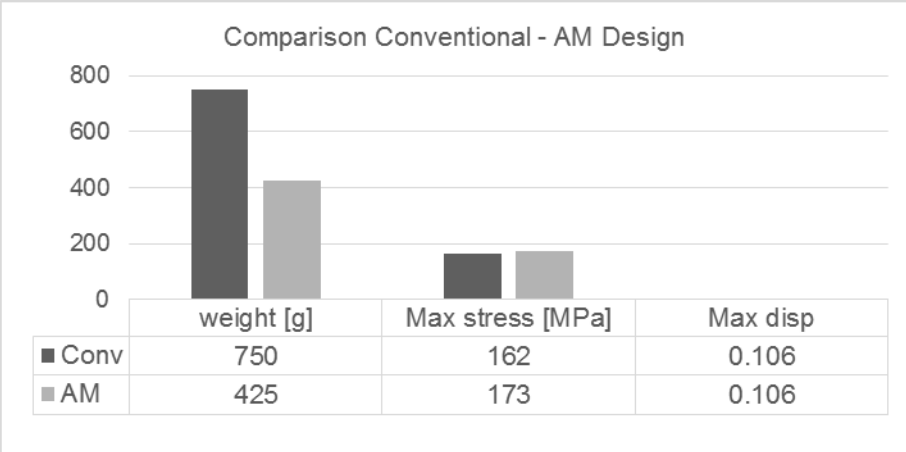

Figure 6: Comparison of conventional and AM-design.

4 COST AND LIFETIME BENEFITS

4.1 Life cycle model and calculation

There is a variety of different calculation models for a lifecycle cost analysis focusing on different aspects and applications. The model that is applied in this paper is an adaption of the DIN EN60030-3-3 to the specifics of AM and the aerospace industry.

The DIN 60300-3-3 (2005) can be applied for different use cases as it is an universal approach which splits the three phases development, operation and aftercare into six phases and assigns every one occurring expenses. It takes aspects of the cost structure, the product structure, different type of costs and cost elements into account and explains the procedure of the cost estimation as well as the presentation of the results [17] [18].

The calculation of the sample part is done for the conventional and for the additive design to show where benefits can be achieved. The major unit quantity is caused by the material required for the assembly of a new manufactured aircraft. This is why the following calculation covers for the batch size of levers for one aircraft, consequently an order of 60 parts applying the topology optimized design.

For both technologies the starting point is the concept and definition phase where the specifications are documented and a draft is composed. The next phase, design and development, consists of the design, the FEM analysis and the optimization as well as a prototype manufacturing and quality related efforts. While prototyping is considerably lower for AM, the optimization and design for AM leads to higher costs. Due to that, AM overall leads to higher expenses in this phase than milling.

The production is the third phase and a key aspect of the comparison. The lever is oriented in the build chamber in a 45° angle (‘v’-formation) to minimize the amount of support structures. The part’s bounding box has a length of 126 mm, a depth of 65 mm and a height of 79 mm. The latter value is an important cost driver for the calculation as the height significantly determines the build time. The build chamber of the machine selected at the DMRC is 280x280x350 mm^3 huge and applies a 400 W laser. Thus, the bounding box can be positioned six times within the build chamber without stacking parts on each to reduce support structure. The support structure volume for each part is expected to be 10% of the lever’s volume as well as another 10% of its weight for a loss of powder during the handling process. They are both waste but still resulting in a buy-to-fly ratio close to one. The material for AM is about ten times more expensive than the one for milling but with a stock removal share of 87% for milling the lever, AM is only less than 20% more expensive. The data preparation for each technology has to be done only once. The high acquisition costs for the AM machine is balanced by a much higher utilization rate of 83% [19] as the AM machine can operate over night and during the weekend independently. Another cost factor for AM is the post-processing of the manufactured parts. The considered sample part demands the milling of the interfaces and the functional surfaces. Overall, the costs for the production of the batch size 60 are three times more expensive for AM, partially driven by the aerospace requirements. The effort in installation phase does not much differ between the two technologies.

The usually longest phase of each product, usage and maintenance, defines the most cost-efficient technology. For aerospace, the weight is critical for the fuel consumption. The AM design of the lever weighs 43% less than the conventional design. The fuel consumption of one kilogram weight for one kilometer has been extracted from several data of airlines, authorities and literature. When taking the further influence factors (CO_2 certificates, maintenance etc.) into account the milling part is 1.75 times more expensive during operation phase than the AM part. The disposal costs for both technologies are similar and do not affect the result.

4.2 Calculation results

The calculated costs show that AM can generate a benefit throughout the whole product life cycle. The accomplishment of a 43% weight reduction for the AM design benefits from the aerospace characteristics. Having considerably higher production costs can be compensated by much lower operation costs (see fig. 7).

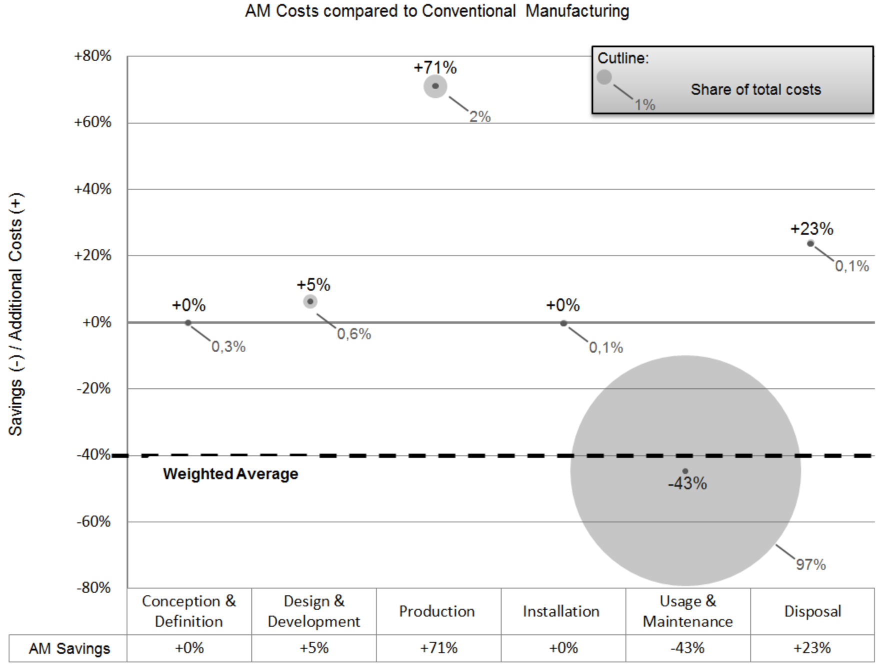

Figure 7: Comparison of life cycle costs for conventional and additive manufacturing.

As the operation phase represents from the overall costs 94% for AM and 98% for milling, it becomes obvious that this is the key phase defining the most cost-efficient technology for an application in aerospace. The considerably lower production costs of milling cannot balance the savings during the operation phase of the lightweight AM part design.

This is why the production batch does not influence the overall result. The calculation has been done for 60 levers, being able to provide one complete aircraft with the required parts. The actual order quantity per year is much higher, the savings during the operation time, too. All in all every lever is 40% more cost-efficient than the milled part. The exact figures have to be judged with caution as there are many influence factors that cannot be assessed accurately. Nevertheless they still indicate a distribution of the costs for the different phases and reveal the comparison between the two considered technologies.

5 CONCLUSION

The topology optimization offers great potential for weight savings while the part’s performance part can be improved. The proposed methodology for redesign gives the opportunity of regaining high complex topology optimization shapes in short time for use in further CAD-development. This enables a cost effective high complex design as the lead time for weight / performance optimization is reduced from days to hours.
The optimization and the concurrent calculation show that AM can generate considerable benefits throughout the life cycle with a focus on the operation phase. Especially the aerospace industry can benefit from this due to the long product life cycle and the high fuel consumption. The higher production costs can be balanced by the savings during the operation phase. This implies that the application of AM in this industry, but also in other branches, enables far-reaching benefits in terms of costs but also of environmental issues. There are already use cases where AM can compete in terms of production costs and with further technological developments, this is subject to further change. Therefore, it should be checked regularly for developments to identify possible cost-efficient applications.
Further research effort has to be put in the development of better optimization algorithms and the compatibility of different data models. For aeronautics a further analysis of the ecological impacts of AM could strengthen the position of the technology as this topic becomes more and more important.

ACKNOWLEDGMENTS

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SESSION D
Supply Chain Design and Management

LEAN MANUFACTURING APPLICATION AT POLARIS, C&R DIVISION ALI GROUP S.P.A.

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Abstract
ALI S.p.A., an Italian family company founded 50 years ago, is today the world leader in manufacturing food service equipment.
The company's policy from the beginning has been to acquire and support new companies, but leave them autonomous and responsible for the results. All the companies are devoted to develop an extremely specialized line of products in order to offer the perfect solution for every customer in every market. At the same time, they have to gain the result by themselves in order to be and remain successful in the market. The result of this policy is well explained by the following chart in fig. 1.

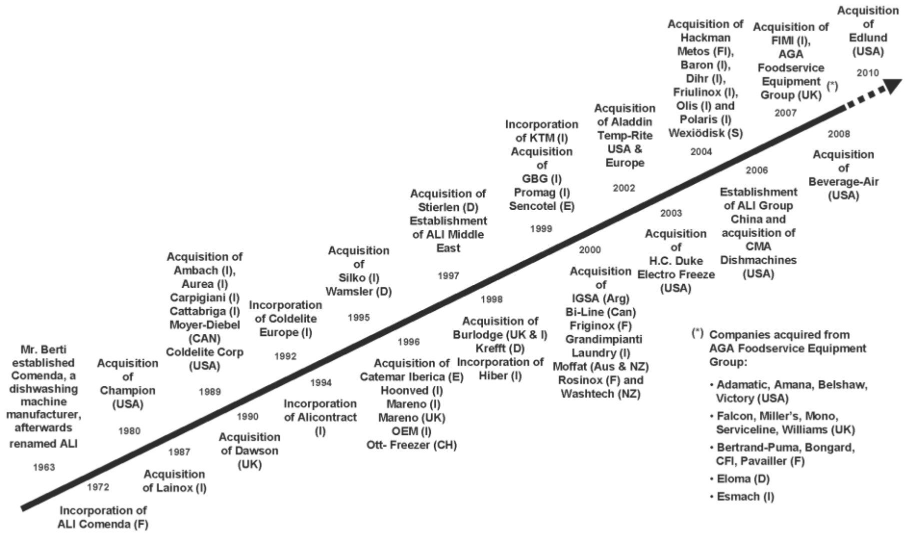

Figure 1: Growth of the company.

Keywords:
Change, commitment, flexible, reliable, profitable

1 INTRODUCTION

After one of the big acquisitions, made in year 2004, the needs to re-organize a group of Italian companies with a strong geographically and products proximity raised: a group of ten different companies / brands producing similar products, with no competitive volumes and some profitability issue.
It should be easy to imagine the level of overlapping in many of the synonymous functions in the different companies (e.g. R&D) were duplicated struggling with the same components and norms as well as the laboratories. The purchasing people were dealing with the same supplier's world, buying probably things very close in terms of performance, metal working plants were not able to have enough volumes to be really performing or cost effective.
The birth of the new business unit, called Cooking & Refrigeration Division, was founded on a specific target: all the manufacturing and industrial aspects needed to be addressed in order to find a new model able to maximize savings and performance, and increase the strength on the market and the profitability of the commercial brands.
The industrial asset of the different companies involved has been reviewed and all the factories have been specialized as much as possible (fig. 2).

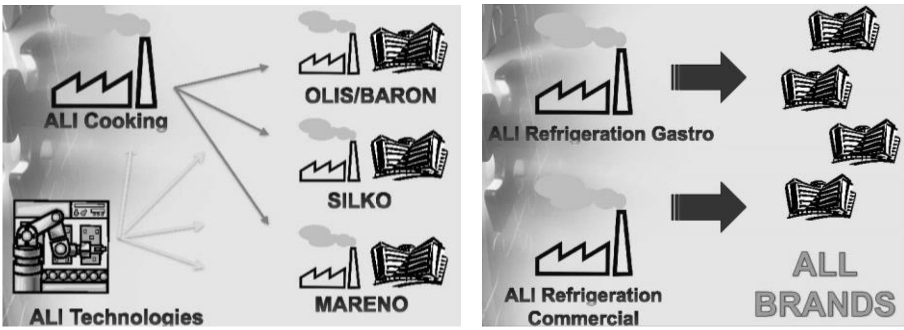

Figure 2: The new manufacturing concept.

The change has been dramatic:

- Unique project responsibility with very ambitious target
- All the staff process (HR, Finance, Administration) centralized
- Dedicated product line creation (R&D, Lab, Marketing, Purchasing, etc)
- Lean manufacturing principle chosen as a driver to manage a huge production concept change

- Internal task force within the operations team to consolidate a strong application of the methodology in each factory
- Factories specialized by product line
- Resize and/or relocate production process and factories

All the factories went through a real internal revolution in terms of global change of the old consolidated process. None of the factories is now working with the old system/process from the production layout to the planning system: everything has been redesigned and deployed. Commitment and strong decision making leadership have been required to the management in order to achieve the expected results, but, at the same time, the involvement of all the people and the positive response to change have been impressive.

2 LEAN MANUFACTURING APPLICATION AT THE PLANT

In this view the case described below is related to one of the lean manufacturing application in a refrigeration plant, which is characterized as follows:

- Founded in 1989
- Joint Ali group 2004
- Number of employees 90
- Export > 80 %
- Facility covered area 8.000 sqm
- Approx. 10.000 units per year
- Net sales 12 million €

The plant's main problems were:

- Long delivery time (4 to 6 weeks)
- Low delivery reliability (< 70 %)
- Lack of flexibility
- Low efficiency rate (< 75 %)
- High level of stock
- Lack of profitability (90 people vs 12 ml/€ T/O)

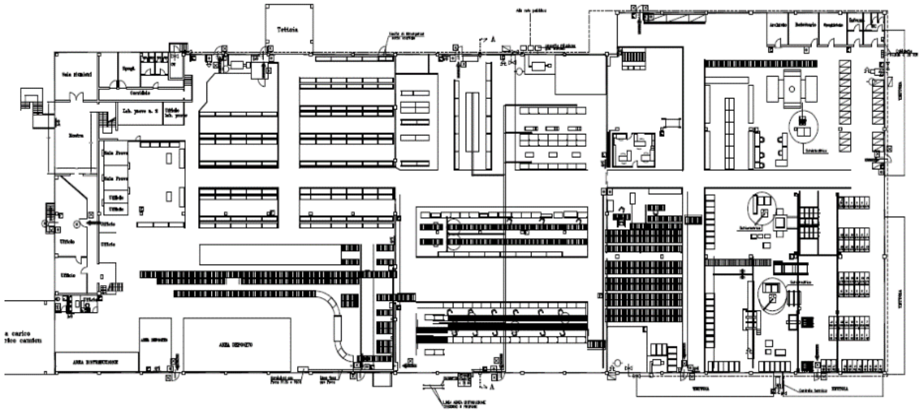

Figure 3: Original plant layout.

As shown in the drawing (fig. 3), the previous production frame was based on a shop floor organization with different production areas planned and managed separately. Each area had dedicated ‘PUSH’ production program with dedicated stock of parts and finished subassembly. The six main separate production areas were:

- Supplier / warehouse
- Compressors assembly line
- Stainless steel area
- Foaming preparation
- Foaming
- Cabinet assembly line + test area

The minimum lead time was six weeks and promised dates were not reliable. In that condition, it was not possible to synchronize properly the different area to fulfill the main production schedule, which resulted in missing parts, random internal and external quality issues and global low efficiency rate.

3 FIRST PROJECT PHASE

One of the project pillar for the team was to work at the same time both on the product and on the production process in order to get a real flow out of the actual inefficient situation. The product structure presented old concept and low flexibility. Having identified this structure as one of the main obstacles, the team decided to remove it. A thorough application of DFM has given the people the possibility to focus and change a lot of ‘old fashioned’ manufacturing solutions/issues with new ones, improving at the same time the working conditions in many area of the factory and the throughput time.

3.1 Example of DFM application

One of the most important DFM application has helped to reduce the heavy and labor-intensive activity of foaming preparation. In order to be foamed, the cabinet needs to be preassembled in its inner part, outside part and make a sandwich to be sealed. In the previous situation, the task was performed by three operators, one for the inner, the second for the outside and the third for helping his colleagues to create the sandwich assembling this parts and sealing. Raw material was spread around the working area with no assembly logic. The production engineer and the operators analyzed all the activities, developing a new workstation based on the concept that just one operator should be able to assemble all the parts.

Together with the R&D engineer, the parts were modified and the station was developed in order to give all the possible support to the operator making him able to work alone. After developing a prototype station, the group made observations and time measurements putting in place all the improvements needed and making a proper debug in a reasonable time. The final definition of the workstation was then deployed in a proper line with eight identical workstations connected to the foaming machine.

3.2 Pull concept in technological areas

The new product concept was developed focusing on the integration of all the process phases in order to obtain a ‘PULL’ production flow from start to finish.

This concept has involved also important technological part of the process like, for example, foaming. Instead of considering foaming as a complex, dirty and separate technological stage of the process, the idea was to integrate it into the actual physical process flow. Using the flow created with the workstation, the foaming machine was developed in order to be able to accept all the main different models, with reduced set up time thanks to semi-automatic change over. The machine was designed also in order to accept ‘back based’ products, so more complex from the point of view of tooling but faster because the product could get in and out from the foaming without any specific handling tools.

The new production organization shows a unique flow from the first operation (bending) to the final packaging in the assembly line (fig. 4).

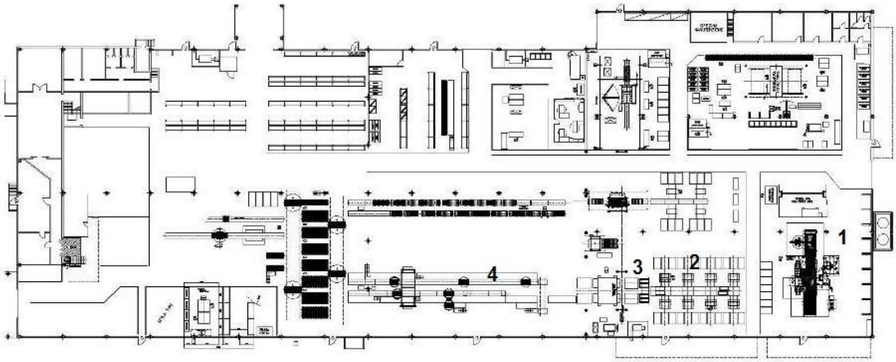

Figure 4: First project layout (1: assembly lines; 2: new assembly preparation cabinet; 3: new foaming machines; 4: new stainless steel department).

3.3 Better stock control

A proper stock of pre-cut material ready for bending was built up at the beginning of the flow. The needs for better stock control forced to move all the materials and components out of the production areas. The team defined the target to 'clean' the lines and the shop floor in order to see the production process clearly in all the steps.

3.4 Main subassembly flow

The focus was on the main subassembly flow. Control panel, compressor group and door. From the material and components required to the handling habits and container. Once defined the correct production flow was defined, those subassembly were the only major stock on the lines, moved to their specific position along the line according the production program in specific bins and container.

3.5 Consumables and high rotation

A specific kanban flow was designed to move this kind of material from the warehouse to the production areas, developing a dedicated withdrawal kanban. Once redesigned the subassembly areas, preparation and integrated foaming, the new flow started. After a first period of two months for the learning curve and the workforce training, some positive results started to became visible, namely:

- Reduction of materials in the process (stock reduction)
- Safe and ergonomic working areas
- Reduced lead time (increased capacity)

The improvements achieved were visible but at the same time the global efficiency, the capacity and the flexibility required were still not satisfactory. Further, some problems were still evident:

- Lack of synchronism among the subassembly areas (with missing part and generation of inter operational stock)
- Excess of WIP for cabinet long the line
- Heavy weight subassembly handled still manually
- Lack of flexibility (there was a need of 1 or 2 frozen weeks in the production plan)

4 SECOND PROJECT PHASE

The described situation was the result of a year work, the project saw the involvement of a lot of people but was mainly based on a top down approach. The team was in an impasse situation with no clear ideas on how to go on. The answer was: go back to methodology!
A new phase started using as main driver the application of the lean manufacturing tools described in the literature.

4.1 Map of product variation

The team went through a review of the product structure, identifying commonalities and main differences (fig. 5). The analysis of the product linked to data on volumes and repeatability (see next section) gave the view of how to organize two assembly lines dedicated to the high rotation product (called 700 line) and the low rotation product (called mix line).

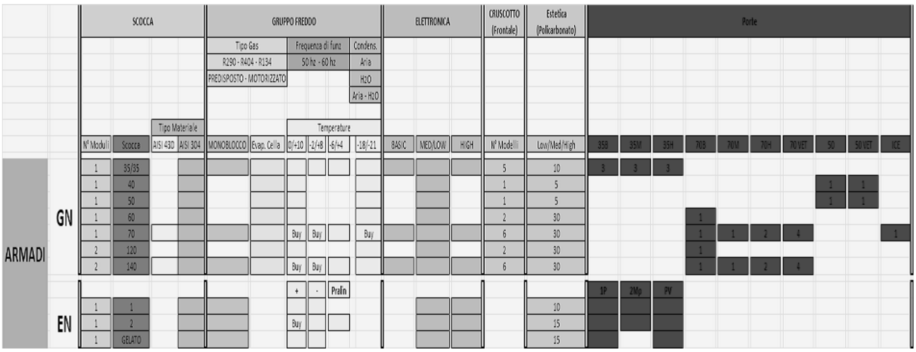

Figure 5: Map of product variations.

4.2 Volumes/frequency analysis

An analysis was done in order to identify which and in which proportion the products contribute to the total revenues (a linear behavior between ratio of volume and revenues is assumed).

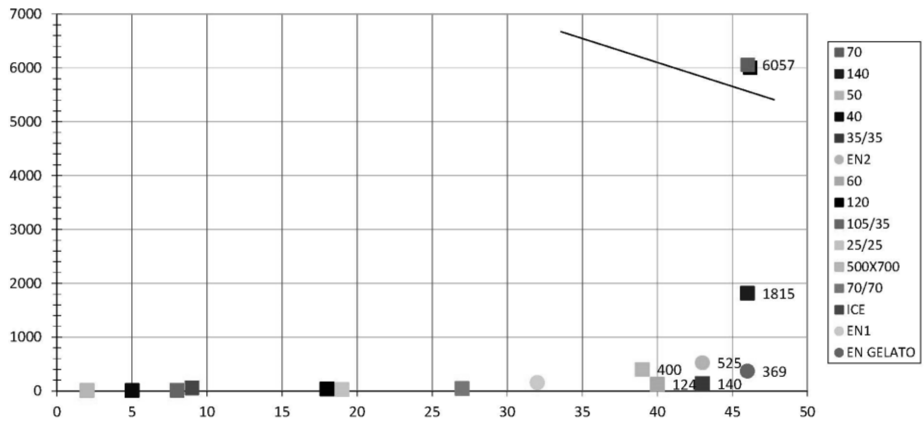

Figure 7: Volumes / frequency.

4.3 Value stream mapping

A proper value stream mapping was performed on the production process giving the real feeling of which operations added value and which not; this required to spend a lot of time in the Gemba.

The VSM displays the current value stream (see fig. 6), identifies the bottlenecks that cause delays, develops a vision of what the future lean system should look like. The focus should be on the viewpoint of the customer, not on the viewpoint of the department or process step. ‘Value stream’ consists of all the actions (both value adding and non–value adding) currently required to bring a product through the main flow.

The VSM generates main benefits, in particular:

- Helps to highlight the source of waste in the value stream, computing the total lead time and the flow index
- Shows the link between the information flow and the material flow

Figure 6: Value stream mapping.

But the real breakthrough activity was the Muda Free exercise. This exercise gave the idea that it is possible to have at a workstation only the needed material in the right quantity, in order to give the operator the possibility to focus on his activity and speed up the cycle time too.

4.4 Implementing a new feeding material system

Having realized the potential improvement in productivity by applying this simple rule, it was clear to the team that a new material handling organization had to be settled up. One of the key decisions regarded the kind of material handling system, which means the method of supplying materials to the lines and the operators. This decision affects all the other activities performed as well as the performance of the assembly line. The kitting system was the answer: the team decided to prepare in advance all the material needed to produce one cabinet a time and to remove all the other material from the assembly line.

The kitting system is based on few simple rules:

- Have a dedicated supermarket (separate or not from the central warehouse) with all the locations of material mapped in the system

- Have dedicated kitting trolley designed properly for the part to be transported
- Have a trained picker
- Trolley has to be complete. Incomplete trolleys cannot leave the supermarket (this rule makes the elimination of the missing part problem really possible)

Any material occurrence or missing part is a problem for the purchasing / procurement and warehouse people, and needs to be resolved there and in the right time, in this way the line operators will focus their attention on quality and productivity. The starting point to set up a kitting system is to design the supermarket correctly: It should be clearly mapped, easily refilled, and the picker's path to complete the trolley should not be too long. In kits, all items are presented in a logical order so they can be removed from the container as quickly as possible without damage. It is important to keep it simple and the kit itself is structured or laid out in a predetermined and effective way. The trolleys' shape and the supermarket were the result of team work performed by warehouse operators, assembly operators and the lean project team: no resistance was encountered at the start of the new system.
The kitting implementation brings many benefits in different aspects of the production process:

- Benefits to solve quality problems:
    - Safer use of components that are similar in appearance
    - Kitting ensures that the latest bill of material is used
    - Early identification of low quality components
- Benefits on flexibility:
    - The assembly areas could become more flexible and free from leftover components
    - Improved control over and better visibility of the flow of components on the shop floor
    - As a consequence, part availability will also improve product changeover that can be easily accomplished
    - Less work-in-process at the work stations, and consequently shorter lead times
- Benefits on learning:
    - Assembly workers know and recognize kits more easily and this results in easier training (lower learning curves) and reduction of training cost
    - It would be easy to notice if a component is missing, given that the kit package is properly designed

In summary, the decision about the material supply system and picking activities affected heavily the performance of the assembly line.

The learning curve period was very short: less then a month was enough to see all the benefits listed above and the result, after a couple of years, is shown in the graphs of fig. 8-10.

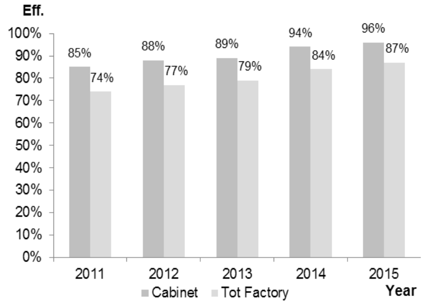

Figure 8: Labor efficiency.

Figure 9: Production volumes.

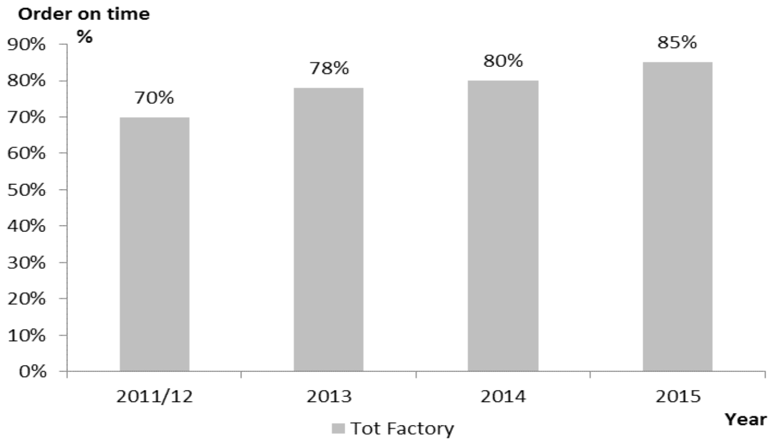

Figure 10: Delivery reliability.

The average lead time today is 7 to 9 working days, the efficiency is more than 90% and the delivery reliability is often more than 85%. The study here reported has the little ambition to describe the spirit and the vision that drive and inspire, even today, the CHANGE in our factories. Vision is as important as action to have the best control on the production system. A committed management should have a strong vision and clear idea of its future goals to establish the most effective production system. Lean manufacturing techniques are seen as a revolutionary change in the mindset. Lean manufacturing techniques help companies not only to control their production but also to combine the improvements in operational and commercial aspects and manage them to find the way that provides long-term business success and further improvement. All these principles inspire the change management process started two years ago and that today is still sparkling alive in the divisions' factories.

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SUSTAINABLE LOGISTIC NETWORKS FOR PROJECT BASED ENTERPRISES: AN OPTIMIZATION MODEL

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Abstract
The triple bottom line concept highlights that there are activities at the intersection of social, environmental, and economic performance that result in long-term economic benefits and competitive advantage for the firm. Logistics offer a great opportunity of recognizing such activities leading to sustainable supply network management. Optimization of sustainable supply networks for project based enterprises (PBEs) has not experienced great attention in literature. For construction companies, in particular, a different trade-off among the design, procurement, production, and installation requirements can arise for each project and should be properly managed. In this study, an optimization model is developed, which is linking design features, installation sequence-based constraints and learning-forgetting concepts in production to the supply network configuration. Constraint programming is adopted in order not to limit model objective and constraints to linear functions.

Keywords:
Sustainable supply chain, construction, project based enterprises, production planning, constraint programming

1 INTRODUCTION

The application of the sustainability concept is becoming a highly relevant issue for operations management and in general for supply chain management (SCM). No commonly accepted definitions of SCM are accepted [1] but traditionally it can be considered as the management of physical, logical and financial flows in networks of intra- and inter-organizational relationships jointly adding value and achieving customer satisfaction [2][3]. Nowadays this typical focus on economic and financial results has to be integrated into the concept of the triple bottom line (TBL), introduced by Elkington [4], which points out that there are, at the intersection of social, environmental and economic performances, activities to be pursued by organizations, that positively affect the first two items and also turn into long-term competitive advantage and economic benefits for the firm, as also underlined in [5]. TBL definitely offers the chance to introduce

the topic of sustainability in the context of SCM, which brings to the development of sustainable supply chain management (SSCM). The latter is so defined by Ahi and Searcy [6] in their comprehensive review that the creation of coordinated supply chains through the voluntary integration of economic, environmental and social considerations with key inter-organizational business systems is designed to efficiently and effectively manage the material, information and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over short- and long-term.
Coordination, reactivity and flexibility between the several SSC phases are fundamental when considering project based enterprises, in which the core business is represented by the development of projects where innovation and planning have to cohabit in order to reach high innovation and sustainability levels without neglecting the control on the efficiency dimension. When taking into account SSC for PBEs in the construction field, e.g. facade and curtain wall markets, a scarce literature has been worked out, while a specific research should be addressed because of the difficulties of the scenario which has to be faced by these kind of firms.
In this paper a model for the optimization of the tactical level involving all of the three aspects of the triple bottom line is presented. Thus, in section 2 complexity of SSC in construction PBEs is described in a detailed way through a comparative analysis of the main differences from the traditional manufacturing market. The optimization model is then fully described in section 3. Finally, ongoing research conclusions are summarized in section 4.

2 SSCM IN CONSTRUCTION INDUSTRY

A construction project can be defined as a set of activities which aim is to handover a new building to the client within a set period of time and through limited financial and human resources. Respect of time and capacity has to be reflected into the contractual program of the project. In order to avoid extra-costs, disruptions or client charges for delays in work completion, project milestones on critical paths have to be strictly followed by all of the SSC actors which basically are: design department, purchasing department, production department; installation site. It comes clear that the activities involving every department lead to manage significant trade-offs since each construction project, due to its peculiarities, has plenty of custom elements to be designed and purchased with low repetitiveness rates and engineered to order components to be produced. Stated that all of the process has to be pulled out by the contractual due dates, and that a batch of elements of the same type causes no setup costs or slowdowns, it becomes relevant to optimize the production on the assembly line without compromising site activities. In fact, for example in a curtain wall building production, the same element can be installed into different floors or elevations, which have different installation priorities. Moreover most construction sites do not have huge space to stock large elements, so the company cannot deliver much more items than the ones specified in the delivery schedule, unless stockpiled into the production plant or into an external warehouse, thus is generating inventory costs. On the other side, if the produced components do not meet site installation demand on a given day, then delays in the contractual handover of parts of the project may be caused with the risk of incurring in penalty costs.

Make-to-stock manufacturing can benefit from the research literature on production planning and organization by applying the largely developed concept of EOQ and the principles of lean throughout the entire supply chain. As far as construction market is concerned, production scheduling has been investigated in the field of the precast industry, which, by the way, has large similarities to the manufacturing production assembly [7]. In fact precast elements, such as columns, beams and slabs, are necessary to the concrete building and structural elements which are obtained by molds usage at a centralized plant and then transported to the building site for the assembly phase. As described in [8], the production of precast elements requires multiple processes: mold preparing, concrete mixing and casting, curing, stripping and product finishing and storing, which must be done in the same mold. Given a due date, a number of jobs, a number of molds and a set of mixing formulas, the authors try to determine the job assignment to the molds, the formula assignment to the jobs, and the mold sequence to minimize the product cost while satisfying the due date through MIP. Leu and Hwang [9] present a genetic algorithm-based searching technique to maximize precast plant production under the constraint of limited resources.

Precast fabrication planning models, anyway, cannot be used for PBEs because no such variety of materials, components and typologies inside one single project has to be managed and highly restricted batch production is possible. Since a lack of literature on the topic of construction PBEs is recognized, the model presented in this paper wants to integrate the complex features characterizing the building construction industry by taking into account the different stakeholders' interests.

A construction PBE, as a common manufacturing firm, has to improve the economic result by maximizing the production of items, but the main difference is that each element has a unique location on the building to be handover to the client within specific delivery dates set into the contractual program. For this reason, the number of transports in a project for a construction PBE is strictly linked to the production sequence and it has to be taken into account not only during the scheduling, but also during the planning phase, since every unit has to come on site by mirroring the installation program or with a minimum acceptable slack time: Unless the project budget allows the usage of an external warehouse or the company is equipped with a large storage area, the stocking space on site is limited.

Therefore installation scheduling has to be observed and logistically organized on a few days basis. Hence, to green the PBE supply chain from the environmental point of view without compromising site activities, it has to be considered that production optimization has direct implication on the fulfillment of containers or trucks.
The social theme of the TBL can be introduced into the production planning through the learn-forget curve model. Workers, in fact, improve their performances according to the production sequence, which mixes up the various typologies of elements by taking into account the due dates stated on the project program. Hence production phase in construction PBEs can be defined as discontinuous, subjected to not only learning but also to forgetting phenomenon. By inserting the learning-forgetting curve into the production planning model more realistic cycle times can be calculated and managed, thus reducing the work stress of the personnel. Moreover the planning on the horizon shows the real production capacity of the assembly line, by making more reliable forecasts during the project planning definition.
In the next session it is described how all the above issues have been incorporated into the proposed production planning model for PBEs.

3 OPTIMISING PRODUCTION PLANNING FOR PBEs

The PBE production planning problem has been modeled and solved by constraint programming (CP) [10]. The main advantage for adopting CP relies on the unlimited type of relations between variables that a modeler can adopt to describe the desired properties of the solutions and the objective to be pursued. Moreover, as compared with techniques such as genetic algorithms, simulated annealing and taboo search, constraint-based systems are usually easier to modify and maintain due to the separation of the modeling phase from the solving one, which allows to easily add or remove constraints while preserving the main structure of the model. This flexibility can be particularly useful in the case of PBE's, where each project can present peculiarities to be inserted into the general production planning model.
We coded and solved the model using the comet package, which provides an object-oriented language with a number of innovative modeling and control abstractions, while embedding the best algorithms and the best search strategies developed by the CP research community [11].
The best sustainable solution is identified by assigning a cost to feasible solutions, in line with the findings that cost minimization dominates quantitative models for SSCM [12]. Three main components have been introduced in order to foster sustainable solutions:

1. The cost of poor utilization of the assembly line
2. The cost associated with holding inventories when anticipation of production is allowed with respect to actual delivery to the construction site
3. The cost of poor utilization of the containers' space

The cost of poor utilization of the assembly line is calculated taking into account the learning-forgetting phenomenon typical of the limited productions in PBEs. This allows to embrace the social dimension of sustainability by achieving better working conditions, since less pressure on workers can arise when the assembly plan is generated at feasible cycle times instead of standard ones. The learning-forgetting model adopted in our optimization is described in the following section 3.1.
The second cost is introduced to manage the trade-off between fully exploiting the assembly line capacity and meeting due dates by make-to-stock quantities and holding related inventories.
Finally, the third component is introduced to take into account the environmental dimension of sustainability by fostering full truck loading, so that less travels are required to the construction plant, with related reduction of GHG emissions from fossil fuel combustion.
The objective function as well as all constraints needed to introduce PBEs' peculiarities into the production planning process are reported in section 3.2.

3.1 The learning-forgetting phenomenon
The learning-forgetting curve concept has here been applied to production planning of custom and engineer to order units, departing from the study by Jaber and Bonney [13], who introduced a model suitable for make to stock manufacturing plants. The authors use Wright's [14] power learning curve in the form:

$$T_j = T_1 j^{-l} \tag{1}$$

where T_j is the time to produce the *j*th unit, j is the production period, T_1 is the theoretical time required to produce the first unit, and l is the learning slope.
The used forgetting curve is the one of Carlson and Rowe [15]:

$$\hat{T}_x = \hat{T}_1 x^f \tag{2}$$

where $\hat{T}_x$ is the time for the *x*th unit of lost experience of the forgetting curve, x is the amount of output that would have been accumulated if interruption did not occur, $\hat{T}_1$ is the equivalent time for the first unit of the forgetting curve and f is the forgetting slope.
The increase in time to produce the first unit in the next production run depends on the length of the interruption and the time to produce the *q*th unit which is when the interruption occurred and can be calculated as:

$$\hat{T}_{q+1} = (\alpha + 1)^{-l} \tag{3}$$

where q represents the quantity of units produced in each cycle, α is the amount of equivalent units of experience at the beginning of a production run after an interruption period of length t_b ($0 \le \alpha \le q$). The equation for α is:

$$\alpha = q^{\frac{l+f}{l}} (q+s)^{-\frac{f}{l}} \tag{4}$$

with s being the number of units that would have been produced in time $t_b \le t_B$ (t_B is the time for total forgetting to occur), assuming that there have been no interruption in production, calculated as in eq. (5).

$$(q+s) = \left[\frac{1-l}{T_1} t_b + q^{1-l} \right]^{\frac{1}{1-l}} \tag{5}$$

The forgetting slope f can be calculated as follows:

$$f = \frac{l(1-l)\log q}{\log(1+C)} \tag{6}$$

where C, the ratio of total forgetting time t_B and the time to produce a total of q units under learning, is given in eq. (7).

$$C = \frac{t_B}{t_P} = \frac{t_B}{\int_0^q T_1 y^{-l} dy} = \frac{t_B}{\frac{T_1}{1-l} q^{1-l}} \tag{7}$$

The above described Jaber and Bonney's model can recursively be adopted for every ith cycle by the following eqs (8), where T is the cumulative time to produce M_i units after a production break and T_{1i} is the time for the first unit:

$$T_i = \frac{T_{1i}}{1-l} M^{1-l} \tag{8a}$$

$$T_{1i} = T_1 (1 + \alpha_i)^{-l} \tag{8b}$$

The model presented in this paper integrates the previous learning-forgetting curve results, thanks to a preprocessor, which calculates for each potential sequence of learning phases and breaks during the planning horizon the values of α_i and T_{1i} for each possible q quantities. These values are then passed as input table data to the main model, which selects the proper parameters on the basis of the current value of production variables. For a planning horizon involving n periods, the possible sequences are $2^{(n+1)}$, reflecting absence/presence of production in each period and the chance the part has never been assembled in the previous planning horizons.

Corresponding parameters to identify periods of consecutive productions as well as breaks are used by the main model to properly associate learning-forgetting values.

3.2 The CP model

Each assembled element of a construction project is assigned with a unique code number, which is associated with a due date resembling the expected sequence requirements at the construction site.
The decision variables of the model are therefore the period within the planning horizon *H* during which the element *i* should be produced (the variable is set to 0 if element *i* is not conveniently produced in *H*) and the period in which it should be shipped.
Auxiliary variables are introduced to easily manage the objective function and constraints. Both decision and auxiliary variables are in Italic style in model equations and are reported in tab. 1. Parameters, instead, are in regular Times New Roman style; the related input list is reported in tab. 2.

Table 1: Model variables. N is the set of elements of the project, H the set of planning periods, *H** the number of periods in the planning horizon, *M* the set of different part types to be assembled, *P* the set of different types of unit loads, *S* the set of different setup classes.

Variable	*Range*	*Description*
$period[i]$	$i \in N$	Production period of element *i*
$shipment[i]$	$i \in N$	Shipment period of element *i*
$prod[i, j]$	$i \in N, j \in H$	1 if *i* is produced in *j*, 0 otherwise
$delivery[i, j]$	$i \in N, j \in H$	1 if *i* is produced in *j*, 0 otherwise
$prod\_part[k, j]$	$k \in M, j \in H$	Quantities of part type *k* produced in period *j*
$t[k]$	$k \in M$	Total assembly time for part type *k* in *H*
$setup[s, j]$	$s \in S, j \in H$	1 if parts of setup class *h* are assembled in *j*, 0 otherwise
$prod\_seq[k, l]$	$k \in M$, $l \in [0..\mathrm{H}^*]$	1 if part type *k* is assembled in *l*, 0 otherwise; *l*=0 stands for previous horizons
$lf[k]$	$k \in M$,	Learning-forgetting sequence in horizon
$ltl[h, j]$	$h \in P, j \in H$	Total truck space lost by unit load class *h*
$unprod[j]$	$j \in H$	Total idle time of the assembly line in period *j*
$unload[j]$	$j \in H$	Total empty space in trucks in period *j*
$inventory$	-	Total inventory for parts assembled in *H*

The objective function is shown in eq. (9), where the binary parameter *bin* should be set to 1 by the user if anticipation of production is allowed, 0 otherwise. The model can so support both pure assembly-to-order production with direct shipping to the construction site and the assembly-to-stock one, on the basis of the production strategy and available storage space of the PBE, and can collect related performances for analysis.

$$\sum_{j \in H} \left(unprod[j] \cdot c_{up} + unload[j] \cdot c_{ltl} \right) + bin \cdot inventory \cdot c_{stock} \tag{9}$$

The main constraints of the model are shown in eqs. (10–26). For sake of simplicity, constraints linking the decision variables to the related Boolean auxiliary variables are omitted.

The first group of constraints (see eqs. 10-19) sets due dates satisfaction and production-shipment relations. In particular, every element should be assembled matching its due date (eq. 10) and shipped after its assembly (eq. 11). Every element can be assembled in one period only (eq. 12) and must be produced if its due date is within the planning horizon. Similarly, eqs. (14-15) set the analogous relations for shipping. If inventory is not allowed, then the assembly of each element can be anticipated with respect the due date only of the maximum slack granted by the construction site (eq. 16) and shipped immediately (eq. 17). Otherwise, inventory allows to anticipate production taking into account the maximum duration of stay eventually set by the firm (eq. 18) and shipped to the construction site accordingly (eq. 19).

$$period[i] \leq \mathrm{duedate}\,[i] \quad \forall i \in N \tag{10}$$

$$shipment[i] \geq period\,[i] \quad \forall i \in N \tag{11}$$

$$\sum_{j \in H} prod[i,j] \leq 1 \quad \forall i \in N \tag{12}$$

$$\mathrm{duedate}\,[i] \in H \Rightarrow \sum_{j \in H} prod[i,j] = 1 \quad \forall i \in N \tag{13}$$

$$\sum_{j \in H} delivery[i,j] \leq 1 \quad \forall i \in N \tag{14}$$

$$\mathrm{duedate}\,[i] \in H \Rightarrow \sum_{j \in H} delivery[i,j] = 1 \quad \forall i \in N \tag{15}$$

$$prod[i,j] = 1 \wedge bin = 0 \Rightarrow period\,[i] \geq \mathrm{duedate}[i] - \mathrm{slackP} \quad \forall i \in N, j \in H \tag{16}$$

$$prod[i,j] = 1 \wedge bin = 0 \Rightarrow shipment[i] = period\,[i] \quad \forall i \in N, j \in H \tag{17}$$

$$prod[i,j] = 1 \wedge bin = 1 \Rightarrow period\,[i] \geq \mathrm{duedate}[i] - \mathrm{stockP} \quad \forall i \in N, j \in H \tag{18}$$

$$prod[i, j] == 1 \wedge bin = 1 \Rightarrow \text{duedate}[i] - \text{slackP} \le shipment[i] \le \text{duedate}[i] \quad \forall i \in N \tag{19}$$

The second group of constraints (eqs. 20-26) aims at calculating the total assembly time within the planning horizon, introducing lost times for setups and learning-forgetting phenomena. In particular, each part type is assigned to a defined class of setup: For exteriors and curtain walls PBEs it commonly reflects the different conveyor width needed to transfer a part along the assembly line and the time needed to adjust it, which is quite constant for every change. Thus the different type of setups incurred within the planning horizon can be estimated by eq. (20).

$$prod[i, j] = 1 \Rightarrow setup[\text{su}[\text{part}[i]], j] = 1 \quad \forall i \in N, j \in H \tag{20}$$

As concerns learning-forgetting phenomena, to exploit benefits of combinatorial optimization, each current solution in terms of quantities per part type (see eq. 21) is associated with the corresponding sequence of production periods and breaks by eqs. (22). This in turn is used to assign the proper combination of learning and forgetting time intervals. On the basis of such production periods and breaks and the current production quantities, proper preprocessed parameters for equations in section 3.1 can be retrieved. The assignment of proper cycle times for learning-forgetting phenomena with variable quantities and periods rely on the *table* constraint offered by Comet.

It is a kind of constraint given in extension, which bounds three variables to take values according to one of the enumerated triples contained in the table object given as its parameter. Learning and forgetting data have been organized as such tables (see tab. 2), so that they can be easily assigned to auxiliary variables. In eq. (23) is reported an example of such constraints used to assign the time interval for the first break *tf* (*tf* replaces *tb* in eq 5), in the case of 1 break only in the production sequence, which arises from an interruption with respect to the last production in the past, while production is considered as continuous in the current planning horizon. This variable in turn is used, together with the equivalent past production q_P and the time for the first unit T_1 (see table 2), to assign the time to produce the first unit T_{1P} in the current horizon (see eq. 24), which is then introduced into eq (25) to assess the proper cumulative time for each part type k within the planning horizon, when learning-forgetting phenomena are considered.

Table 2: Model input data. C is the set of possible combinations of leaning-forgetting periods in *H*, *N* is the total number of elements of the project, *H** the number of periods in the planning horizon, *M* the number of different part types to be assembled, *P* the number of different type of unit loads, *S* the number of different setup classes, *U* the number of unit load classes.

Input	*Range*	*Description*
lf_sequence[c, l]	$c \in C$, $l \in$ H*	Possible learning-forgetting sequences
part[i]	$i \in N$	Part type associated with element *i*
su[k]	$k \in M$	Setup class associated with part type *k*
start		Start period of the planning horizon
slackP		Allowed anticipation of delivery to site
stockP		Allowed duration of stay for inventory
duedate[i]	$i \in N$	Due date of element *i*
qP[k]	$k \in M$	Equivalent past production for part type *k*
L		Learning slope
su_{last}		Setup class of the last assembly
$T_1[k]$	$k \in M$	Cycle time for the first unit of part type *k*
height[k]	$k \in M$	Height of part type *k* if horizontally laid
ul[k]	$k \in M$	Unit load class of part type *k*
htruck		Available height in trucks
hpal[h]	$h \in U$	Pallet height for unit load class *h*
c_{up}		Cost for production loss [€/min]
c_{ltl}		Cost for less than truck loading [€/m]
c_{stock}		Unit cost of inventory [€/unit/min]
capacity		Assembly line capacity per period [min]

$$prod\_part[k, j] = \sum_{i \in N:\mathrm{part}[i]=k} prod[i, j] \quad \forall k \in M, j \in H \tag{21}$$

$$prod\_part[k, j] > 0 \Rightarrow prod\_seq[k, j - \mathrm{start} + 1] = 1 \quad \forall k \in M, j \in H \tag{22a}$$

$$prod\_part[k, j] = 0 \Rightarrow prod\_seq[k, j - \mathrm{start} + 1] = 0 \quad \forall k \in M, j \in H \tag{22b}$$

$$prod\_seq[k, l] = \mathrm{lf\_sequence}[c, l] \Rightarrow lf[k] = c \quad \forall k \in M, l \in H^*, c \in C \tag{22c}$$

$$tf1[k] = \mathrm{Lf\_Tf}[lf[k]] \quad \forall k \in M \tag{23}$$

$$t_{1P}[k] = \mathrm{Lf\_T1}[tf1[k], \mathrm{q_P}[k], \mathrm{T_1}[k]] \quad \forall k \in M \tag{24}$$

$$t[k] = \frac{t_{1P}[\mathrm{k}]}{1-l}\left(\sum_{\mathrm{j}\in\mathrm{H}} prod\_part[k, j]\right)^{1-l} \quad \forall k \in M \tag{25}$$

Thus production loss on assembly line can be set as in eq. (26), under the hypothesis of a conveyor change with respect to the last production in the previous horizon:

$$setup[\mathrm{su}_{\mathrm{last}}, k] = 0 \Rightarrow unprod = \mathrm{capacity} - \sum_{k\in M} t[k] \quad - \mathrm{t}_{\mathrm{su}} \sum_{j\in H}\sum_{s\in S} setup[s,j] \tag{26}$$

As regards lost space in trucks, it is estimated by assuming that each part type can be associated with a unit load class: this means that elements of different part types can be stacked during transport only if they belong to the same class. For curtain wall contractors, the main dimension to be optimized is the height of a single stack, being the other dimensions typically so large that the number of stacks in the truck can be considered as a constant for each project. Thus, lost space is evaluated by the modulo operator % as in the following eq. (27), when considering a single stack typically divided into 2 unit loads to facilitate material handling.

$$unload[j] = \sum_{h} \sum_{i:\mathrm{ul}[part[i]]=h} delivery[i, j] \cdot \mathrm{height}[part[i]] \ \% \ (\mathrm{htruck} - 2 \cdot \mathrm{hpal}[h]) \tag{27}$$

Finally, inventory is set as in the following eq. 28:

$$inventory = \sum_{i\in N} (shipment[i] - period[i]) \tag{28}$$

4 CONCLUSION

The The concept of *sustainable construction* has come to the surface and the expression is generally accepted into the construction management vocabulary [16][17]. Therefore contractors are paying more attention to environmental strategy and environmental impact assessment. In this scenario SSCM becomes more and more relevant and a model for the decision making on long, mid and short terms is needed. In this paper a new model for the production planning in construction PBEs has been developed by considering the features that characterizes that kind of market. The main difficulty to manage is the fact that each production unit belongs to a unique location of the building, which is assigned to an installation contractual due date. Moreover in many cases, stocking space on site is restricted and materials have to be delivered just in time according to the daily installation schedule or with a minimum allowed slack time. Therefore, installation sequence cannot be ignored during the production phase, even if to improve the efficiency on the assembly line, code variability and setups have to be minimized. Our model is aimed at finding the best balance between these site and production needs in order to enhance the company performances from the social, economic and environmental point of views, by taking into account production loss, inventory and less-than-truck load transport costs. Thanks to the introduction of the learning-forgetting curve, the model presented in this paper allows to reduce working stress on operators by considering more reliable production planning rates. Moreover decision-making over the mid-term is supported: by inserting different values for slackP and stockP input parameters, the company can test, through different simulations, whether it is necessary and/or convenient to pay for a storage area where to stock the units produced in advance on the due date, thus maximizing assembly line efficiency and minimizing the number of transports to site.

Further testing and simulations of the model by using real data coming from one of worldwide leading contractors in the curtain wall sector are being performed. Firstly, experiments in order to assess computational time performance of pure mathematical optimization are running, then, if computational times reveal to be unacceptable because of the complexity and size of real-life instances, the main CP process will be hybridized with adaptive large neighborhood search (LNS) [18], which has been proven to lead to very good computational performance in other complex problems such as sequencing of automated warehouse machines [19].

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AN INNOVATIVE MODULAR AGRIBUSINESS HUB FOR THE VOLGA REGION

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Abstract
The 'Volga Region' is an historical land inside the Russian Federation that includes territories adjacent to the flow of the Volga River. The Autonomous Republic of Tatarstan is the ancient original region, possessing a unique culture in which east and western traditions are placed, idioms are shared and it is placed in the middle of the Volga region. Kazan is the capital of Tatarstan, a modern and visionary town, where it would be possible to design and develop an advanced and innovative agribusiness infrastructure and where the concept of 'Hub' in the housing and in the distribution of food could be introduced. The main concepts exploited in this project are modularity, standardization and use of ICT facilities. The module will be the pallet, the standard is the Euro Pallet, the warehouse class A, as regards ICT devices, the RFID equipment and the satellite control.

Keywords:
Agribusiness, hub, RFID, Kazan, Tatarstan, Volga region

1 INTRODUCTION

It is now the correct moment in the present conditions of Tatarstan's vision, to develop an advanced agribusiness infrastructure and to introduce the concept of 'Hub' in the housing and in the distribution of food. The main problem, in this region, is the seasonality of agricultural products with consequent price fluctuations. So the creation of an innovative 'Hub' would definitely grant to keep the prices of agricultural products steady and to be able to have them available through the year. The model used as a reference for the design is the 'Marché International de Rungis' near Paris, France. Moreover, one of the aspects of traditional culture of the Tatar people is adherence of production 'Ḥalāl', which means breeding of animals, growing them up and then slaughter them according to Islamic canons. Thus, there is a serious problem of industrial slaughter of animals in the agro-industrial complex of the region. At the present time, the share of household slaughter is 90% of the general manufacture of meat, and such slaughter, as a rule, is made without carrying out veterinary and sanitary control which includes many infringements of technological and sanitary rules.

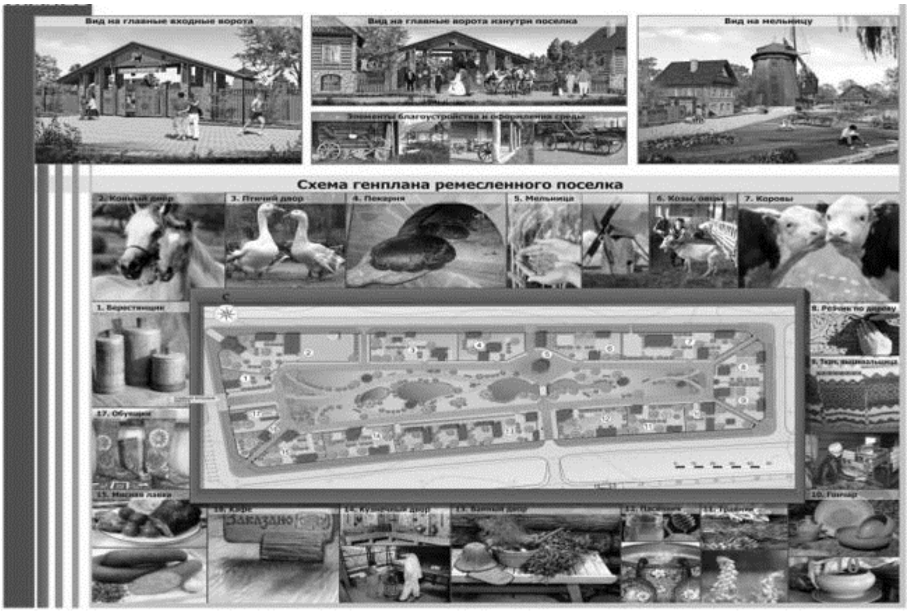

Figure 1: Sketch of the Halāl complex.

Taking into account all the mentioned above, the whole project would also include the realization of a modern technological complex for cattle slaughtering in accordance with religious requirements ‘Ḥalāl’, and onsite, other facilities (fig. 1). This project will treat only the hub facilities.
In the following sections, the discussion will be based on these subjects:

- The utilization of the ISO standard ‘Euro Pallet’ as the main module
- The construction of the warehouse class A
- The ICT equipment and devices

2 THE MODULE

In architecture, the concept of module is stated as a ‘*repetitive dimensional or functional unit used in planning, recording, or construction buildings or other structures’* [1]. The use of module leads to a more precise and accurate design and avoids, for example, as has already happened, the design of a hospital in which the beds, for their dimensions, do not cross through the doors. Many architects utilize the module, in other words a selected unit, which is used repeatedly in the aggregate constructions. For example, Le Corbusier developed the 'Modulor' [2] in the long tradition of Vitruvius and Leonardo da Vinci's 'Vitruvian Man', introducing a scale of visual measures. Modular warehouses are typical today but no one using its modular unit as a 'visual measure' like the pallet.

2.1 The pallet as the module

It is commonly known that a pallet is a flat transport and handling structure that supports goods in a stable fashion. Wooden pallets are preferred in our project. They typically consist of three or four stringers that support several deck boards, on top of which goods are placed. In a pallet measurement, the first number is the stringer length and the second is the deck board length. Pallet users want pallets to be easily passed through buildings, to stack and fit in racks, to be accessible to forklifts and pallet jacks and to function in automated warehouses as the one of our project. The real novelty in this work is to use the pallet as a module unit, through which the whole construction will be designed.

2.2 The ISO Euro pallet

The International Organization for Standardization (ISO) sanctions six pallet dimensions, detailed in *ISO Standard 6780: Flat pallets for intercontinental materials handling—Principal dimensions and tolerances*.[3] The pallet chosen in the present project is the EUR 3, 1.000 W x 1.200 L millimeters, most used in Europe and in Asia (fig. 2 and 3). This will be the standard module.

Figure 2: A EUR 3 pallet.

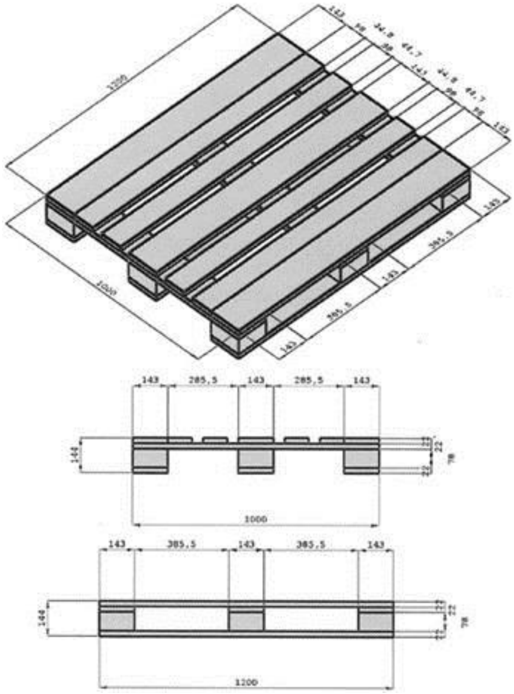

Figure 3: The EUR 3 pallet dimensions.

3 THE CONSTRUCTION OF THE HUB

Utilizing the module for the designing of the hub, in this case the dimensions of the EUR 3 pallet, will guarantee a precise procedure of work and the ability to maintain a constant control on the project. It is a bit like proceeding with Lego bricks. You may always have the option to have an overall view. So, the modular design approach is here adopted. It subdivides the building into smaller parts, called modules, with the dimensions of the chosen pallets. This modular system is characterized by functional partitioning into discrete scalable, reusable modules, rigorous use of well-defined modular interfaces and making use of industry standards for interfaces.

3.1 The warehouse

Commercial and industrial real estate can be broken down into several different categories, as shopping centers, office buildings, or warehouses. Particularly, warehouse/distribution buildings are commonly the largest ones and are used for warehousing and distributing products. NAIOP [4], in these terms defines warehouse: *a facility primarily used for the storage and/or* *distribution of materials, goods, and merchandise.* Typical characteristics are shown in the matrix displayed in fig. 4.

	Building Type					
	Manufacturing	Warehouse			Flex	
			Distribution			
Primary Type	*General Purpose*	*General Purpose Warehouse*	*General Purpose Distribution*	*Truck Terminal*	*General Purpose Flex*	*Service Center/ Showroom*
Primary Use	Manufacturing	Storage, Distribution	Distribution	Truck Trans-shipment	R&D, Storage, Office, Lab, Light Mfg, High Tech Uses, Data/Call Center	Retail Showroom, Storage
Sub-Sets	Heavy, Light Manufacturing	Bulk Warehouse, Cold/Refrigerator Storage, Freezer Storage, High-Cube	Overnight Delivery Services, Air Cargo	Heavy, Light Manufacturing		
Size (SF)	Any	Any	Any	Any	Any	Any
Clear Height (ft)	10+	16+	16+	12-16	10-24	Any
Loading Docks/Doors	Yes	Yes	Yes	Cross-dock	Yes	Yes
Door-to-Square-Foot Ratio	Varies	1:5k-15k	1:3k-10k	1:500-5k	1:15k+	1:10k
Office Percentage	<20%	<15%	<20%	<10%	30-100%	30+%
Vehicle Parking Ratio	Varies	Low	Low	Varies	High	High
Truck Turning Radius (ft)	130	130	120-130	130	110	110

Figure 4: Industrial building types (source: NAIOP).

3.2 The warehouse

Regarding the present project, a warehouse in class 'A' was chosen. In this respect, a subjective classification system [5] divides buildings into three categories: 'Class A', 'Class B' and 'Class C'. Building classifications differentiate among buildings within a relevant market area and are primarily based on quoted rents, building systems and services, tenant and building finish and location. Buildings must exhibit more than one of the characteristics but do not need to exhibit all of the characteristics to be considered under a specific classification. The following matrix (fig. 5) illustrates the primary considerations for determining classification of office buildings as either class A, B or C.

	Class A	Class B	Class C
Rents	Asking gross rents are based on a specified range between the top 30-40% of the office rents in the marketplace.	Asking gross rents are based on a specified range between the asking gross rents for Class A and Class C space.	Asking gross rents are based on a specified range between the bottom 10-20% of the office rents in the marketplace.
Location	Excellent, well located.	Average to good location.	Less desirable location. Depend chiefly on lower price to attract tenants.
Building Systems	The mechanical, elevator, HVAC and utility systems have capacities to deliver services that **meet both current tenant requirements and anticipated future tenant needs**.	The mechanical, elevator, HVAC and utility systems have adequate capacities to deliver services **currently required by tenants**.	The mechanical, elevator, HVAC and utility systems have capacities that **may not meet current tenant needs**.
Building Finish	High quality design and materials. Buildings must continue to remain competitive with new construction.	Average to good quality design and materials.	Dated appearance.
Building Services	**Above average** maintenance, management and upkeep.	**Average** to good maintenance, management and upkeep.	**Below average** maintenance, management and upkeep.

Figure 5: Industrial building classification, according to NAIOP.

3.3 The hub

The Merriam-Webster Dictionary defines a hub as ‘*A center of activity - An airport of city through which an airline routes most of its flights*’. It is so thinkable to borrow that concept for giving a definition to the agribusiness hub as ‘*A central location that connects multiple producers and dealers on a single network*’. The distinction between warehouse and hub is great. Today’s agribusiness warehouses have evolved into crucial hubs in supply chain networks. They are moving goods to the market more effectively than ever before and taking on value-added functions that they can perform more efficiently than any other link in the supply chain. Here are some bullet points, taken from an article written by Clifford F. Lynch of C.F. Lynch & Associates [6], concerning hub (distribution center):

- *A hub offers value-added services*. Rather than simply offering static storage, a hub provides a myriad of services for clients, whether those clients are external or internal company departments and functions. In fact, a well-organized and -managed distribution center will provide whatever services are necessary to complete the order cycle, including order processing, order preparation, shipping, receiving, transportation, returned goods processing and performance measurement.

- *A hub is customer focused*. While a warehouse is focused on the most efficient and cost-effective methods of storing products within its walls a hub's sole mission is to provide outstanding service to its customers.
- *A hub is technology-driven*. The distribution center of today must have in place state-of-the-art order processing, transportation management and warehouse management systems to scan bar codes, plan loads, process orders and locate product efficiently.
- *A hub is relationship-conscious*. Whether its clients are outside companies or other company departments, a distribution center must remain focused on its customers' requirements. A distribution center is the principal link between suppliers and customers, and its management must be conversant not only with the customers' needs but with the most efficient and cost-effective methods of meeting those needs. By contrast, a storage warehouse is so inwardly focused, in most cases, that there is very little understanding of what customer service really means.

4 THE ICT EQUIPMENT AND DEVICES

ICT (information and communications technology) is a term that includes any communication device or application, e.g. old and new media and so on, as well as the various services and applications associated with them.
ICT embraces the IT, TLC and A/V digital worlds. The ICT equipment provides IT service management. The use of ICT technologies enables to implement significant savings in the management of lean and led to be always anytime and anywhere. Pallet-level tagging provides a quick, automated, cost efficient and accurate way to track all the items through the supply chain and in the retail environment. This includes better visibility and control of inventory and an expansion of producer experience capabilities.

4.1 RFID

Radio-frequency identification (RFID) is the wireless use of electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects. The tags contain electronically stored information. RFID tags are used in many industries. In the present case, RFID-tagged products can be tracked from the site of production, through warehouses, until the users. Many organizations have set standards for RFID, including the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), ASTM International, the DASH7 Alliance and EPCglobal. This project refers to ISO/IEC 18000 [7], an international standard that describes a series of diverse RFID technologies, each using a unique frequency range. RFID has been used, e.g., to tag the components of the concept car 'Punto Student' (fig. 6), so that, when it entered into the car-repair garage for service, the defective parts did 'outing' by themselves.

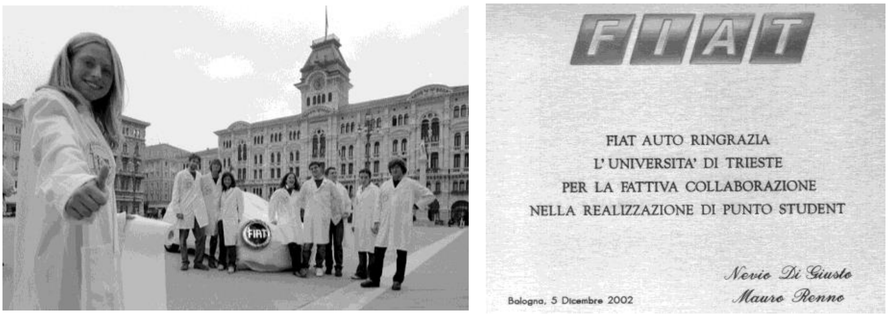

Figure 6: The project 'Punto Student', the ideal car for Italian students, a concept car, equipped with RFID tech, presented at the Motorshow 2002, Bologna, Italy.

RFID technology is a simple method of exchanging data between two entities namely a reader/writer and a tag. This communication allows information about the tag or the element carrying the tag to be determined and in this way it enables processes to be managed more easily. Key uses currently include production control, identification, authenticity features/authenticity protection, logistics and container management, animal identification, payment functions, contactless chip cards, management of goods and inventories, position identification, time clocking and admission control. In the present case, the tag will be attached to each pallet. The main concept, here, is to use the RFID ILT item-level tagging, in which our items are the pallets, so to track them to better control their location and inventory through the supply chain.

4.2 Satellite

Tracking vehicles and monitoring single items by satellite is today a common practice anywhere in the world. Therefore, wherever short and long haul transportation carriers go, by means of satellite and satellite-cellular terminals, it will be possible, in a near real-time, truck tracking and pallets monitoring. Pallet fleet managers will be informed of the operational status and location of the pallets and of the trucks, also utilizing invaluable, low-cost data communications links for location checking and virtually any other requirement. Important actions to increase productivity are, e.g., to transmit electronic documents, such as forms, work orders, instructions, personnel identification, completion acknowledgements, billing signatures and text messages for exchanging them in-cab with truck drivers. The aim, in this project is to track every single pallet from the producer to the warehouse and, moreover, inside it.

5 THE PROJECT

Agribusiness involves the production, distribution, consumption of food, clothing and shelter. It includes all economic activity in the food and fiber system which encompasses the input supply industries, agricultural production and post-harvest value-added activities, such as commodity processing, food manufacturing and food distribution [8]. The agribusiness supply chain includes a number of processes such as supply management, production management and demand management to customers through a competitive distribution channel [9]. Each step of the way can be plagued with issues such as diversity of production and demand, bulkiness of produce, perishability and seasonality. Highlighting the complexity and importance of supply chain management within businesses handling agricultural products, agribusiness supply chain management addresses issues that help readers systematically approach decision making in the agribusiness sector. Managers in all areas of the agro-food system must be competent, flexible and informed [10].

5.1 Main principles

The hub's main prerogative is its positioning near to a highway, because in Russia it is common using trucks instead of the train, even for the reduced cost of automotive fuel. Inside the value chain all actors should be involved - from manufacturers, to drivers of trucks, to hub's personnel, to dealers and so on. To avoid risk of stock all merchandise will be on consignment. Thus, the modes of operation of the hub will be two: either requested by dealers (FIFO) or attempted sale by manufacturers (LIFO).

5.2 Description

The supply chain includes the following steps:

1. The producers shall affix bar codes (approx. 1kB each one) on individual packaging (boxes, cartons, cans, etc.) and RFID on pallets and all on trust and collaboration. Of course, random checks will take place throughout the supply chain. The two technologies exchange information in different ways. Therefore, the systems complement each other, perform valuable services in different fields of applications and can be efficiently used in combination as well.
2. Data on pallet prepared by the producers will be sent via the web to the hub.
3. The trucks will start from the manufacturers and will be monitored by satellite in their path, in order to predict the date and time of delivery to the hub.
4. Once reached its destination in the hub, the truck will pass through special antennas that will control input and output via the RFID put on pallets, by implementing the warehouse incoming and downloading outgoing.

5. Other efficient antennas deliver high-throughput, high capacity communication, enabling organizations to capture, move and manage critical information to and from every point of agribusiness activity.
6. The pallets will be placed on the shelves and one can, at any time, check the availability and amount of stored goods. Other values entered in the RFID may show the exact dimensions of the content placed on the pallet and the storage temperature for perishable foods.
7. The discharge from the warehouse and the consequent variation of the goods in account sale, into sold and then with the respective bank payment may take place in an automatic way.

5.3 Economic factors

An economic analysis of the Volga region was already made and the result is that it will be possible to create strong economic growth in agribusiness in that area. ‘Warehouse is nothing more than the management of space and time’, says Thomas W. Speh [11]. The world is depending on the agricultural economy to stay strong and vibrant and provide needed food [12]. The most important cost factors, e.g. handling, storage, operation administration and general expenses were discussed. SWOT analysis was positive and business plan forecasted a great gross margin.

6 CONCLUSION

The request for a new high-tech warehouse construction is very relevant in Tatarstan because their production is still not enough for the internal market and so they are forced to import from abroad and to store and distribute products. Now, it must be chosen whether to build a new one or expand an existing one, such as a large already existing warehouse in an industrial area near Kazan, along the most important highway, which has loading docks to load and unload goods from trucks. The main objection is naturally to allow either transport optimization along the supply chain or to have an optimal inventory also regarding service quality. The aim is to go towards a completely automated system, in which pallets and goods will move on a totally plant of totally plants of automated conveyors and cranes for an automated storage and retrieval system, controlled by computer running logistics automation software. However, all of this will be done step by step. At first the construction of the building, designed using the ‘pallet module unit’ (fig. 7). Then the tagging project of the goods to track exactly their position using RFID and satellite tech facilities. Not less important will be the education of the workers to provide personnel development and continuation training. The goal is to require operators to work and handle only the tasks, to achieve the result of a fully automated warehouse hub.

Figure 7: Rendering of the agribusiness hub.

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A CONCEPTUAL FRAMEWORK FOR A LEAN AND GREEN MODEL IN INTERNAL LOGISTICS – HOW CAN WE COMBINE THE TWO PARADIGMS?

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Abstract
Two emerging trends intertwine in logistics to create increasingly waste reductive and sustainable logistics systems – lean logistics and green logistics. Despite the fact that there are separate streams of research, scholars explore some intersections on lean and green. Companies, nowadays are maybe missing the opportunity for synergies that are available with improved simultaneous introduction of both paradigms into their systems, they may also fail to address important trade-offs that may occur when there is incompatibility between strategic initiatives. According to economic niche, our paper offers a literature review as a starting point for a wider research in which we will be developing a conceptual framework for a lean and green internal logistics model.

Keywords:
Logistics, internal logistics, lean, green, sustainable

1 INTRODUCTION

Technological developments, emerging markets and rapidly growing population are nowadays increasingly affecting the rising demand for products and services. The latter puts great pressure on logistics, especially in the implementation of, e.g., delivery of material just-in-time (JIT), effective management material within processes and timely delivery of finished products.
Logistics operations are often being characterized by a high degree of manual control and consequently have a significant impact on the price of operations. Therefore there exist many initiatives for possible improvements. This means that logistics plays a significant role in today's businesses, particularly their effectiveness and competitiveness.
Failure in material or information flows may result in costly time breaks/interruptions, which explain the importance of a well-functioning logistics system to support all operational units [1]. We also have to acknowledge that the global logistics costs were estimated at USD 6,732 billion, and corresponded to 13.8 per cent of the world's GDP in 2002 [2], so every failure, inconsistency or any kind of waste can represents great costs.

One of modern companies' challenges besides eliminating non-value added activities in logistics processes is also sustainable logistics for climate protection. The impact of logistics on environment is vast due to occupying land for transportation and storage, such as transportation access, consuming fuel, transport and storage equipment, generating waste, producing loss and waste due to distribution processing, consuming material, etc. According to statistics of the 'Internationale Energieagentur' almost one third of carbon dioxide (CO_2) emissions are caused by transport activities and one of four of these are due to the intralogistics segment [3].
Processes of intralogistics offer optimization potential, economic and ecological, therefore many companies today are looking for comprehensive management philosophies, which would enable efficient intralogistics system with little wastes as well as environmentally efficient and sustainable. This leads to management tools to promote the development of customer services, lowering costs for all related processes and sustainable business politics. By accepting these aspects of management, where the basic achievement is excellence through continuous improvement and the search for new management concepts, are leading the company to a lean and green thinking.
The area of intralogistics has been rarely exposed to such research which would enable obtaining measurement criteria for measuring the level of leanness and greenness and therefore enable system improvement in a leaner and more sustainable way. Most of these were in fact made in the area of lean manufacturing management, which is the precursor of lean logistics (LL) as it developed from it precisely because lean manufacturing is rich in logistics concepts.
Based on the points of interests of both paradigms and lack of research coexistence, we will try to point out some indications on how to obtain the measurement criteria and consequently develop a conceptual framework for the hybrid system of lean and green internal logistics.

2 METHODOLOGY

An extensive literature review has been conducted in the fields of logistics, intralogistics, lean manufacturing, LL and sustainable or GL using mainly Google Scholar. The latter allows searching within many sources, among them peer-reviewed papers, theses, books, abstracts and articles, from both academic and professional organizations and publishers. It discovers the most relevant research across multiple disciplines and when used in conjunction with a university research library, it directly links you to multiple databases such as Elsevier, Science Direct, Springer Link, Wiley Interscience, EBSCO Business Source, Premier and JSTOR.
The development of the keywords was an iterative process. We firstly employed a brainstorming technique and secondly used a snowballing process to add keywords to the search as they were discovered in the

literature. These additional keywords were added until a point of saturation was reached, where no new keywords or articles were identified.
The articles' titles, abstracts and texts containing key words: lean, lean manufacturing, LL, GL, sustainable logistics, lean intralogistics and green intralogistics were scanned to determine the possible connections of both aspects. Non-relevant articles were eliminated.

3 THE DEVELOPMENT OF THE TWO PARADIGMS

With the economic development emerged the need to increase efficiency and to reduce any losses, mainly due to the level of costs caused by logistics activities. The main reason for high costs lies in the fact that logistics activities are highly substantial in assets. They are often identified with a high degree of manual control and human resource management, which in turn greatly affects the execution of operations. The importance of maintaining low costs in a bid to maintain the competitiveness is of substantial significance; consequently, companies are forced to examine every part of their organization for potential improvements.
For this reason, in the market began to emerge different management philosophies, one of which was lean philosophy. The latter first appeared somewhere in the fifties in Japan in response to mass production. The Japanese, especially Toyota as a beginner, wished to develop a pull system and remove wastes such as: excess time, losses in manpower, equipment, space, and stocks within the internal logistics system. Thus it began to develop an aspect ratio of the area of logistics and thereby emerged the new concept of LL.
One of the current, pressing global topics is the pollution caused by industry, i.e. in a large proportion also of logistics. Because of the importance of sustainable thinking and desire to reduce negative impacts on the environment, it has emerged as a new, sustainable philosophy: green logistics (GL).
Many researchers have studied both philosophies separately, not often together and even more rarely, in the field of intralogistics. The importance of joint research in this case is significant as it is the implementation of such a common system that is more efficient and has a double effect: It is cost-effective and environmentally friendly. Both philosophies sometimes operate complementary and often not. Lean solutions are sometimes not sustainable, so it is difficult to find an optimal lean and green, however, some researchers state that the adoption practices of lean manufacturing, consequently also LL will improve the environmental performance of production facilities or in other words, lean is green [4].

3.1 Lean paradigm in the field of intralogistics

It is no novelty that the beginning of lean thinking comes from the Toyota manufacturing system [5, 6, 7, 8] and that it is also a subject of a work entitled *The Machine that Changed the World* [9] which highlighted Japanese production methods in comparison to traditional Western mass production systems. According to [10] Taiichi Ohno started working on the Toyota Production System (TPS) in the late 1940s and continued in late 1980's unhindered by the advancements in computers, which allowed mass production to be enhanced by manufacturing resource planning computer systems. By the 1970s Toyota's own supply base was lean and by 1980 also their distribution base. It was at that time that supplier manuals were produced and the lean approach was shared with other companies besides Toyota. Taiichi Ohno at that time also identified seven wastes, activities that add cost but no value: (1) production of goods not yet ordered, (2) waiting, (3) rectification of mistakes, (4) excess processing, (5) excess movement, (6) excess transport and (7) excess stock [11, 12].

Soon after the appearance of the *lean production* concept, also appeared a new concept – LL. Womack and Jones [13] studied the transformation of the Toyota US parts distribution system, back to the second-tier parts manufacturer of a replacement bumper and compared it with its system in Japan. Even Toyota saw lean improvements in logistics especially in the fields or within manufacturing, delivery, ordering, warehouse management, dealers and network structure. According to Baudin [14], LL is a logistical dimension of lean manufacturing. Its primary objective is to deliver the right materials to the right locations, in the right quantities, and in the right presentation; its second to do all this efficiently. LL tailors approaches to the demand structures of different items as to one-size-fits-all. It is a pull system: Materials move when the destination signals that it is ready for them. The same author continues that LL could be and has been the concept applied to services, but they have focused on the manufacturing as a domain whereas it is rich in logistics concepts, approaches and techniques which can be addressed as 'lean' because either they are part of the TPS or they were adapted from it for application in different contexts.

According to [15], LL also takes its fundamental philosophy from the TPS and is based around extended TPS right along supply chains from customers' right back to raw material extraction. This kind of approach has been developed in order to overcome some of the fragmentation problems of traditional functional and business thinking. Within the scope of LL concepts such as value, value streams, flow, pull and perfection have been discussed. Bowersox, Closs and Cooper [16] state that LL refers to the superior ability to design and administer systems to control movement and geographical positioning of raw materials, work-in-process, and finished inventories at the lowest cost. In other words LL simply put, can be described as a way to recognize and eliminate wasteful activities from the supply chain in order to increase product flow and speed.

The main objectives of LL are [14] delivering the materials needed, when needed, in the exact quantity needed, and conventionally presented, to production for inbound logistics and to customer to outbound logistics;

without degrading delivery, pursue the elimination of waste in the logistics process.
To sum up, lean brought disciplines and a large number of tools and techniques to logistics. Using these tools, it allows companies to uncover and deal with waste and inefficiencies. Some researchers have categorized them according to the area of deployment, namely internally and externally oriented lean practices [17, 18, 19].The latter [19] divided them into six areas: (1) processes and equipment, (2) production planning and control, (3) human resources, (4) product design, (5) relationships with suppliers and (6) relations with customers. The first four are defined as internally oriented and the last two externally oriented lean practices.

3.2 Green paradigm in the field of intralogistics

Lean thinking is based on the assumption that time contraction reveals the hidden quality problems and that their solutions lead to improved, cost-effective business processes [20]. The authors further contend that if time contraction implies to lower emissions, then as by the emissions measurements, a lean system is always greener. If the reduction of time does not lead to reduced emissions, it is necessary to find a way or further changes of the lean system to become greener.
Typical metrics for measuring eco-efficiency include outputs which are not products, material usage, use of hazardous waste, energy use, water use, air emissions, hazardous waste and water pollution [21]. None of these is directly optimized for the establishment of a typical lean system so it is difficult to know whether a lean process operates in accordance with the optimal environmental, ecological principles. Simpson and Mason [22] have developed a sustainable value stream mapping by adding sustainable metrics (carbon dioxide, which is generated in the supply chain divided by the weight of the product). Similarly, also [23] advises adding environmental aspects to value stream mapping. Other additions to the conventional value stream mapping includes mapping flows connected with energy use, water and material use in accordance with finding the hidden sources of wastes in the value stream [21].
Based on the literature, we found that green practices can help businesses become leaner. By studying the winners and finalists of the Shingo awards [22] identified the link between green operations and lean results. They found out that lean companies, which include green practices, achieve better lean results than companies that do not. In short, the findings indicate that only when both concepts are implemented simultaneously, they can disclose their full potential and contribute a greater contribution than if they were implemented separately. As such, [23] and [24] emphasize that while lean practices can lead to environmental contributions, conversely environmental practices often lead to improved lean practices.
Green intralogistics, which is our main focus, is taking place in four different operating levels: (1) internal processes and operations, (2) components and driving mechanisms (3) machinery and equipment and (4) in-process

working conditions. After forming the basis for comparison placed in the energy assessment and evaluation of sources for machinery, equipment and internal processes, we can carry out the evaluation of the sustainability of the whole system. This, in turn is the starting point for the introduction of procedures that are developed to conserve natural resources [25].

4 BRINGING THE TWO CONCEPTS TOGETHER

There are separate streams of research on lean and green, however, some researchers explore some cross-sections of these two paradigms. This represents a critical review, for companies are possibly missing the opportunity for synergies that are available with improved simultaneous introduction and also they may fail to address important trade-offs that may occur when there are incompatibilities between strategic initiatives. For example green and lean strategies can be seen as compatible initiatives because of their common focus on waste removal [26]. Many companies have implemented lean practices and thereby improved the efficiency of their own processes. Leaner processes create value by eliminating wastes in supply chains [27] including the production of goods that have not yet been ordered, waiting time, repairing of errors and excess processing, movements, transport and stock [15].

Literature on lean supply chain also focuses on specific functional areas, including lean logistics [27]. Kleindorfer et al. [26] are of the opinion that companies, due to the wider adoption of lean practices in supply chain and the growing pressure on environmental management, began to incorporate these environmentally-friendly practices in their own scheme of reducing waste. The implementation of both initiatives, lean and green, has despite the simplicity intended to illustrate the potential synergies and conflicts that arise when any combination of green or lean is implemented. The combination of both initiatives adds management complexity of intralogistics of a certain company. The obstacles of rearranging intralogistics according to the principles of green must also not be overlooked, including the lack of ecological awareness [28], a general default principle that ecology does not pay off [29], and the perception that green initiatives are time consuming and expensive.

Rothenberg et al. [30] are of the opinion that only a handful of environmental experts examined the relationships between the various aspects of lean and green practices. Porter and Van der Linde [31] laid the argument that here is an issue about two completely different things, but some experts have recognized their possible cooperation. Dües et al. [32] describe green as a 'public good blending of lean' and interpret these positive side effects as efforts to reduce waste and reducing pollution. Many companies have a natural tendency to move towards green practices. Generally speaking, most of the research concerning the link between lean and green touch the efficient use of energy and resources and lower waste and pollution [22, 26, 31, 32, 33, 34, 35]. Certain companies are therefore resisting the implementation of environmental initiatives because they can be time consuming and expensive [31]. Lean production and mass adaptation need more settings that generate more waste and consume more energy [32]. Changing production technologies which would produce more environmentally responsible processes and products require a lot of pre-investment for which the return is not necessarily realized in the short term, as with the lean cost-declining strategies [28].

Improvements in production systems can lead to direct and indirect benefits for environmental management, often in the form of reduction of waste [36]. The objectives set to achieve leanness, thus become a catalyst for a successful implementation of green practices and also help to achieve the desired objectives [22, 31, 32]. Rothenberg et al. [30], who studied the intersection of lean and green paradigm in supply chain found a cross-section in the following parameters: management techniques and lowering waste, people and organization, reducing delivery time, key performance indicator: the level of service, and also a set of common tools and practices, that they share. The main common point is in the objective of disposing of waste of both paradigms. Nevertheless, a waste of both paradigms is defined otherwise but both respectively target the removal of excess: the waste in the broadest sense. LL is focusing on removing seven wastes related to the efficient flow, while GL is focusing on green wastes in the form of inefficient use or waste production [26, 34]. Despite the fact that these two paradigms have different goals for the removal of waste, they respectively target the same type of waste, in particular, storage, transport and production or outputs which are not products [30].

Too much stock in a company means for the company additional risks and retention of capital, also, stocks need storage space which must be adequately lighted, heated or cooled, which is considered as waste from the environmental perspective [37]. As for transport, both paradigms respectively target less transport to reduce costs [20, 34].

Techniques for reducing waste are for the two paradigms often similar, with a focus on business and production-processing practices [31]. We achieve waste reduction through changes in business practices by adjusting the corporate culture of the company [26]. This means changing the company's vision and the integration of lean and green in support functions. Both, green and lean paradigm examine how to integrate the production or process renovation in accordance with extension of the product use or to enable easy recycling of products, as well as more efficient processes, i.e. with as little waste [22].

5 CONCLUSION

This paper suggests some missing areas in the field of lean and green in intralogistics, it also indicates different ways of thinking on the possible collaboration of the two concepts. It is evident that for each paradigm there is a significant amount of research, while a clear lack of research was noticed, that would combine both of them. Kleindorfer et al. [26] investigated the combination of lean, green and global strategy of supply chain and concluded that when environmental regulations will become increasingly stringent, companies will be forced to deal with this kind of interaction paradigms.

King and Lenox [34] raise this link to a new level and describe the lean and green practices as a synergistic association to environmental and operational management. The synergy of each partner affects the other in a positive manner and thereby increases the benefits of this type of union. Synergy is often described by the equation 1 + 1 = 3, which means that the combined practice better results than the sum of the individual performance. So, in synergy of lean and green practices, the leanness has to push forward the greenness, while at the same time the greenness has to be synergetic to leanness. Nevertheless, the combination of lean and green practices mentioned in published articles is only a handful of those available, which could explain how managers can integrate green methodologies in the current lean practices. Facing with resource constraints, many managers simultaneously target the integration of lean and green principles into their operations [30].

This literature review is a starting point for a wider research in which we will be developing a conceptual framework which will look for cross data between different information gathered by the approach of lean and green paradigm. A key indicator of the first aspect is cost due to the trend of elimination of wastes, while a key indicator of the second is lowering of CO_2 at all levels. Based on two basic objectives (primary cost reduction and CO_2, secondary everything else) we want to plan a hybrid model of lean and green intralogistics. The hybrid model will cover both, economical benefit and sustainable contribution and will also encompass at least three intralogistics areas, e.g. spatial planning, internal logistics and ergonomics in the workplace. The overall objective of an individual area also allows specific criteria of activities for planning, management and control of operational processes within the internal logistics operations of each company. Objectives with each step down concretize until they reach the lowest point, which is in this case the individual criteria of each area; thus becoming a criterion for the evaluation of a green and lean intralogistics of an individual company and can consequently act as a guide for potential improvements.

To conclude, we have to mention that the importance of developing a hybrid model combining lean and green in the area of intralogistics is significant as it is the implementation of such a model both, more efficient and has a double effect; it is cost-effective and environmentally friendly.

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LEAN PROCUREMENT AND SUPPLIER INTEGRATION

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Abstract
The purpose of this paper is to enhance the theory of lean management, extending its principles to the procurement function.
The present research aims to conceptualize lean procurement and supplier integration, focusing on the implementation process, describing how the lean philosophy can be applied to the procurement environment, from the perspective of a small/medium-sized manufacturing enterprise: This work is an abstraction of a road map for the application of lean principles to the procurement area.

Keywords:
Partnership, supplier integration, e-procurement, lean procurement, value stream map

1 INTRODUCTION

The origin of lean came from Toyota Motor Corporation and their Toyota Production System [1] who conceived the denomination 'lean' was John Krafcik [1] at the end of the '80s, but the true philosophy spilled already over in the first years of the '80s, from the 'Far-East', to the western automobile companies, as a reaction to the competition from Japan's cheaper products, but with high quality. It was set in opposition to mass production approach: the new lean proposal required less human efforts, production machinery and investments [1]; however, a strong partnership with suppliers was essential.
Toyota's success triggered a worldwide transformation, spreading the lean culture globally, fostering the development of lean manufacturing and supply chain philosophy. Automotive was not the only manufacturing sector in which lean was efficiently implemented [2]: In fact, service industry, healthcare and government are just examples in which lean found rich soil to grow up strong. Nyakagwa [3] states that lean could be implemented successfully in every business process, including procurement.
An important key factor in lean is the relationship with suppliers: The supplier plays an important role to tackle the increasing competitive market.

1.1 Lean procurement

Procurement is the acquisition of goods, services or works from an external source. It is necessary that the purchased goods are appropriate in terms of quantity, quality and procured at the best possible cost and for sure on time [4].

The term ‘procurement’ is a quite new-coined term that indicates the evolution of purchasing function to an enrichment of its role inside the company management. The function operates to perform purchasing strategies and plans, in order to reach organization’s objectives, building up strong relationships to suppliers and partners. As explained by Weel [5], the purchasing function has gone from the only action of buying to supply chain management (SCM) and thus this department has enriched its scope by including improved administrative routines and supplier development.

Nowadays, managing procurement is getting more and more convoluted: The amount of costs (materials and management) connected to the procurement activities are more than 15% of the industrial cost of the final product [4]. On this point, it has to be considered that the operational environment, in the course of time, has become more complicated: suppliers’ partnerships, industrial flows and unpredictability of the demand.

Lean theory helps the procurement department to carry out supply tasks efficiently and keep it low-cost. The aim of this application to procurement processes consists in simplifying supply flows, widening and standardizing the flow of information provided from procurement department to:

- Management
- Suppliers
- Internal customers (component users)

Simplification and standardization make processes error-proofed and increase flow speed (LT reduction); on the other hand, enlarged information streams lead the company to a higher control level and to the identification of the managing lever used to reach the overall objectives [4].

Lean thinking could be seen as a sort of flexible automation, achieved by cheap and simple technologies. For example, in some cases, MRP is replaced by tools like ‘JIT’ and ‘kanban’ which are simpler and more verifiable.

Weel [5] affirmed that a ‘Lean company uses fewer suppliers and involves them in joint-improvements and development’. With this modus operandi, there is a clear understanding for suppliers about goals regarding quality, delivery and costs which also warrants a businesslike and efficient performance measurement process.

Further Nicoletti [4] states: ‘Lean companies have more focus on increasing their suppliers’ capabilities, in order to reduce costs and improve quality’. For instance, a supplier that has the capability of an adequate understanding of forecast data and the ability to efficiently manage operational processes is a supplier that can react quickly to sudden changes of requirements.

2 LEAN PROCUREMENT AND SUPPLIER INTEGRATION

This section has the ambition to be a road map for the application of lean principles. The methodology follows three main steps: understand the flow, suppliers' integration and lean warehouse.

2.1 Understand the flow

The aim is to get the supply chain thinking, in order to set, as objectives, the entire value chain's outturns and not singular players' goals. Procurement will have the role of a collector between two chain rings; in a supply more and more by pulling the final customer creating joint advantages for the entire members.

Procurement dashboard

If the procurement department can be assimilated to an aircraft [4], a cockpit of tools is fundamental in order to recognize its position during the rise, the cruising speed and altimetry; also procurement needs a KPIs dashboard, to have all the magnitudes that describe the procurement performances under control. Choi [6] believed that it is not possible to establish partnerships without understanding how suppliers carry out their activities. The baseline for creating a partner relationship with a supplier, is to know as much as possible about him, in order to communicate at the same level. The action may need time, but will be advantageous for sure - for both companies and by means of this comprehension, it is possible to set common goals to reach. Understanding supplier technology is the right way for procurement to plan purchase orders that are in line with suppliers' capacity and lead times, anticipate and ward off supply criticality. As a result of target setting, it is important to control the process.

Every company's process, for the matter of being improved, has to be measured systematically based on objective parameters, well known as KPIs, or rather Key Performance Indicators.

These KPIs should measure [7]:

- The service level, provided to the final user of buying components (internal or external customer).
- The procurement cycle time.
- The complexity of the procurement management.
- The vendor performances.
- The purchasing lead times.
- Monitoring the inventory level.

Value stream map

Value stream mapping (often cited as VSM) is a tool that can be used to map and to analyze the processes and activities within the company and across the supply chain, to identify areas of improvement. Once applied to purchasing, the resulting flow diagram has the aim to understand the

material and information flows, in terms of value, in order to trace waste present in the company's procurement process [8].
The essence is to map the entire process, from customer order to delivery of raw material, manufacturing and final delivery to the customer. The value stream map has thus the purpose of enouncing and simplifying processes in lean perspective.
Value stream mapping [4]:

- Provides common language related to value and process.
- Describes actual situation.
- Links material and information flows to processes.
- Represents the starting point for every value flow's improvement.

Mapping activity occurs following three phases of:

1. Clusterization of SKU in product family group.
2. Mapping of actual flows (as-is analysis).
3. Defining of future flows (to-be analysis).

Clusterization has to be carried out on supplied components, under a specific logic, that could be gathering SKUs per commodity-related family, rather than for technology, for the modality to compete to the realization of finished product or for the type of finished product itself, etc. [8].
A good manner to cluster is to group-buy components per technology [4] like in fig. 1. This way highlights all the upstream production phases upon the supplier and thus, defines suppliers as possessors of a special mix of technologies. The aim is just to focus on a limited number of families and not on every single component simultaneously, in order to manage only one problem at a time. After an opportune clusterization it is suitable to classify families for greater potential improvement margin, in terms of economical enhancement and internal/external customer satisfaction.
Mapping the actual procurement flows is called 'Current State Map' or 'As-Is Analysis' expressed in fig. 2. The current state map takes the initial picture of the procurement flow and waste which are related to family groups defined in previous step.
As proposed by Rother and Shook [8], a correct mapping of 'As-Is Scenario' follows the guidelines to draw the Current State Map below:

- Record VOC (voice of the customer), defining what is the value perceived by the customer.
- Observe the activities in working team.
- Draw operative and basic processes.
- Information about the basic processes, according to the type of company (e.g. time spent, number of persons required and starting/waiting time to carry out each phase of basic processes).

- Record material flows (buffers each transportation, inside or outside of the plant, that is related to the procurement process).
- Record information flows (communications, forecasted and ordered quantities).

Once the draw of as-is analysis is complete, it is necessary to reshape the flow, perform the future state map or to-be analysis. Most of the waste revealed in the previous analysis must be taken off.
The objective of future state analysis is to trace a process that outcomes only what is required, in terms of mix, quantity, variability and lowering costs and wastes. In order to obtain a lean process, some guidelines are proposed by Rother and Shook [8]:

- Focus on clusters identified.
- Implement a continuous flow where possible.
- Implement a pull system where possible.
- Try to level volumes.

Generally VSM is used to comprehend and analyze the process, to define which activities are value-adding and which are waste in processes, find duplications of stocks among the organization and its suppliers, pinpoint where defects happens and examine scheduling and batch sizing [9].
In a second step, suppliers can be involved also, in order to extend the value stream map.

CLUSTER	ITA P.O. (YTD 2013)	
Consumables	€	13.008.714
Decorations	€	9.499.099
Indirect Materials	€	11.653.573
Metal Semifinished Comp.	€	7.311.025
Packaging	€	57.278.009
Plastic Comp	€	27.971.694
Plastic Comp Acetate	€	1.250.803
Plastic Comp Inj	€	2.561.203
Precious Materials	€	8.250.961
Raw Metal Comp.	€	17.126.456
Raw Metal Material	€	6.495.562
Raw Plastic Material	€	38.574.998
Small Comp.	€	15.356.220
Strass	€	1.926.251
Total	*€*	*218.264.568*

Figure 1. Clusterization.

	Somma di h/Week	%
Adding Value Activity	**312,1**	**49%**
Not Adding Value but Necessary	**228,3**	**35%**
Waste	**82,2**	**13%**
Alignment of Purchase Order Portfolio with Suppliers	35,6	6%
Allocation Run	10,3	2%
B.O.M. variation analysis	5,3	1%
Occasional Meetings (also with Proc. Staff)	21,7	3%
Other KPIs Analysis	9,3	1%

Figure 2. Waste activities (VSM).

2.2 Suppliers' integration

Choi [6] sustains that the focus of procurement activities does not regard maximizing profit on the suppliers' loss, and declares that the main objective is to create a win-win collaboration between the organization and suppliers, where the first may profit by price reduction, but the supplier achieves cost savings. As stated by Weel [5], collaboration is a construct to delineate cooperation, where both sides work to build up value, however, compete when the profits have to be divided.

Integrated strategy

Supplier integration and development have been defined by Krause, Scanell and Calantone [10] as ‘every activity undertaken by a buying firm to improve supplier performance, supplier capabilities or both and to meet the buying firm’s short- and/or long-term supply needs’. The objective is to get capable suppliers and create improvements in the supply chain. On the other hand, integration is a relevant instrument to influence suppliers and their Lean approach [3]: an integrated supplier, being in contact with customer’s best practices and being influenced by them.

Sako [11] wrote that there is an abyss between a relationship where the buyer is just a good source of best practices and a relationship where the buyer actually teaches the know-how and enhances the supplier’s capability.

Choi [6] affirms that a proper lean organization not only has to be successfully committed to lean philosophy, but its suppliers must be aligned and conscious about the systems of the organization itself too. Recently competitors within the market are no longer single players: The entire supply chain itself is competing. Sako [11] suggests that no more local objectives should be followed, but global and optimal ones must be accepted as a goal for the whole supply chain. A lean supply chain could be considered like an extended organization and to be successful it must develop a culture of leadership [10], a call for continuous improvement and collective learning among parties in the network, to diffuse lean education. Communication tools like, for instance, EDI, enhance deeper partnerships. An example of this principle is displayed in fig. 3. For the supplier, this report shows up the predicted requirements of the customer production about the components supplied, the projected stock and the purchase orders already released. With this simple tool, the supplier can efficiently manage his production and deliver on time.

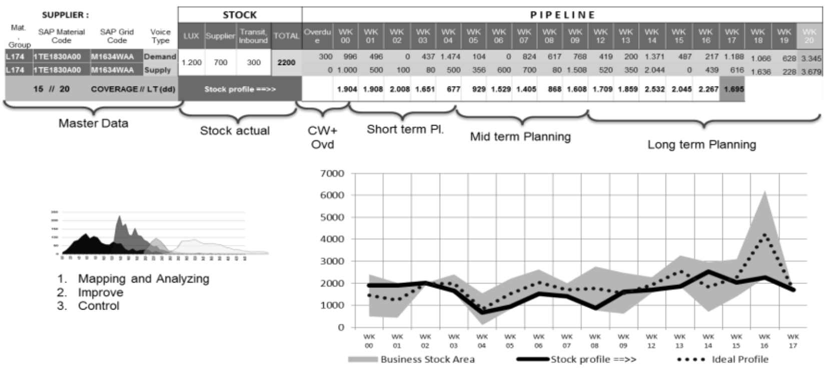

Figure 3. Projected stock report.

Partnership increases performance, enhances communication, and sets loyalty between parties, fostering a global vision that brings the supply chain to achieve higher results. The benefits of deep collaboration are operation enhancement, process and product quality improvement, and profitable connection to supplier know-how.
Hereinafter, information sharing, positive mediation of conflicts, mental elasticity and joint interaction, are fundamental to build a profitable work relationship [3]. This change can be achieved because operational activities, like order placing, expediting, receiving, and invoice checking, may be automatized; for example, by using EDI, to cut down manual tasks, adopting on-line kanban's call-offs to manage the warehouse, transferring new responsibility to suppliers. In order to obtain an efficient supply chain, reducing wastes in just one organization is not enough: wastes must be eliminated along the whole supply chain.
Hines [13] theorized two types of waste:

- Coordination along the supply chain. This waste is generated by lack in correlation between systems and procedure, among organization and suppliers. Hines suggested establishing common quality standards, to be coordinated on paperwork and system, to cut down transport and inter-company communication, and to set automatic communication channels (e.g. EDI);
- Development along the supply chain. This waste is related to each company and stands inside them. In order to help the supplier's development, a strategic development plan is required, that includes organization to offer specific support, in terms of knowledge sharing and system integration.

In a partnership, the focus is also to eliminate waste in such procurement activities, like a large number of order confirmations, invoices, repacking, checks, returns, expediting, and for sure, exceeding inventories.

E – procurement

One of the most powerful approaches to support lean procurement, is the application of the 'Lean and Digitalize' method. It consists the enhancement of procurement's informatics tools, known as e-procurement, in order to give an effective process improvement [14]. The first frame that supports e-procurement is the enterprise resource planning system.
ERP is the corporate's big and fully integrated system, which provides support to many organizational departments like planning department, sales department, procurement department, industrial logistics, marketing department and product industrialization's ones. By means of ERP, the organization gears itself with automatic and efficient tools, which lead to bring benefit to the whole supply chain process.
Especially for Procurement Department, it sustains the following tasks:

- Purchasing strategy definition, providing all the information related to the procurement process.
- Function and department integration, it provides a huge amount of information of every organizational area to every department which requires them.
- Management and administration process, all data are stored and provided by only one system.
- Forecast and requirements analysis, it simplifies the decision making process by the interpretation of forecast factors and market trends.

ERP is a strategic value to the company, it is generally very expensive and needs a long integrating time, but, if well established, the return of the investment is very quick. It allows improvements in POs managing, cost reduction and time saving.
E-procurement refers to the utilization of electronic methods, generally through the internet, in order to conduct transactions in a business-to-business (B2B) environment. As stated by Pearcy and Parker [15], objective of e-procurement solutions is to automate information sharing processes and accelerate the procurement workflows in order to improve the efficiency of the supply chain. As Nicoletti [14] affirms: 'Collaboration and joint efforts, in order to lower costs and streamline the value-adding processes, can be done just if information sharing is running'.
The information sharing process and order issuing could be managed by the electronic data interchange system. EDI enables the establishment of e-order approach, which is the process of creating and approving procurement requisitions, placing purchase orders, as well as receiving goods ordered, by using software systems based on the Internet. EDI facilitates transactions between customer and suppliers, by integrating databases and using a standardized format for purchasing orders (.xml) that, for example, permits suppliers to automatically upload it in its own system. Fig. 4 shows an example of EDI interface: the supplier can access to the internet-based platform and be informed about the state of the purchase orders, delivery date and, in case, postpone them directly through the EDI.
Nicoletti [14] describes five benefits of the implementation of e-procurement approach:

- Reducing order processing cost and cycle times;
- Providing enterprise-wide access to corporate procurement capabilities;
- Empowering desktop requisitioning through employee self-service;
- Achieving procurement software integration with company's back office systems;
- Elevating the procurement function to a position of strategic importance within the organization.

Well-set e-procurement frames can have an impact on the whole procurement function and its processes.

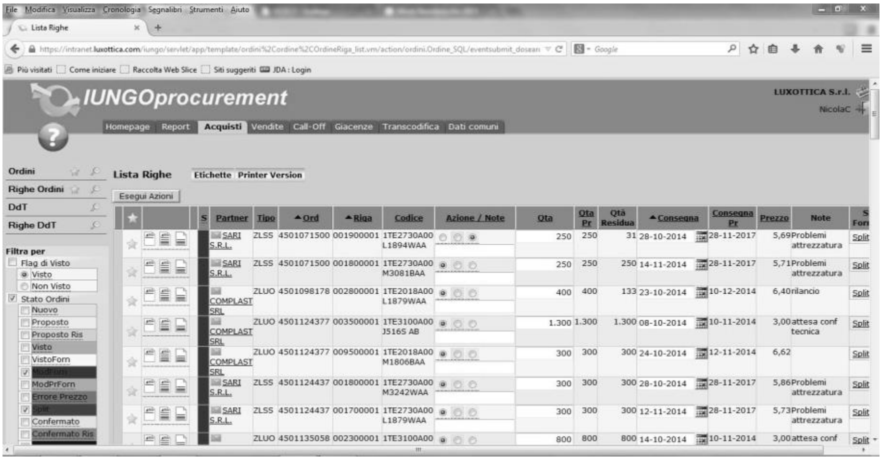

Figure 4. Example of EDI platform.

2.3 Lean warehouse

The objective of lean logistics, according to Taiichi Ohno [16], is to efficiently deliver the right materials, to the right place, in the right quantities. Liker states [12] that the purpose of lean logistics is to 'oil' the supply chain, to permit to respond rapidly to the market, to make an order and lower stock levels.

Sharing information is a distinctive feature of lean approach and is extremely important for inventory management. The first optimization is to set an order for a lot quantity, both to optimize batching for incoming material and to be closer to the supplier's production to optimize the supplier production planning program. Due to the fact that 'one piece flow' is not immediately applicable, it is necessary to define lot quantity to be taken in charge by logistic department, and an easily applicable method could be the economic order quantity method. The lot quantity has to be decreased, step by step, to stretch to the ideal target: 'one piece flow'.

Kanban

Kanban is a Japanese term that could be translated as 'signboard' (kan=visual, ban=card).

Kanban is a signal to call what is required, in order to replace what has been used. The replenishment can happen just if the authorization (card/signal) is presented. Who presents this authorization is an internal or external customer. Kanban is not just a piece of paper, but contains all the information to manufacture and deliver the components (e.g. component code, machine code, number of pieces, destination). The kanban approach consists of an error-proof, visual pull system, which efficiently controls the flow and inventories, allowing small batches and process efficiency. The concept is relatively simple: an operative department must activate, in order to elaborate the quantities communicated from a downstream department, by means of a card [17].

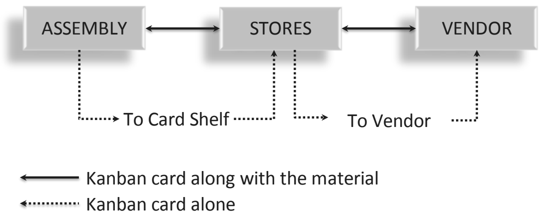

Figure 5. Kanban flow.

Kanban applied to supplier-customer's flow runs just the same way as an internal kanban, and authorizes supplier to deliver parts [17], as fig. 5 shows: Kanban permits the synchronization between upstream processes (customer's ones) and downstream processes (supplier's ones).
The kanban system creates materials and information streams from vendor to the customer. It prevents overproduction and exaggerate goods movements, assists as a flow order, discovers process's problems and cuts down the stock level. Under the lean and digitize logic, the 'card' is replaced by an electronic kanban: e-kanban.
Electronic kanban goes like the original tool, but with the further benefit of a quick information delivery, and thereby transfer time. Vadugu [18] states the electronic kanban requires nothing but Internet access, using EDI (electronic data interchange) as a conveyor of electronic kanban signals. The application of kanban approach is possible even though vendors are not using it [14]: an organization can use kanban internally, and when time to replenishment occurs, EDI sends orders that linearly correspond to the conditions required by kanban. In this scenario, the supplier might not even be aware that the orders are issued by a kanban, but just keeping eye to the stable flow of small orders.

Consignment inventory and vendor management inventory
A further integration of the suppliers into the organization processes is called consignment inventory. CI, as it was born, is more a financial method than a management one. Customer stores are all buying components in its own warehouse, but the emission of a commercial invoice is postponed to the precise instant where the goods are picked to be used in the production department. It permits the customer to have a safety stock that does not weight on profit and loss account. As stated by Jewkes and Bookbinder [19], consignment inventory is performed in order to shorten purchasing lead

times, and to delay the moment of payment. On the other hand, the advantages for the vendor are at least three:

- The expenses of inventory management are upon the customers;
- The vendor can optimize goods production and transport, producing and shipping bigger batches (scale economy);
- Customer's satisfaction and loyalty increase.

A special type of CI, vendor management inventory (VMI) [20], runs quite similar: without dispatching any order the buyer dispatches, to the supplier, just information about his requirements and about its own stock level. Supplier compares the actual customer's stock level to the established order point, in order to take the decision to produce/ship goods. If the gap is negative, supplier delivers the difference. This approach is restricted for companies that have a reliable and quick logistic network.
Benefits for the buyer are evident: the organization does not pay, until the component is near to be utilized in production. The vendor benefits consist in much more visibility on customer's requirements and, as a consequence of this fact, on the facilitation of production planning [19].
A correct applied VMI is an efficient method to represent bullwhip effects, reduce lead times and improve visibility. Suppliers are committed to manage stocks of their components at the customer's warehouse, or keeping components at their own buildings.

3 CONCLUSION

This paper has described the implementation of lean methodology in the procurement environment, by focusing on supplier integration. The subject was to involve the procurement department in lean management methodology.
As a starting point of the implementation, the scenario in which the procurement team operates has to be analyzed. By means of value stream mapping and valuing procurement activities, taken in consideration from the internal customer's point of view, it is possible to identify areas of intervention. The approach follows three paths for the implementation proceeds: The first one is the optimization of internal flows, reorganization of procurement function and clusterization of components per technology. The second path is the integration of suppliers by means of the improvement of the EDI interface and the creation of a tool to share a structured view of company's production requirements and stocks with selected suppliers. The tool has the aim to increase the long term visibility of suppliers. The third path is the implementation of two techniques based on 'Just in Time' approach, in order to manage the company's inventory efficiently.
The lean approach is a crucial resource to raise the performance of the procurement function.

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SIMULATION MODEL OF SPARE PARTS MANAGEMENT IN A COMMERCIAL POOL CONTRACT

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Abstract
In the aviation context, the process of determining the optimum stock level for spare parts is a complex optimization problem, because of the high stock costs and the high availability requirements. In step with the continuous evolution of the market and the ever-increasing related competitiveness, nowadays a new trend in contracts' structure is emerging, the so-called pool contract. This contract envisages two main actors, a supplier and a customer, in a multi-echelon structure with generally the possibility of a multi-transportation supply strategy, related to the items criticality. This research aims to develop an object-oriented simulation framework that captures the fundamental elements for modelling the stock of a customer airline involved in a pool contract. The model is applied on a pool contract of a European airline, in order to validate the results obtained by the application of the classical METRIC model with respect to availability constraints.

Keywords:
Pool, METRIC, spare parts, simulation

1 NTRODUCTION

Reliable spare parts supply is a key element to provide service continuity in several industries where high availability levels are generally required.
In these industries (e.g. aviation, telecommunication, defense, oil drilling, etc.) stock-outs have critical consequences, generating heavy reductions in service levels and huge related costs. For this reason, it is necessary to size carefully the line replaceable units (LRU) stock level in each location, in order to avoid the stock-outs consequences.
Airline industry is a common field of application for innovative spare parts management techniques, because of required high service level and high spare parts cost. The International Air Transport Association (IATA)'s Maintenance Cost Task Force analysis [1] shows that maintenance cost takes up about 13% of the total operating cost. It is therefore necessary to develop a strategy to size carefully LRUs stock levels.
As a competitive leverage to decrease the inventory costs, some airlines are outsourcing the ownership of the spare parts stocks, settling contract where

the part is available in specific maintenance centers. The maintenance supplier is commonly another airline that benefits of risk compensation, considering the high unlikelihood of simultaneous breakdowns: multiple airlines share the spare parts and the total stocks managed by the maintenance supplier are lower than if each airline had its own stock. Spare parts become variable costs for the customer airline and a business income for the maintenance supplier. We can define this kind of outsourcing a 'commercial pool contract' as the maintenance supplier builds a pool of airlines that share spare parts.

Although many researchers studied the spare parts management problem, developing models to size the optimal level of stocks in the maintenance network, few researches are present in literature related to pool contracts. However, in 2015, Costantino et al. [2] developed a modelling for the commercial pool contract adapting the traditional models to an innovative perspective. The first step of this model consists in determining the best strategy: Stock or not stock a spare part, according to its criticality, its commercial value, and its historic number of requests. Then, once selected the spare parts to stock, it is necessary to determine their optimum stock level, by the application of a METRIC-like model.

This paper develops a simulation model to verify the METRIC-like traditional solution, which permits to determine the optimum stock level in a pool contract.

In summary, the contributions of the paper are as follows. At first, the literature review shows the actual need of modelling the features of a commercial pool contract because of its expanding applications in the airline industry. Then, section 3 describes the characteristic features of a generic commercial pool contract, and thus the simulation model features. It shows also the assumptions of a generic METRIC-like formulation, which describes these features. Section 4 shows a case study, i.e. the application of the model to a European airline, highlighting and comparing the outcomes related to the analytic solution and the simulation solution. Lastly, section 5 summarizes the outcome of the study, with particular reference to the possibility of further studies, to enhance the reliability of the analytic modelling.

2 LITERATURE REVIEW

From the fundamental work of Sherbrooke [3], the research on spare parts management considers a system-oriented inventory problem, developing many evolutions of the original multi-echelon technique for recoverable item control (METRIC) model. According to a general point of view, the objective of the METRIC and its variants is to allocate the inventory level to ensure the parts fill rate and the minimum holding or backorder cost, subject to a service level requirement. A significant amount of METRIC-like models provides extension to the original one, introducing multi-item [4], multi-

indenture [5], multi-echelon network [6], even for different demand models [7]. Some authors integrate the level of repair analysis [8,9], the capacity constraints of the maintenance centers [10-12].
Note that the wide application in industries confirms the importance of these models. It is possible to retrieve METRIC application (e.g.) in the Royal Netherlands Navy [13], in the weapon management [14], in civil [15] and military [16] airline contexts and in defense systems [17].
The recent introduction of the commercial pool in the airline industry motivates the analysis and results of this study, where a supplier benefits of the risk-pooling effect accumulating the demand for spare parts from several aircraft fleets [18]. The International Airlines Technical Pool association (IATP) now offers 11 pooled recovery kit all around the world [19]. Recently, some commercial pool contracts are available among producers (e.g. Airbus, Boeing Company, Rolls Royce Holding PLC) or airlines (e.g. Air China Technic, Air France Industries KLM Engineering & Maintenance, British Airways Engineering, Delta TechOps, Lufthansa Technik) providing MRO services.
A cumulative spare parts supply usually represents a competitive advantage in terms of average number of backorders reduction and total annual costs [20, 21]. In the commercial pool contract, the customer needs to define its local inventory with the two missions of achieving a minimum cost and a target service level, where the supplier determine its stock level at the central depot. As explained later in details, the commercial pool contract provides an in-pool cost to ensure the availability of a part in a distant central depot of the supplier and an optional additional cost to keep the part available at the customer, with different time of replacement on the airplane and replenishment.
This paper focuses on the items stock in the customer base, adopting a METRIC-like formulation to determine the optimum stock levels and verifying them by a simulation model.

3 COMMERCIAL POOL CONTRACT

The generic formulation of a commercial pool contract defines the rules for two main actors:

- The supplier (central department – CD): a company who provides the facilities, the competences and the certifications to execute maintenance services, selling these services to other companies, i.e. the customer.
- The customer (local department– LD): a company who does not own the facilities, the competences or the certifications to execute maintenance services. To ensure its target service level, the customer acquires maintenance services from another company, i.e. the supplier.

In case of a failure, the customer local maintenance department (LMD) can only substitute the inefficient item with an efficient one and ships this repairable item to the central maintenance department (CMD) of the supplier who has the facilities, the competences and the certifications to repair and manage the spare parts stock.
An (S-1, S) replenishment policy enables the shipment of a substitute efficient item anytime the supplier receives an inefficient item. The contract sects a service level agreement in terms of shipping time of a substitute item and of on-time shipments (fill rate) in a fixed period. The customer has to pay a fee in order to have access to the main stock (pool base) of the CMD and a shipping cost for any shipment.
The commercial pool contract regulates two transportation modes: standard request (STN) and quick request (QCK) with different shipping times, fill rates and costs due to different shipping processes.
In the STN process, the customer can demand for a local department kit (LDK), i.e. a subset of spare parts to keep at the LMD, in order to ensure a prompt response to the more critical requests. When a failure of an LDK item occurs, the customer directly substitutes the efficient item in the LDK and ships to the CMD the inefficient item removed from the failed equipment. The same (S-1, S) replenishment policy enables a shipment of an efficient item from the CMD to the LMD, which stocks it for next potential requests. This process generates an additional cost to the customer, which has to pay the supplier a percentage of the entire cost of the LDK item per month, for any LDK item (stock cost).
In addition to the STN, the supplier offers also the quick request, a faster transportation mode with specific contractual limits. While QCK does not provide any stock cost, its shipping cost is higher and, even though the shipping time is very short, it causes a degradation of customer performance in terms of availability due to the delayed substitution of the inefficient item. Furthermore, the customer can use this transportation mode only with respect to a contractual limit, in terms of QCK percentage of the total requests. The supplier does not accomplish the customer requests that exceed this limit, in order to avoid the customer abuse of QCK. Fig. 1 sketches the logic features of the two transportation modes, highlighting the differences of the two processes.
The selection of the optimal transportation mode for each item is based on a heuristic algorithm developed by Costantino et al. [2], which envisages the contractual service level agreement, logistic costs and availability requirements. According to this logic, the QCK item stock level in the LDK is therefore automatically set to 0, while the LDK stock level for the STN item requires an optimization process. At this step, decision-makers usually optimize the stock-level by the application of METRIC-like models.
For the purpose of this paper, it is necessary to focus on the STN items rather than on the QCK-selection algorithm. Once selected the best transportation mode strategy, for the STN items, the problem is indeed a conventional application of a METRIC-like model.

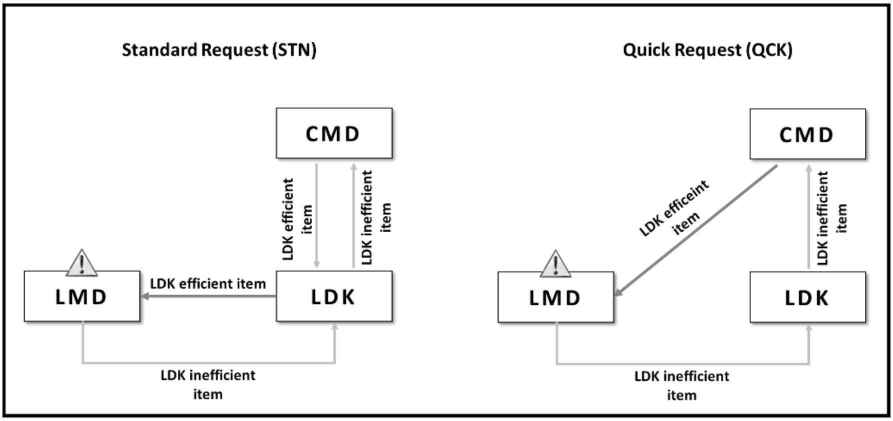

Figure 1: Transportation modes in a commercial pool contract.

This formulation generally requires assessing and comparing different allocations of stock. For this purpose it is necessary to assign a function to the expected backorder of an LRU at the LD, the so-called *EBO(s)*, for a stock quantity *s* and a request quantity *x*. The general formulation of *EBO(s)*, (probability that *x* > *s*) takes into account the mean demand value and the ordering and shipping time of items to define $Pr\{x\}$.

$$EBO(s) = \sum_{x=s+1}^{\infty} (x - s)\, Pr\{x\} \tag{1}$$

According to the features of the series, $Pr\{x\}$ assumes a Poisson, if $(variance/mean) \leq 1,$ or a negative binomial,
if $(variance/mean) > 1,$ shape. The ordering and shipping time contributes in defining the parameters of the distribution [5].
The aircraft availability is the series system of the availability of the items, which are function of their relative *EBO(s)*, under the hypothesis that each aircraft needs all its items to be available, in line with the assumptions of the QCK-selection algorithm. For the evaluated model, given that any site has a minimum required number of available aircrafts to satisfy its flight plan, a failure on an aircraft reduces the availability only if the number of available aircrafts is lower than the minimum required. An imperfection switching action model the possibility of successfully reassign the cold aircraft in a specific flight plan, taking into account the possibility of ongoing extraordinary maintenance operation. In this condition, a redundant system with (N-M) stand-by units, in which M of N must be operating models the availability of the fleet at the LD. Note that the decision-maker determines the target availability for the fleet, A_{target} which has to verify $A_{fleet} \geq A_{target}$ based on the airline policy.

$$A_{fleet} = A_{aircraft}{}^{M}\left(1 + P_{mod}\sum_{n=0}^{N-M}\frac{\left[-\ln A_{aircraft}{}^{M}\right]^{n}}{n!}\right) \tag{2}$$

$$A_{aircraft} = \prod_{i=1}^{I} A_i \tag{3}$$

$$A_i = \left(1 - \frac{EBO_i}{N}\right) \tag{4}$$

$$EBO_i \leq N \tag{5}$$

4 CASE STUDY

A case study of spare parts management for the Airbus 320 fleet of a European airline illustrates the features of the model. The QCK-selection algorithm firstly separates the QCK items from the STN items, but it is possible to neglect this step because in line with the purpose of this paper, which aims to consider only the STN items and verify the analytic optimum stock level reliability. It is therefore possible to neglect QCK items for simulation analysis.

The first step of this analysis consists in applying the METRIC model to define the STN items optimum stock levels, which permit to respect the constraint on the fleet availability. Then, the simulation model calculates the effective availability relative to the stock levels prescribed by the analytical METRIC formulation.

The simulation model therefore calculates the real number of Back Orders (BOs), considering the historic trend of each item demand, the optimum stock level yet obtained by METRIC formulation and the ordering and shipping time. It is possible to calculate the item availability in a period T, as the BOs divided by the total demand of the item.

$$A_i^{*} = \sum_{t=0}^{T}\frac{BO_i^t}{m_i^t} \tag{6}$$

BO_i^t represents the BO of the item *i* at the time *t*.

At this step, it is possible to compare the METRIC analytic availability to the simulation availability for each item to verify the accuracy of the model.

The analysis considers 1745 STN items.

The comparison defines two classes of items, the ones characterized by the agreement between METRIC and simulation results, i.e. Class A, and the ones for which the simulations results show the METRIC inaccuracy, i.e. Class B. The METRIC has proved itself useful to determine the optimum stock level for the bigger percentage of the items (i.e. Class A, 82.75%). However, a not negligible set of items (i.e. Class B, 17.25%) demonstrates that the analytic formulation is not able to confirm the theoretical optimum results. Table 1 summarizes these outcomes.

Table 1: Example of table.

Item Class	Number of Items	Relative percentage
Class A $(A_i^* \geq A_i)$	1444	82.75%
Class B $(A_i^* < A_i)$	301	17.25%

The further step consists in an analysis of the Class B series, trying to highlight common features. In this case, it is useful to observe that the demands of items for which METRIC is inefficient have strange trends in the two years. Fig. 2 shows some examples of the demands considered, where the time axis, which contemplates 822 days of historic data, is clustered according to the ordering and shipping time. The examined pool contract, indeed, contemplates a standard ordering and shipping time for each item, i.e. 20 days. Note that this hypothesis does not invalidate the results of the model, but it is used only to have a more understandable graphical overview of the trends.

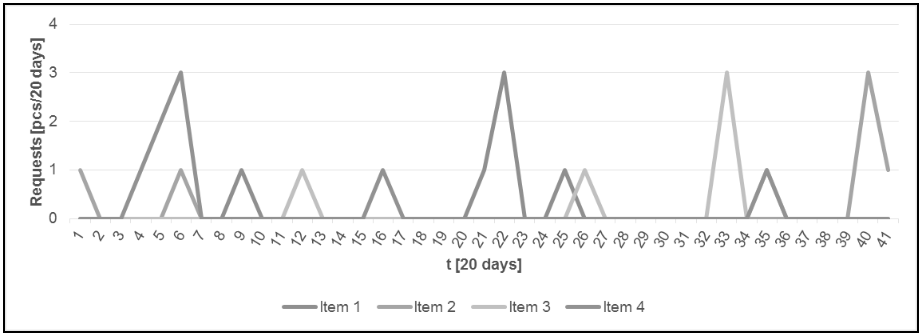

Figure 2: Examples of Class B demand trends.

In order to highlight common treats of Class B series it is possible to underline that in the majority of cases, Class B demands have irregular time intervals and very variable quantities. It is thus possible to evaluate this double characterization of spare parts demand, by two parameters:

- ADI (average inter-demand interval): the average interval between two demands of the same item, usually expressed in periods, and in this case, indeed, the order and shipping time, i.e. 20 days, represents the period.
- CV (coefficient of variation): the standard deviation of the demand divided by the average demand.

$$ADI = \frac{\sum_{i=1}^{N} t_i}{N} \tag{7}$$

$$CV = \frac{\sqrt{\frac{\sum_{i=1}^{N}(\varepsilon_i - \varepsilon)^2}{N}}}{\varepsilon} \tag{8}$$

where $\varepsilon = \frac{\sum_{i=1}^{N} \varepsilon_i}{N}$

Note that N in ADI represent the number of periods with non-zero demand, while for CV it is the number of all periods.
Ghobbar et al. [22] suggest some cut values capable of detail the characterization of the spare parts demand. Fig. 3 represents these cut values and localize the Class B demand in the graph. No Class B items are localized in the slow moving area or erratic area.

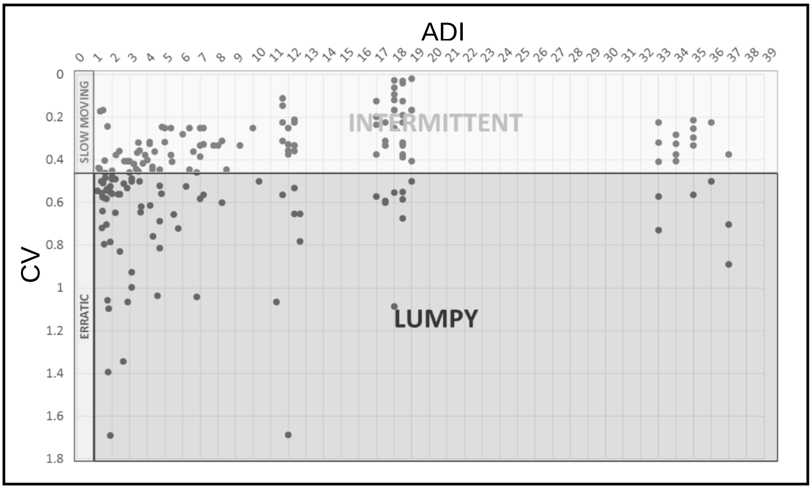

Figure 3: Class B item localized in the CV-ADI plane.

5 CONCLUSION

Commercial pool is an innovative inventory strategy that envisions the outsourcing of the spare parts ownership and benefit of risk compensation. However, even in a pool, the customer can demand for a local department kit (LDK), i.e. a subset of spare parts to keep at the local maintenance department in order to have prompt substitution of more critical items. The optimum sizing of the LDK items can be obtained by the application of METRIC-like models, broadly used in literature for this scope. This paper applies a METRIC-like analytical formulation in order to determine the optimum stock level at the LDK and it then compares the obtained results with a simulation model. Analyzing 1745 item demands, in the majority of cases (1444, i.e. 82.75%) the METRIC-like model offers a stock level capable of generating an analytical availability in line with the simulated one. However, METRIC does not offer reliable outcomes for a not negligible set of items (301, i.e. 17.25%). Analyzing in-depth these items, it is easily observed that their demands have irregular time intervals and very variable quantities. By two parameters, i.e. ADI (Average inter-demand interval) and CV (Coefficient of variation), it is thus possible to evaluate this double characterization of spare parts demand. The analysis permits to identify common treats of these demands and obtain a preliminary evaluation of METRIC reliability based on the results of this paper: METRIC-like model is not reliable for lumpy or intermittent demands process. According to this paper results, it emerges the need to review METRIC standard hypotheses, which fail to represent lumpy or erratic demand trends. The authors suggest changing the standard model, which is usually based on Poisson or Negative Binomial process, by the adoption of an empirical correction in the definition of the parameters of these distributions, based on the features of the series, (e.g.) standard deviation, ADI, CV, etc.
Otherwise, it would be possible to adopt different distributions, which better fit the demand process in case of Lumpy or Erratic demand process.
However, the authors would like to highlight that it would be necessary to confirm these hypotheses in different system structures, (e.g.) multi-echelon or multi-indenture. The comparison process defined in this paper, with a larger amount of data, will permit to make the METRIC process even more robust and resilient to better model each type of demand process.

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DESIGN OF COMPACT STORAGE SYSTEM

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Abstract
Storage facilities, including warehouses, distribution centers and container terminals can be found everywhere in supply chain networks. They form the key nodes in supply chain networks, decoupling demand from supply in time and quantity. Over the past decades, these facilities have evolved towards higher storage density, more automation, and more intelligent control.
The compact storage systems are the emerging solutions, permitting an exploitation of up to 98% of the storage volume and surface.
In the last years, few researches have been carried out in estimating performance of these storage systems and consequently in defining their configuration. All of them are focused on the retrieval of items from the stock locations.
In this paper, some solutions of commercial compact storage systems are illustrated and discussed. Then, a mathematical model has been developed in order to estimate the total time for retrieval and storage activities for a particular kind of storage system. The performance assessment and optimal configuration of the system are defined. Finally, the analysis of results permits to identify some guidelines to help the practitioners during the design process.

Keywords:
Compact storage systems, automated storage and retrieval systems, warehousing, logistics

1 INTRODUCTION

Storage facilities, including warehouses, distribution centers and container terminals can be found everywhere in supply chain networks. They form the key nodes in supply chain networks decoupling demand from supply in time and quantity.
Over the past decades, these facilities have evolved towards higher storage density, more automation, and more intelligent control.
This development is nowadays particularly attractive as:

- Land becomes more scarce and expensive in many densely populated areas, like the North-Eastern part of Italy.

- Space is scarce and energy consumption relevant, like within ships, aircrafts or coldstores and temperature-controlled warehouses.
- Costs of technology-based systems are decreasing.

As a result, a new generation of storage systems is emerging: dense, autonomous and intelligent (DAI) storage systems, also called ‘compact storage systems’.
As these systems do not depend on aisles for stacker cranes, they allow an exploitation of up to 98% of the storage volume and surface.
On the other hand, several limitations are present in the kinematics performance of these systems, especially in such industrial environments in which system response times have to be shortened to earn customers.
Such storage systems are today still rare and have not been widely studied in the academic literature, yet [1, 2]. Nevertheless, they are increasingly used, for example in automated car parking systems and in the container storage systems in the Netherland and Northern-Europe countries.
For this reason, new research efforts are strongly needed to better understand the applicability and the performance of this kind of innovative and fully automated storage system in new and ambitious industrial settings, providing new design approaches in order to significantly increase the system response times.

2 COMPACT STORAGE SYSTEMS: STATE OF THE ART

In general, compact storage systems are widespread for storing products with relatively low unit-load demand [3, 4] and are characterized by high space-usage efficiency. Different types of compact storage systems have been introduced with different handling systems to allow movements along the x-, y- and z- directions, e.g. conveyor-based compact storage systems with cranes or satellite-based compact storage systems with cranes [5]. Other innovative kinds of compact storage systems have been developed in the last years from commercial companies but only few of them have been investigated by academics.

2.1 Autonomous vehicle storage and retrieval systems (AVS/RS)

The most common type of compact storage system is a compact warehouse with shuttles and multiple deep-storage lanes (fig. 1). This system consists of compact shelving where shuttles can move, a machine S/R and an I/O location (or deposit). The machine S/R moves in both horizontal and vertical directions simultaneously. The shuttles are connected to the machine S/R and they can move inside the lane storage, reaching the selected location where storing or retrieving the units, whilst the stain S/R awaits the beginning of the lane. All movements start with the machine S/R from the I/O point (located at the bottom left of the rack). The loading units are stored from and retrieved at the point of I/O on a conveyor. The main limitation of these systems is that units must be handled several times if different products are stored on the same line. This is necessary in order to remove the load units stored in front of the product that must be recovered.

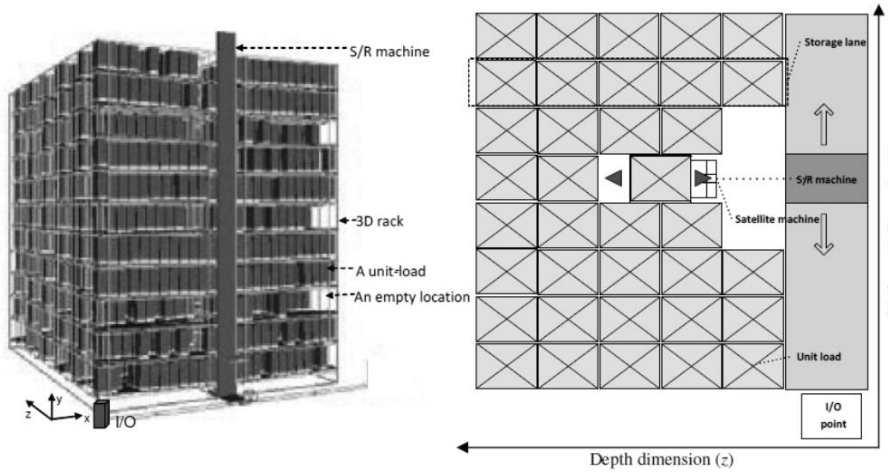

Figure 1: Top view of a AVS/RS, from [5].

Several papers have studied compact storage systems and AVS/RS, proposing analytical or simulation models for travel time estimation, optimization of system design, storage assignment and operations policy. Park and Webster [6] were the first to study compact storage systems, proposing a conceptual model for the design of this type of systems, based on the minimization of the expected travel time. Then, De Koster et al. [4] investigated the optimal storage rack design of conveyor-based compact storage systems with random storage. Yu and De Koster [1, 2] introduced a travel time model with a full turnover-based storage policy. Stadtler [7] and Zaerpour et al. [8] studied unit load storage assignment in satellite-based compact storage systems using cranes.

An innovative solution is the shuttle-based compact storage system (fig. 2) where lifts are used instead of cranes, coupling the flexibility of shuttle-based systems (created by adding or removing shuttles) with the space efficiency of compact storage [5].

As described by [5], a cross-aisle is located in the middle of the each storage level, where a conveyor moves the pallets between the shuttle waiting positions and inbound or outbound workstations.

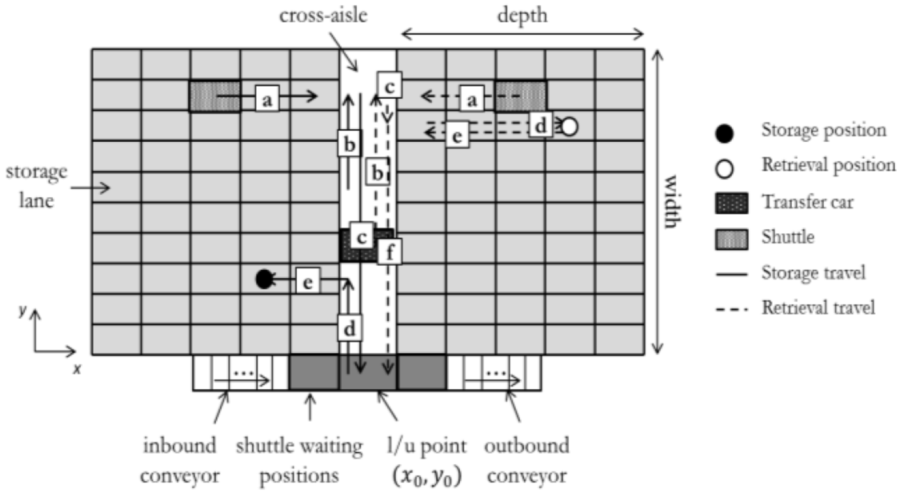

Figure 2: Top view of a shuttle-based compact storage system, from [5].

This kind of compact storage systems has been studied by several authors. The approach introduced by Perotti et al. [5] is particularly interesting; its authors have studied these systems, analyzing their performance through analytical modelling focusing on a single-tier in order to remove the complexity of modelling the interactions among tiers for the first step of the research and use this piece of work as building block for studying the multi-tier system.

2.2 Live-cube storage system

Although these storage systems are still rare, they are increasingly used, for example in automated car parking systems. Compared to traditional storage facilities, live-cube storage systems need less space. They are based on the famous Sam Loyd's sliding puzzles, but translated in a 3D form (fig. 3).

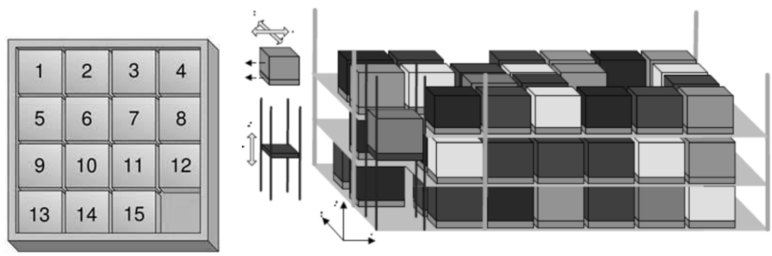

Figure 3: The famous Sam Loyd's sliding puzzle and a scheme of Live-Cube Storage system.

The slide-puzzle architecture, in fact, presents an opportunity to design storage spaces with the highest possible storage density [9].
Puzzle-based storage systems usually apply a Random storage policy [10]. This policy is studied widely in the literature in relation to most traditional AS/RS warehouses [4, 11, 12, 13]. In many studies, e.g. [11, 13], it is used as a benchmark to measure the improvements of other storage policies. Contrarily, these systems have not been widely studied in the academic literature, yet. Until the works of Gue and Kim [9, 14], nothing has been known about their operational performance. Gue and Kim [9] developed analytical results for storage configurations of a single-level live-cube system having a single empty location and experimental results for configurations with multiple empty locations. Today we can find few studies that focus on this topic [1, 2]. Alfieri et al. [15] proposed a work that considered a cheaper alternative, in which a set of AGVs are dispatched to shelves in order to move them. This variant denotes a more complex management scenario, since it is not only necessary to plan shelf movements but also dispatching of vehicles. Recently Zaerour et al. [16] studied random storage in a live-cube storage system where loads are stored multi-deep. They derive the expected travel time of a random load from its storage location to the input/output point. They also optimize system dimensions by minimizing the expected travel time. A research effort is now asked in literature to better understand these storage systems and bring them to achieve high logistics performance.

2.3 Autostore

One of the latest solutions appeared on the market is represented by the innovative logistics system for storage and retrieval, proposed by a commercial company, where small robots move and handle traditional bins both horizontally and vertically.
This system is optimized for light and small loads and it is based on a modular grid on which the robots translate in all directions to access and serve the various picking stations.
It has high modularity and flexibility, due to the dimensions of grid and number of robots, it easily fits in already existing buildings and its productivity can increase by inserting new robots while maintaining the occupied area.
The items stored in containers are piled in several columns and they are handled by robots, which are able to access each storage pile and to serve each picking station.
Thanks to an elevator based on a set of cables, the robot retrieves the bin on top of each column. If the item contained in this bin is not required, it is restocked on the top of another storage pile and the robot can retrieve the next bin.
Then, when the picked bin contains the required item, the robot moves to the column related to the input-output location and here it releases the bin to the picking station (fig. 4).

Such solution allows obtaining a high density of storage but with low selectivity, in fact the underlying bins are not directly accessible. This problem is solved with several storage policies and correct management of the robots.

Figure 4: Autostore storage system.

From the academic point of view, to our best knowledge, any contribution hasn't been developed about the design and management of this particular compact storage system.
In this case, the main problems are related to:

- The calculation of the optimal dimensions of the system, such as height of piles and number of piles for horizontal dimensions.
- The estimation of number of robots in order to guarantee a certain productivity.

3 DESIGN OF THE AUTOSTORE SOLUTION

3.1 Problem statement

The problem is to develop and to validate a mathematical model in order to estimate the unit cycle time to stock and to retrieve a bin to and from a general location.
The unit cycle time is function of the dimensions of the systems and the positioning of input-output locations. It can be divided into several parts: time to reach the pile where the bin is stocked, function of horizontal dimensions of the storage system, and time to perform all the retrieval activities, which depends on the height of the system.
The robot can move in one direction per time. Once the robot has reached the pile where the item is stocked, it can start to recover all the bins stocked above the required one. These bins have been stocked temporarily in the closest piles and eventually they are restocked by the other free robots.

Then it can pick the required bin and it comes back to the input-output location in order to release it to the picking station.
Based on this operating policy, the following mathematical model has been introduced and analyzed in order to define the optimal dimensions of the storage system and to estimate the number of required robots.

3.2 Mathematical model

Several notations are necessary in order to explain the following equations.

J : number of bins in *x*-direction;

C : number of bins in *y*-direction;

N : number of bins in *z*-direction;

l_b, w_b, h_b : bin sizes [m];

$s = s_x = s_y$, s_z : speed of the robot [m/s];

$t_x = {J \cdot l_b}/{s_x}$: time dimension of x-direction [s];

$t_y = {C \cdot w_b}/{s_y}$: time dimension of y-direction [s];

$t_z = {N \cdot h_b}/{s_z}$: time dimension of z-direction [s];

The time needed to stock and to retrieve a bin from a general location with (L_x, L_y, N_z) distances from the input-output location can be estimated as follows:

$$T = 2 \cdot \left(\frac{L_x}{s} + \frac{L_y}{s} \right) + \\ + \frac{[\sum_{i=1}^{i=Nz} (i-1)] \cdot 2 \cdot l_b}{s} + \frac{[\sum_{i=1}^{i=Nz} (i-1)] \cdot 2 \cdot h_b}{s_z} + \frac{N \cdot h_b}{s_z} \tag{1}$$

In order to optimize the dimension of the storage system, it is necessary to estimate the average cycle time from the previous one, fixed the input-output location, as follows:

$$\hat{T} = 2 * \left(\frac{J}{2} \cdot \frac{l_b}{s} + \frac{C}{2} \cdot \frac{w_b}{s} \right) + \\ + \left[\sum_{i=1}^{i=N/2} (i-1) \right] \cdot \frac{1}{2} \cdot 2 \cdot \frac{w_b + l_b}{2 \cdot s} + \left[\sum_{i=1}^{i=N/2} (i-1) \right] \cdot 2 \cdot \frac{h_b}{s_z} + \frac{N \cdot h_b}{s_z} \tag{2}$$

In this case, a corner position of input-output location has been considered.
Fixing the number of levels in z- direction, N, it is possible to derive the optimal values of other two dimensions of the storage system with these formulas:

$$C = \sqrt{\frac{k \cdot l_b}{w_b \cdot N}} \tag{3}$$

$$J = \frac{k}{N \cdot \sqrt{\frac{k \cdot l_b}{w_b \cdot N}}} \tag{4}$$

where $J \cdot C \cdot N = k$ and as a consequence the ratio between x and y dimensions is:

$$\frac{C}{J} = \frac{l_b}{w_b} \tag{5}$$

$$N = \left(4 \cdot \frac{k + w_b}{J \cdot s} + \frac{w_b + l_b}{2 \cdot s} + \frac{2 \cdot h_b}{s_z} - \frac{4 \cdot h_b}{s_z} \right) \Bigg/ \left(\frac{w_b + l_b}{2 \cdot s} + \frac{2 \cdot h_b}{s_z} \right) \tag{6}$$

$$C = \frac{k}{N \cdot J} \tag{7}$$

Using these formulas, the productivity of a robot can be determined, fixing a certain level of availability of the robot, called A, as follows:

$$M = 3600 \Big/ A \cdot \hat{T} \tag{8}$$

Then the total number of machines necessary to guarantee the total productivity of the system M_s is easily calculated as:

$$N_r = \left\lceil M_s \Big/ M \right\rceil \tag{9}$$

3.3 Validation and comparison with real applications

This mathematical model have been applied to real case studies in order to understand their validity and applicability.
From the website of autostore producer, several case studies have been collected with all the useful parameters for the comparison between the results of these formulas and real application.

	YELLOW CUBE	ASDA
Grid dimensions (Lx,Ly,Lz) [m]	40 x 18 x 6	48.8 x 29 x 6.8
Number of bins	32000	44860
I/O Locations	10	10
Horizontal Speed [m/s]	3	3
Vertical Speed [m/s]	1.6	1.6
Real Productivity [bin/h]	700	3350
Real Number of robots	35	140
Expected Number of robots (eq. 9)	31	141

Figure 6: Comparison with real applications.

As demonstrated by these two comparisons, the model introduced in this research well approximates the behavior of the system in real applications.
Then, the introduced equation can be applied during the design phase of these innovative compact storage systems in order to optimize both the storage capacity and their productivity.

4 CONCLUSION

In this paper, new compact storage systems have been introduced and discussed from a technical and academic point of view. From the literature review, no contributions have been found about a new type of these systems, called commercially Autostore. This system is very interesting and several applications demonstrate its validity but no mathematical models have not been developed yet in order to estimate the performance.
Then, in this research, analytical model has been introduced to cover this gap, permitting the assessment of total retrieval and storage time.
Starting from these equations, the optimal dimensions of the system have been calculated in order to minimize the total time.
Finally, the comparison of the introduced model with real case studies has permitted to validate them.
Future researches will investigate more deeply on this topic and will be focused on the optimization of the overall system under special conditions, varying the storage policy or the number of levels where the robots can move.

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IMPROVING THE PRODUCTIVITY OF A MAN-TO-GOODS ORDER PICKING SYSTEM THROUGH OPTIMIZATION OF ORDER BATCHING

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Abstract
Order picking has long been identified as the most labor costly and intensively activity in warehouse management. The orders from the customers need to be fulfilled tightly and timely. In order to keep the required high service level, the warehouse has to increase the picking productivity under the constraints of limited capacity. This paper concerns a man-to-goods order picking system, in which the order pickers have to drive with a pallet jack to the storage locations. Considering that the orders are mostly small orders which consist of less lines, it is efficient to combine several single customer orders into one picking order. Under this circumstance, this paper intends to answer the question of how customer orders should be grouped into picking orders with the aim of minimizing the total travel length through the warehouse. Consequently the productivity of the order picking system can be improved. An optimization problem for order batching is introduced. The optimization method of order batching is then proposed. Based on the simulation of different scenarios of incoming orders, it can be concluded that the developed method is effective in improving the productivity of the concerned order picking system.

Keywords:
Order picking, man-to-goods, order batching, picking productivity, genetic algorithm

1 INTRODUCTION

Order picking is the process of retrieving products from storage or buffer areas in response to a specific customer order in a warehouse. In most warehouses order picking is the most important process because it consumes the most labor and determines the response time to the customers. It is estimated that the order-picking cost accounts for as much as 55-60% of the total warehouse operating expense [1]. Nowadays the market is characterized by many product varieties, small order sizes, and

shorter response times. This kind of development induces more challenges for warehouse operations. Order picking has been considered as the highest priority area for the improvement of the operation efficiency of a warehouse [2]. To achieve higher productivity of order picking it is then essential to reduce the travel times of order pickers, which comprises the greatest part of the expense of order picking [3].
There are different measures of reducing the travel time of order pickers. One efficient way of improving the productivity of order picking is to move the goods to the order picker either automatically through using automated storage and retrieval technologies or manually through forklift trucks. In either case, the traveling time of the order picker is saved, which results in a higher efficiency in fulfilling the customer orders. However, the capacity investment either in hardware or in labors is consequently increased significantly. That is why most order picking systems are still man-to-goods or picker-to-parts picking systems, in which the order pickers collect the requested articles during walking or riding through the warehouse. However, the travel time can still be reduced through proper layout design of the storage area, optimal slotting of the articles in the corresponding convenient locations, applying different zones for parallel order picking, grouping a set of orders in a single picking tour and sequencing the items on the pick list, etc.
This paper deals with order batching, which groups several customer orders into a picking order. Through order batching the articles for several customers can be picked in one picking tour. This results in a significant reduction of total picking time needed to collect the requested articles of all customer orders. Order batching has been proven to be pivotal for an efficient organization of the picking operations [4]. That is why this paper develops a method based on genetic algorithm to solve general order batching problem for improving the productivity of order picking.
The remainder of this paper is organized as follows. In section 2, the order batching problem is described and the optimization model is formulated. The optimization method based on genetic algorithm is proposed in section 3 and the results of different scenarios are summarized in section 4. Section 5 concludes the paper.

2 PROBLEM DESCRIPTION AND MODEL FORMULATION

The general order batching problem concerned in the literature is defined as follows: Given a routing strategy and capacity of the picking device, how can a given set of customer orders with known storage locations be grouped into picking orders such that the total length of all picker tours is minimized [5]? Considering the routing strategy, there are mainly four strategies in a single block layout being developed in the literature, namely return strategy, S-shape strategy, largest-gap strategy and Combined strategy [6]. One particular strategy can be selected at first and then sever as input for the

order batching decision. Tours based on the S-shape or largest-gap heuristic are prevalent in practice since order pickers seem to accept only straightforward and non-confusing routing schemes [4] [7] [8]. The capacity of the picking device is either expressed in the number of customer orders, in the number of items to be picked, in volume or in weight.
According to Gademann and van de Velde, the order batching problem can be formulated as an integer programming as follows [9]:

$$\min \sum_{i \in I} d_i x_i \tag{1}$$

$$\text{s.t.} \sum_{i \in I} a_{ji} x_i = 1, \forall j \in J \tag{2}$$

$$\sum_{j=1}^{n} a_{ji} \leq c, \forall i \in I \tag{3}$$

$$x_i \in \{0,1\}, \forall i \in I \tag{4}$$

where x_i is a zero-one variable which means if the ith batch is selected ($x_i = 1$) or not ($x_i = 0$). d_i is the total distance to be traveled to pick all items of the orders in batch i. a_{ji} is a zero-one parameter, which states whether customer order j ($j \in J$) is included in batch i ($a_{ji} = 1$) or not ($a_{ji} = 0$). $J = \{1, 2, \cdots, n\}$ is the set of customer orders. A customer order consists of set of order lines. Each order line is composed of a particular article and the corresponding requested number of items. It is not permitted to split a customer order for one storage area since it would result in an additional, unacceptable consolidation effort. $I = \{1, 2, \cdots, m\}$ is the set of all feasible batches. A batch is in this case a picking list containing the order lines for single customer order or multiple customer orders, which should be processed together and guiding the order picker through the storage. c is the batch size.
The objective function (1) is an evaluation measure of the total distance to be traveled for all batches. The constraint (2) ensures that each order is assigned to exactly one batch. The constraint (3) ensures the feasibility of the batch i. One batch is feasible when there are not more than c customer orders in the batch. The constraint (4) limits the valid value of the variable x_i.

3 GENETIC ALGORITHMS

Genetic algorithm (GA) is a search technique premised on the evolutionary ideas of natural selection and genetic. A GA starts with a population of randomly generated individuals. The population then evolves via successive iterations called ‘generations’. In each generation, the fitness of every individual in the population is evaluated, and then multiple individuals are selected from the current population based on their fitness and modified to form a new population through crossover and mutation. In this GA, the selection strategy is a combination of the tournament selection method and the elite mechanism, which is an efficient selection mechanism [10]. The new population is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population.

3.1 Encoding scheme

GA as a general global search technique has been well established and successfully applied to complex engineering parametric optimization problems [10]. However, if the GA can be used for one specific engineering problem or not depends on the possibility of encoding of the problem.
For the order batching problem, the feasible solution is encoded through a string of integers. Each integer represents one customer order. One string is composed of all customer orders. One integer can only appear once in the string, which fulfills the condition that the customer order cannot be split. For example, the string of integers (10,3,5,2,6,4,7,8,11,1,12,9) shows that there are 12 customer orders which are numbered as integers from 1 to 12. Which customer orders should be grouped together is also encoded in the string? It depends on the batch size, i.e., the capacity of the picking device regarding to customer order. The customer orders in the string from the first number to the number of batch size should be grouped together as one batch and the next customer orders in the amount of the batch size should be in the second batch and so on. Suppose the batch size is four, for 12 customer orders, it is necessary to have three batches. In the string example, the first four customer orders with integers 10, 3, 5, 2 should be grouped together as batch 1; the next four customer orders with integers 6, 4, 7, 8 should be handled in batch 2; and the last four customer orders with integers 11, 1, 12, 9 are distributed to batch 3.

3.2 Crossover operation

For the order batching problem based on the encoding scheme introduced above, the two-point crossover method is used. The operation of just two-point crossover is each to realize. It is only necessary to change the part in between the randomly selected two points in the strings. Since each integer representing one customer order can only appear once in the string, therefore, the repeated integers muss be corrected or repaired. The rule is that only the repeated integers in the exchanged part in the string are replaced by the missed integers from small to large. This process is shown with exact examples in fig. 1.

3.3 Mutation operation

The mutation mechanism allows one randomly selected integer in the string to be exchanged with another randomly selected integer in the string. Fig. 2 illustrates clearly the mutation mechanism.

3.4 Genetic parameters

According to Deb and Goyal [10], the crossover rate influences the evolutionary performance of the GA the most and hence is set to be 0.6, and the mutation rate is set to be 0.05.

	Parent 1:	(10,3,5,	1,12,9,7,8,11,	2,6,4)
	Parent 2:	(4,7,2,	10,5,3,1, 6,12,	8,9,11)
Crossover	In between Child 1:	(10,3,5,	10,5,3,1,6,12,	2,6,4)
	In between Child 2:	(4,7,2,	1,12,9,7,8,11,	8,9,11)
Correction	Child 1:	(10,3,5,	7,8,9,1,11,12,	2,6,4)
	Child 2:	(4,7,2,	1,12,3,5,6,10,	8,9,11)

Figure 1: Cross operation.

Parent :	(10,3,**5**,1,12,9,7,**8**,11,2,6,4)
Child:	(10,3,**8**,1,12,9,7,**5**,11,2,6,4)

Figure 2: Mutation operation.

4 COMPUTATIONAL EXPERIMENTS

In order to evaluate the performance of the proposed genetic algorithm numerically, a single-block dedicated storage system as shown in fig. 3, with two cross aisles and one depot located in front of the leftmost aisle is assumed. A depot in a warehouse is the location where the order pickers start the picking tour and return back. Layouts of this type are frequently used in numerical experiments in the literature [7] [8] [9].

The warehouse consists of six vertically oriented picking aisles. On each side of the aisle there are 30 storage locations. That means through one aisle 60 different items can be reached. The total capacity of the warehouse is 360 locations. Each storage location accommodates one type of item and each item type is stored in only one location. The gray marked rectangles show just schematically the locations of the items ordered by one customer.

If the width or depth of one storage location is considered as the standard distance unit (DU), the distance between two storage locations is one DU, the necessary movement from the first and the last storage location of a picking aisle into the cross aisle is one DU and the center-to-center distance between two aisles amounts to six DUs. The depot is located three DUs away from the first storage location of the leftmost aisle.

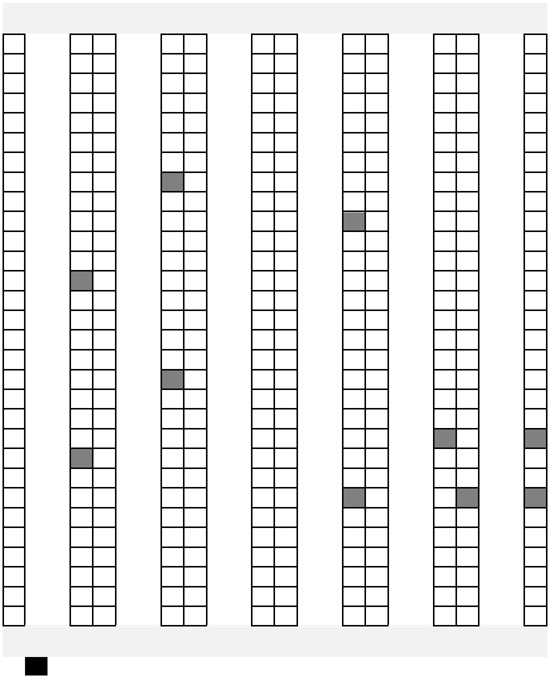

Figure 3: The schematic storage layout.

Based on the 2D warehouse layout in fig. 3, six test problems, referred to as Problems 1 to 6 are generated for the numerical experiments. The number of customer order is varied in six steps from 24 to 144. The number of articles in one customer order is generated in a random manner in the range of $[0,10]$. The capacity the picking device is defined as the maximum number of customer orders. Each picking device can only handle the most six customer order in one tour. The S-shape routing strategy is used for the routing determination. Tab. 1 summarizes the basic information of the six problems and the corresponding batching results obtained from the algorithm.

Table 1: Summary of test problems and batching results.

Problems	P1	P2	P3	P4	P5	P6
No. of orders	24	48	72	96	120	144
Distance (DU)	532	970	1420	1840	2020	2880

5 CONCLUSION

To increase the productivity of warehouse operations, especially order picking, it is essential to optimize the processes which are possible to be optimized. For order picking with many small customer orders in one picking zone or area, it is undoubtedly more economic to collect the items for different customers in one tour than collection of the items for the customers in separate tours. This paper developed a genetic algorithm for the optimal batching of customer orders with minimized total travel distance. Through computational experiments, the algorithm is proved to be efficient. Because of the flexibility of GA itself, it is also possible to use the method for more complex order batching problems. Of course, this needs to be exactly confirmed through more experiments. Furthermore, the performance of the algorithm should be in the future further confirmed by comparing with other methods in the literature.

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SESSION E
Management Practices and Methodology

FIVE STEPS TO EXCELLENCE WITH MSCDPS® - A METHOD THAT COMBINES SOCIO-SCIENTIFIC ASPECTS AND LEAN MANAGEMENT

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Abstract
In a case study, the adaption and implementation of the MSCDPS® method to a Chinese market leading company is demonstrated.
The MSCDPS® method is driven by long time experience in the management of change processes to gain a lean, innovative and self-optimizing organization for medium-sized companies. Its uniqueness is the introduction of socio-scientific insights in the change management for medium-sized companies. Core factor of a successful and self-driven transformation of a whole company is the engagement and qualification of the staff. It combines the TOYOTA approach of continuous improvement and strengthening the lean cooperation of all process partners with the western procedure of revolutionary leaps [8]. With the MSCDPS®-method, the issues identified in the inventory potentials will be implemented with the involvement of employees.
Clients' market position and opportunities will be evaluated and quantified: this will take into account the costs, the durability of the products, etc. Also the strengths and weaknesses of one's competitors will be investigated. The break-even point is affected by the technology used, the fixed and variable costs and the overall flexibility. After this 'frontloading' the 'continuous long lasting strategy to market leadership' can be defined and implemented.
Step 1 'stable, self-optimizing, and sustainable processes': crucial is the development of a kaizen process. Step 2 'Establishment of a product clinic': start of the advancement process for the product, installation of a product clinic, visualization of its results for a continuous learning of the organization. Step 3 'Monitoring, detailed measures': visualization of each process. Step 5 'Approval' of the pilot project, preparation to out roll additional areas": results will be a commitment of management and co-workers for self-optimizing and the on-going strategy. There will be transparent, continuous long lasting processes for problem solving and improved quality, reduced costs and better performance.

Keywords:
Lean management, lean production, product creation process, frontloading, change management, and empowerment

1 WHAT DOES CHANGE MEAN IN DAY-TO-DAY BUSINESS?

Conversion? Change? Reorganization? Nowadays, not a single company that wants to be successful can ignore these questions and decisions. Regardless of their size, turnover, and number of employees, the market requires companies to implement adaptations.
The markets determine the requirements. The requirements of clients and customer groups take center stage in the reorganization of processes and structures. They serve as markers for products and services. All top managements need to remain flexible and continue reorganizing.
Conversion, change, and reorganization develop into processes that are implemented in day-to-day business. In this day and age, scarcely any company can refuse to accept or ignore and postpone changes.
Conversion, change, and reorganization – How can they be carefully planned, successfully implemented, and carried on in the long term? The MSCDPS® method, which was specifically developed to support change processes, is characterized by its focus on sustainability through employee participation and tailored to the possibilities and requirements of medium-sized companies.
Change occurs in small steps, step by step, and never by force. All that is needed is a lot of patience. Patience coupled with awareness of how things are interconnected and understanding of fears and emotional setbacks are indispensable prerequisites for a company to start adopting change processes.
The consulting approach combines technical with socio-scientific approaches. Its strengths lie in the availability of technical and socio-scientific expertise and expertise based on long-time experience as well as the availability of social competences such as empathy, coaching skills, and moderation. The advantage is team cooperation based on the client's problems and questions and a high level of employee acceptance of consultants.
Fig. 1 illustrates the three levels that the MSCDPS® model encompasses: medium-sized companies gain significant advantages in quality through innovation.

2 THE NINE CHARACTERISTICS OF THE MSCDPS® MODEL

MSCDPS® anticipates the so-called 4P of TOYOTA's philosophy [3] – see fig. 2. Quality is the lever for success [22] and the only unique selling point that is effective in the long term because all other product features can be copied. Quality prevents waste in the form of rework, after-sales service, and emergency actions using the most valuable company resources [18,21]. That makes quality the key prerequisite for cost leadership.
The MSCDPS® method, with its focus on quality, is based on nine statements.

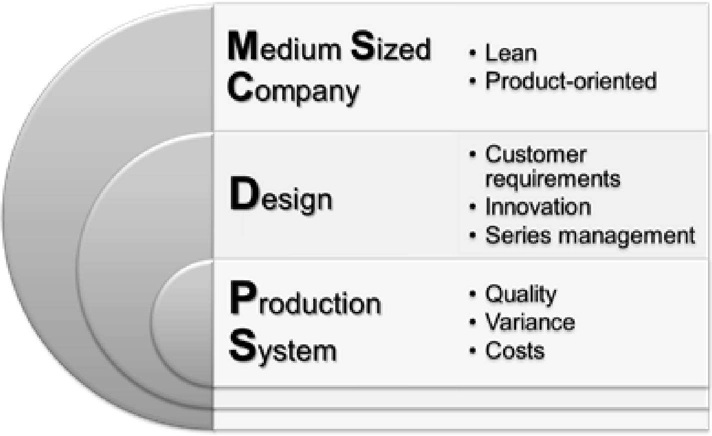

Figure 1: The three levels of the MSCDPS® model.

Characteristic 1: employee participation
Differences in the success of companies can be explained by the use and qualification of their employees. Basically, people feel the need to learn and develop themselves and their environment. A company that supports its employees and encourages them to continue learning and developing themselves will continue to be innovative and successful.

Characteristic 2: customer requirements
Taking into account current and anticipating future customer requirements is a key success factor. One way to get there is by establishing lead customer care.

Characteristic 3: transparency and visualization
Visualization and communications are key instruments of any innovation project. Cockpits visualize key indicators and generate sustainability.

Characteristic 4: communication
Efficient operations of development teams require project space, the so-called OBEYAS (Japanese for large room). The development teams meet there at specific times to hold group meetings and to work. The visualization of the results achieved, often with simple, handwritten, large-format charts and exhibited test or sample parts, induces close, informal communication and a strong sense of belonging to the respective development team across all the operating units involved.

Characteristic 5: executive and employee empowerment
The term empowerment refers to self-empowerment, autonomy, and self-disposal. Empowerment describes courage-generating processes of empowerment in which people start to take their affairs into their own hands. They become aware of and develop their own capabilities and use their individual and collective resources [14]. With the MSCDPS® method, the empowerment of the process participants is strengthened through coaching, mentoring, training, etc.

Characteristic 6: mistakes as a guide
Only in a culture in which mistakes are forgiven does innovation occur; only when risks are faced with courage can new things be created. Mistakes are departures from the accustomed, established path which can generate valuable clues. A culture of error analysis is created, for instance through statistics, in which mistakes are uncovered and improvement processes implemented that demand systematic error analyses such as TOYOTA's well-known A3 procedure [2, 3].

Characteristic 7: studying examples
Benchmarking allows for classification and evaluation of in-house capabilities. A product clinic [10] includes in-house production, for instance also by presenting successful competing products.

Characteristic 8: lean production processes
Lean production is flexible and ready for on-going improvements. Stocks breed inertia and generate financial inflexibility. Lean production operates according to the pull principle: each employee is responsible for an adequate supply of preliminary products and information, fluid processes with the lowest possible volumes, and a willingness to reduce productivity for quality and not pass on flawed products [3, 5, 18, and 19].

Characteristic 9: learning management (going and learning locally)
Successful medium-sized companies have highly competent managements. By establishing exemplary management behavior, regular on-site visits to the place where value is created will become a corporate principle (according to the principle of going and learning locally). Only those decisions are implemented that affect the long-term development of the organization and the product – GEMBA (see fig. 3).

3 MSCDPS® PROJECT TARGETS

With the MSCDPS® method, companies are supported in creating an environment for their employees that encourages their creativity and so makes possible the creation of fascinating products or services.

The interplay of the stakeholders involved in the product-development process and high-level product knowledge up to and at top management levels constitutes the strength of medium-sized companies. With knowledge and experience supported by the latest practical findings from organizational sciences, the MSCDPS® method contributes to the development of the company's strong points through individual adaption of best-in-class development practices—as exemplified by TOYOTA's lean development cycle (see fig. 3).

3.1 Procedure with MSCDPS® process, implementation

The MSCDPS® method starts with a careful determination of the initial situation and task-clarification phase. At the start of the project, all the parties involved have to agree on the project target and approach.

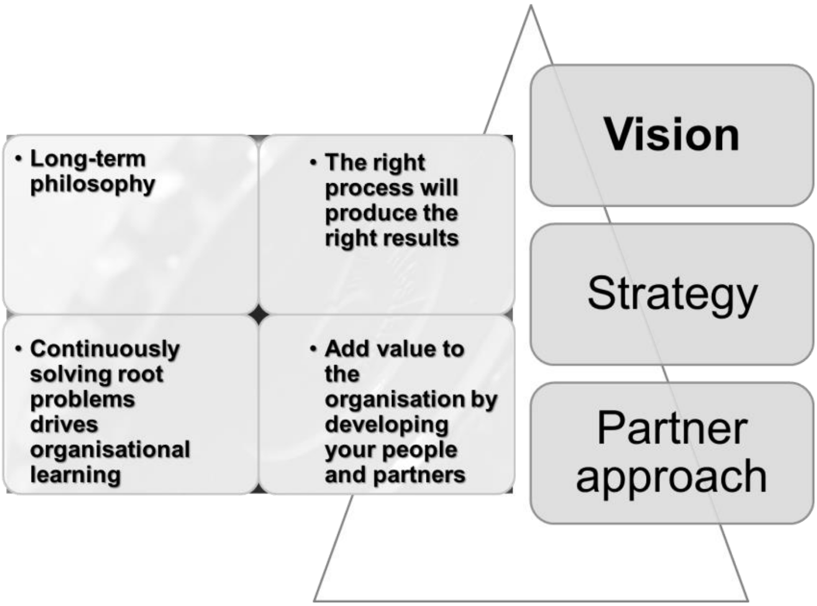

Figure 2: The four basic principles of MSCDPS® adopted from TOYOTA's approach [2].

Over the course of the project, the MSCDPS® method allows for a lot of room for intensive, target-oriented communication. The clear-cut presentation of the circumstances ensures transparency.
MSCDPS® projects cover a wide area, i.e., various alternative solutions are identified. Decisions carefully have been prepared and are documented. A key deciding factor is the robustness of a solution against expected

environmental impacts and the development potential, which contains the preferred solution.

3.2 Consulting steps for the implementation of MSCDPS®

Companies establish processes that assure the on-going flow of required new products [10, 7]. The purchase decision of clients is the product benchmark. By incorporating lead clients in the development process, undesirable developments may be identified early on and evidence may come forth that will make the new product desirable to potential clients. On-going care and trust is what a lead-client relationship requires.
For medium-sized companies to generate scale effects in production and procurement is a seemingly on-going trade-off with the requirement of meeting organizational, customer requirements. Multi-functional solutions that are adapted to customer requirements may meet these requirements. Classic variant management requires a target-oriented organization and is an on-going challenge for the management. Product platforms may be applied to deal with this challenge. The key task is to organize the interface and change management after selecting a minimal number of appropriate platforms.

3.3 MSCDPS® implementation in the company

The first step is to systematically query the product requirements of the clients, management, and other stakeholders through the development and innovation organization.
This includes topics such as:
Which customer requirements are there?

- How is the incorporation of the customer requirements organized in the development specifications?
- How large a share do new developments have in the engineering capacity?
- How does the global product launch function?
- How is the development safeguarded?

With the support of the consultant, the aim is to identify potentials and resources, develop successful strategies, filter out future requirements, and identify internal blockages and insufficient simplicity.

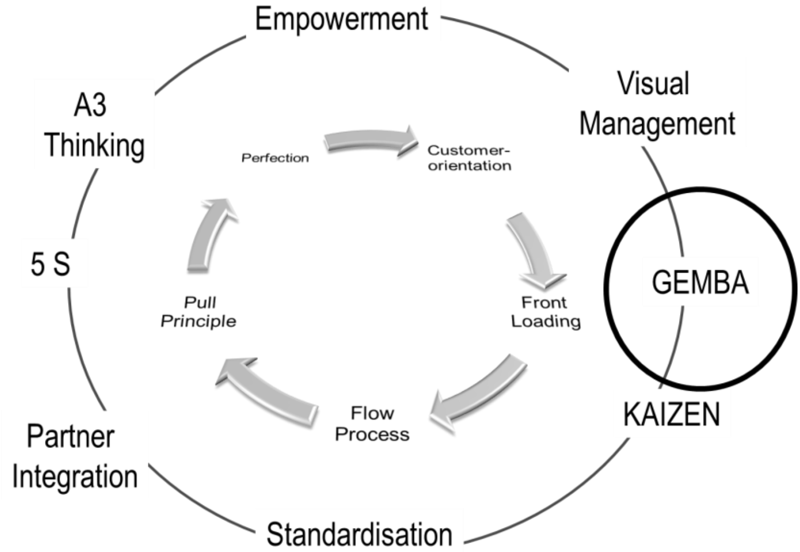

Figure 3: MSCDPS® development circles for perfection [15].

Analysis: taking stock of initial situation

- How is the product-development process structured?
- Inquiries into company documents, organizational chart, and overall concept
- Which competences are available locally?
- How are the lines of communications organized in the area of development?
- Taking into account site-specific requirements
- Size of business units, which locations produce for which markets?

Workshops on target clarification

The workshop is about using the improvement potentials of the participants. During the entire process, evaluations take place throughout all phases to assure reflection of the developed contents and of the group situation. The participants are informed that their opinion is called for and by working in study groups and teams, they may use the opportunity to be heard and participate in a qualified manner in the improvement, reorganization process.

4 THE FIVE-STEP PROGRAM: ACHIEVING EXCELLENCE IN FIVE STEPS

The MSCDPS® procedure has demonstrated its practical suitability in various application scenarios [12, 13]. As a case example, we wish to present the consulting of a Chinese commercial-vehicle company. They want to develop their structures and processes with the procedure so their products will be cleared for delivery to the European and US market and they want to develop build a sustainable organization to be innovative and competitive on an international level.

A practical case study

As organizational developer, we supervise a change process in a German-Chinese joint venture. The Chinese company is a production company with around 2,500 employees. The principal office of the company is in the megacity Zhucheng in Shandong province. The organizational form of the company is functional: It is divided into departments such as production, marketing, development, and procurement.

As our point of departure, we implemented a company audit in April 2015, in which we analyzed and queried the strategic units following the ISO TS 16949 approach.

Prior to initiating on-site operations, we conducted many coordination and preliminary talks on Skype with the company management and our Chinese-language agent from Singapore. We received a comprehensive organizational chart of the company with its individual departments and the persons responsible. In accordance with the departments we singled out for our survey, the respective qualified persons were contacted in advance, informed about our plans, and asked to participate.

To kick off the action in China, the joint-venture agreement was concluded in the presence of representatives of the provincial government. Moreover, the company management arranged for around 100 employees to be present at the preliminary meeting the first morning we were at the company. The individual areas were informed that we were conducting meetings in the company and would carry out an audit. We presented our concept, which we had initially prepared based on findings from the Skype conferences and information from Internet sources such as the company website and our professional experience, in individual, easy-to-follow steps.

At the company, we were welcomed very sympathetically and respectfully. We were met with curiosity and extreme hospitability in all respects. Immediately after the preliminary meeting, we started the actual audit work. In each case, we were accompanied by an English translator. Every evening, we analyzed our results and findings and adapted our next steps to the on-site situation. Each audit activity, which included both surveys and observations at the respective workplace, was carried out as far as possible after the standardized procedure and adapted each time to the workplace conditions. We conducted the surveys as guided interviews with the

executives of each evaluated department. At the site of the workplace, we observed and recorded the machinery, environment, and working situation and conducted and documented further meetings.
It turned out to be extremely helpful that the top managers, the company director himself, and his substitute, the son of the entrepreneur, were at our disposal at all times and that they had informed their executives and the employees about our visit and our task. Some of them were present as guests at the official ceremony of the signing of the joint-venture agreement. And so, the information that a team from Germany would visit the company and conduct meetings and observations filtered through to all company levels. This, and the commitment of the employees, made our work all the easier. At no time did we experience open blockages or obstructions, though this does not mean that there were no possible hidden aspects we were not told about.
Supported by the audit results, our findings, and the experience we had gained locally, we and the company management—after holding intensive discussions on Skype—developed a program for our overall organizational-development plan, which we will initiate in the summer of 2015.

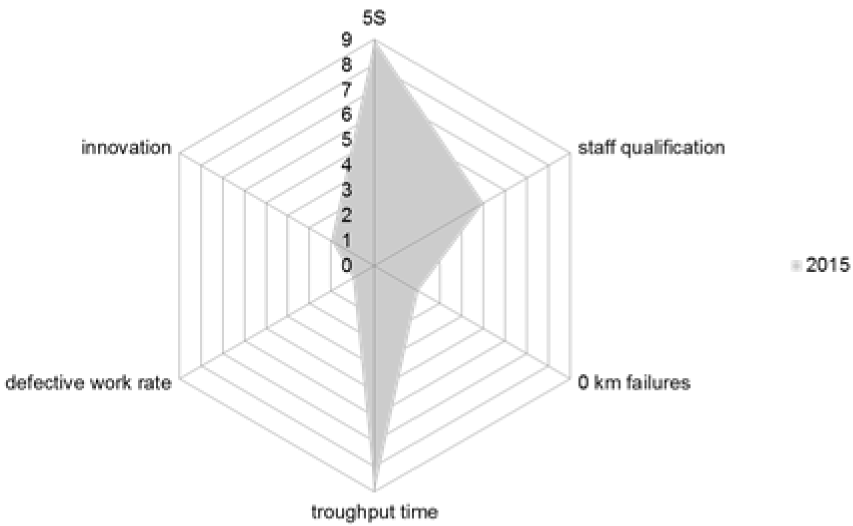

Figure 4: Radar chart of corporate key data.

We would like to highlight one of our audit results, the so-called radar chart with a presentation of key corporate performance data. The picture demonstrates a high level of imbalance. The key data cover the areas workplace innovation, organization, and cleanliness as well as employee qualification, delivered malfunctioning products, production time, and amount of rework. Major shortcomings remain, in particular with the delivered malfunctioning products, rework rate, and innovation.

5 CONCLUSION

Conversion, change, and reorganization involve stress in the company. Executives as well as employees, board and managers are under pressure. Nonetheless, they are required to successfully carry on with the day-to-day operations. The one thing that has to be done is to relieve the strain and commit innovators who manage the reorganization process and support all those involved.

In the case of the Chinese company, the MSCDPS® method was chosen to optimize the processes. Consulting without technical product knowhow and without taking into account the possibility of employee participation will not generate the required concrete success.

Overall, the practical application of the combined consulting approach, which combines technical and socio-scientific knowledge and experience, has proved its worth.

Figure 5: Assembly of axles according to the continuous-production principle.

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CRITICAL FACTORS TO SUCCESSFULLY DEVELOP A3 REPORTS IN HEALTHCARE SECTOR

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Abstract
Many studies recognize that lean management can contribute to address problems of healthcare organizations due to the economic and quality benefits achievable without requiring high investments. A3 report is an improvement tool commonly employed to govern lean implementation with successful results. However, previous studies mainly focus on technical outcomes of A3 reports adoption while social outcomes are often neglected. So far, most of the studies that consider these social outcomes are just speculative and anecdotal, there is no an empirical research of the determinant factors of A3-based kaizen programs in practice. This study employs the results of improvement programs developed at the university hospital of Siena to identify the critical success factors of the social outcomes. These results are considered to develop guidelines for the healthcare organizations and propose approaches for future research.

Keywords:
Lean management, A3 report, employee development, health care

1 INTRODUCTION

Lean management has become a dominant paradigm to resolve quality and economic problems in health care sector [15][20] because this system allows for increasing value for the costumers based on reducing wastes but without high investments [11].
Lean management is commonly implemented by using tools such as the A3 report. The A3 report is a problem-solving tool which helps employees to improve their communication and integration of specialized knowledge to reach successful technical and social outcomes [11][22]. However, despite of the recognized benefits of A3 report, researches on the factors that influence the A3 reports outcomes, mainly social outcomes, are largely anecdotal and speculative [20], thus there is a lack of empirical research of A3 reports in health care sector [24].
Using the framework developed by Farris et al. [21], this research aims to investigate whether the variables influencing social outcomes in

manufacturing organizations also influence the social outcomes in health care sector. We addressed this issue by examining the members of the kaizen teams that performed the A3-based kaizen programs of the university hospital of Siena. Examining similarities and differences in the predictors of social outcomes in both sectors can provide valuable information to both kaizen managers and health care management direction of the hospitals.

2 LEAN MANAGEMENT AND KAIZEN PROGRAMS

Many studies recognize lean management to be the dominant improvement paradigm [21] which can resolve the quality and economic problems of public health care organizations due to the benefits achieved without high investment. The kaizen or continuous improvement is the approach to implement the lean management in any organization such as the health care. This approach is adopted by using mechanism such as problem solving methodologies (A3 report) [25], kaizen events, quality circles, employee suggestion-programs and other ongoing policies that allow employees for improving their daily work [13].

2.1 Kaizen events or rapid improvement events

A kaizen event or rapid improvement event [7] is a focused and structured improvement program, using a dedicated cross-functional team to improve a targeted work area, with specific goals, in an accelerated timeframe [14], (during 5-7 days). This mechanism is characterized by relying on a top-down approach for improvement strategy implementation [7][14], which means that the board decides if and where is needed an improvement program (kaizen event) [14]. According to Farris et al. [21] internal processes is the strongest predictors of social outcomes. In fact, this study suggests to maintain positive group dynamics contributes to increase both the employee participation in future improvement programs and employee problem solving capabilities (understanding of continuous improvement and knowledge).

2.2 Problem solving procedure (A3 report)

Problem solving procedure is carried out by using A3 reports. This kaizen tool, which is the keystone in Toyota production system, is a powerful tool which documents the problem-solving steps, status, reports and planning procedures [11][19] considered by front line workers to resolve daily small problems. In addition, specialized training to understand how an A3 report should be used is not required [11]. A3 report transforms a common organization into a truly continuously improving organization because it increases the rate of organizational learning [14]. This tool establishes a discipline of reasoning [17] to get a better communication and integration of specialized knowledge of human resources and contributes to their development of new problem solving capabilities [17][23] during the kaizen program and the daily work.

The problem solving procedure which employs the A3 report, relies on a bottom-up approach for improvement strategy implementation [24], that is, the employees decide if and where is needed an improvement program.

3 EMPLOYEE DEVELOPMENT

Human resources are acknowledged as the core component in lean organizations according to the lean literature [7][12][18]. In fact, all these kaizen mechanisms stress the key role of employee involvement [2][24] because kaizen programs are practically employee driven [10][26]. Therefore, human resources need to be respected, challenged and developed [26][4] because the level of kaizen mentality [15] that employees achieve is crucial to obtain successful results.

Nevertheless, even though lean literature suggests accomplishing successful technical and social improvements, the last are often neglected. In fact, the development of employee attitudes, knowledge and skills is often a formal objective of kaizen programs [6][12][21][22]. So far, research on the factors that influence social outcomes in lean health care organizations are largely anecdotal and speculative [20][22]. There is a lack of empirical research of A3 reports in health care sector [24]. Thus, empirical research on social outcomes in health care sector is an emerging field.

In the manufacturing sector, there are few empirical studies about the determinant factors that influence the social outcomes. Farris et al. [21] proposed a manage framework to identify the social outcomes. However, this study is considered as kaizen mechanism, the kaizen events or rapid event improvements.

Hence, considering that both kaizen mechanism are based on the PDCA cycle and using the framework developed by Farris et al., the following research question is formulated:

> *To what extent are the factors influencing the social outcomes in healthcare sector similar to the factors that affect the social outcomes in manufacturing sector?*

We address this issue by interviewing the members of the kaizen teams that performed the kaizen programs. Examining similarities and differences in the determinant factors of social outcomes in both sectors allows for explaining how these critical success factors contribute to systematically manage A3-based kaizen programs and to improve and develop the workforce of the organization. Additionally, based on these factors, guidelines can be developed to successfully manage kaizen programs.

4 METHODOLOGY

4.1 Sample selection

Selection criteria were established to increase the validity of study results (tab. 1). The university hospital of Siena was selected because it matches the selection criteria. This health care organization provided data of the kaizen programs that were carried out from January 2013 to December 2014.

Table 1: Selection criteria of the organization (adapted from Farris et al. [21])

Criterion	Description	Purpose
1. Public health care organization	Nowadays, the public health care sector clamors for solutions due to its economic and quality problems.	To contribute to resolve the problems of health care sector.
2. Type of internal organization within the hospital.	All internal organizations, that contribute directly and indirectly to the healing process of patients, will be recruited to increase the generalizability of results.	To provide the baseline similarities in fundamental services.
3. Systematic use of A3 report	All organizations use A3 report as part of a formal organizational strategy.	To demonstrate the management commitment to support the A3 process
4. A3 report employment frequency	All internal organizations have conducted at least an improvement process by employing the A3 report.	To enable an adequate sample size of A3 processes

The University Hospital of Siena

The university hospital of Siena is the unique public health care organization [27] that currently implements the lean management in Italy by employing the A3 report. The kaizen programs are performed by employing parallel teams [5] which are supported by the members of the lean office. This office carries out training courses for all human resources of the hospital to describe the lean principles, techniques and tools. The A3 report is presented to the workers as the key tool to undergo an improvement program. Once an employee has an improvement idea and wants to resolve any work area problems using lean tools, the support of the lean office is often asked to carry out an improvement program. The lean office works as an internal consultant. Although the development of an A3 report is not compulsory, many employees perform one by themselves due to the benefits described during the training and tested by their colleagues. These bottom-up programs are mainly developed out of hours. At the end of each year, the lean day is organized to award the best improvement programs that were developed using the A3 report. So far, 272 hospital employees developed 80 A3-based kaizen programs.

4.2 Instruments and measures

The interviewing instrument was modified considering the data collection instruments employed by Farris et al., [21], previous studies on A3-based kaizen programs and the improvement strategy implementation of the university hospital of Siena. Therefore, the framework developed by Farris et al. was modified (fig. 1). Furthermore, the three hypotheses to identify the direct and indirect predictor were also considered as follows:

- H1: Input factors are predictors of the outcomes.
- H2: Process factors are predictors of the outcomes.
- H3: Process factors mediate the effect of input factors on outcomes.

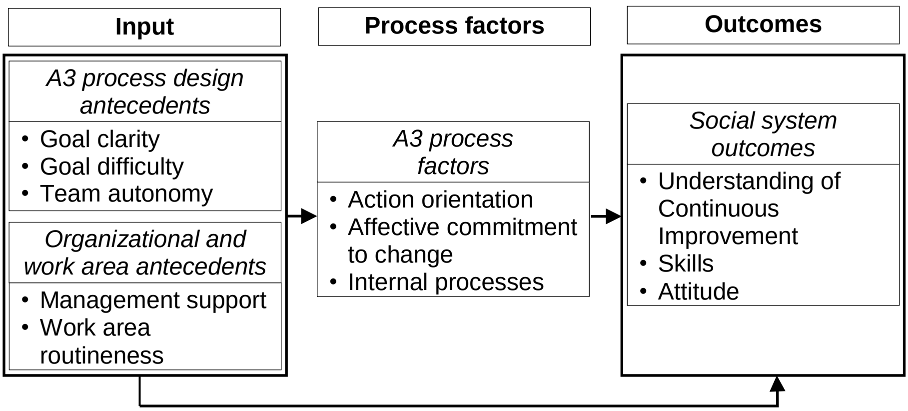

Figure 1: Problem solving (A3 report) management model (adapted from Farris et al. [21]).

The final data collection instrument was established based on the scales that are described in tab. 2. It contains 47 questions which were rated using 6-point Likert scale. For each kaizen program, the team members were interviewed according to their last improvement experience. 100 team members were interviewed which are distinguished as follows: 10 physicians, 4 physiotherapists, 40 nurses, 30 health professionals, 7 health care workers, 9 administrative staff. For the 79% of the team members was their first experience while the rest of them developed more than one A3 report.

Table 2: Theoretical factors.

Instrument	Scales	Items
1. Kick-off	• Goal clarity (GC) • Goal difficulty (GD) • Affective commitment to change (ACC)	• GC1,GC2,GC3,GC4. • GD1,GD2,GD3. • ACC1,ACC2,ACC3,ACC4, ACC5,ACC6.
2. Report-out (input) and process factors	• Internal processes (IP) • Action orientation (AO) • Management support (MS) • Team autonomy (TA)	• IP1,IP2,IP3,IP4,IP5. • AO1,AO2,. • MS1,MS2,MS3,MS4,MS5. • TA1,TA2,TA3,TA4.
3. Report-out outcome	• Understanding of continuous improvement (UCI) • Skills (SK) • Attitude (AT)	• UCI1,UCI2,UCI3. • SK1,SK2,SK3,SK4. • AT1,AT2,AT3,AT4.

4.3 Construct validity

The exploratory factor analysis strictly follows the procedure suggested by Farris et al. The principal component extraction with oblique (direct quartimin) rotation was employed to extract the components. Individual items were considered to have loaded onto a given factor when the loading was 0.5 or greater and all-cross loadings were less than 0.3. The initial database contained 100 questionnaires. Three factor analyses were performed according to the type of instrument described in tab. 2.

Table 3: Pattern matrix for factor analysis of kick-off items.

Items	Component[a]		
	1	2	3
The objective showed what the team want (GC3).	**0.986**	0.037	-0.128
Clear definition of improvement actions (GC2).	**0.917**	-0.007	0.007
Clear definition of the objective (GC1).	**0.825**	-0.035	0.129
The team grasped clearly the objective (GC4).	**0.764**	0.016	0.121
Perform the improvement actions using A3 report (ACC5).	0.624	-0.010	-0.263
Required skills to get the objective (GD3).	-0.086	**0.798**	-0.004
Difficult plan to get the objective (GD2).	-0.034	**0.784**	0.229
Ambitious improvement objective (GD1).	-0.121	**-0.747**	0.171
The A3 report is the correct improvement strategy (ACC2).	0.109	0.023	**0.772**
The A3 report helped to hold improvements (ACC3).	-0.095	0.152	**0.718**
The A3 report was useful for future improvement (ACC4).	0.108	-0.078	**0.713**
The A3-method will improve my work area (ACC6).	0.221	-0.153	**0.676**
Confidence about using the A3 report (ACC1).	0.149	-0.159	**0.670**

[a]Each item is considered loaded onto a construct if its loading is ≥ 0.500 and all-cross loadings were ≤ than 0.300.

Tables 3-5 present the results of factor analyses. For each item labelled in tables, the letters refer to the scale name, while the number refers to the item ID. As shown in tab. 3 and 4, the factors analysis supported the construction of the scales. Most of the underlying factors that were extracted matched the content of the multi-item scales and thus were used in further analyses.

Table 4: Pattern matrix for factor analysis of report-out input items.

Items	**Component[a]**			
	1	**2**	**3**	**4**
Respect for the team member opinion (IP3).	**0.938**	0.016	-0.099	-0.063
Respect for the team member feeling (IP4).	**0.904**	0.039	0.039	0.010
Account of team members' contribution (IP2).	**0.896**	-0.052	0.018	0.056
Team members communicated openly (IP1).	**0.875**	-0.019	0.041	-0.015
Appreciation of team member skills (IP5).	**0.827**	0.203	0.090	0.029
Freedom to modify the work area (TA2).	0.022	**0.878**	-0.111	0.031
Freedom to ideate an improvement (TA1).	0.122	**0.831**	-0.077	-0.095
Freedom to how schedule the time (TA3).	0.155	**0.815**	0.057	0.055
Help of other workers to improve any area (MS5).	0.115	-0.090	**0.799**	-0.071
Support of a sponsor to improve any area (MS3).	-0.028	-0.021	**0.761**	-0.025
Immediate test of changes (AO1).	-0.122	0.046	-0.030	**0.907**
Time to ideate a change (AO2).	0.226	-0.110	0.206	**0.649**

[a]Each item is considered loaded onto a construct if its loading is ≥ 0.500 and all-cross loadings were ≤ than 0.300.

Table 5: Pattern matrix for factor analysis of report-out outcome items.

Items	**Component[a]**
	1
Motivation to perform better the daily work activities (AT1).	**0.918**
Improvement of interest of team members toward their work area (AT3).	**0.884**
Knowledge improvement of how apply continuous improvement (UCI2).	**0.883**
Generate new improvement ideas after the A3 report experience (SK1)	**0.875**
Happiness to participate in a continuous improvement program (AT2).	**0.873**
Knowledge improvement of continuous improvement theory (UCI)	**0.822**
Participation in future improvement activities (AT4)	**0.822**
Develop new skills after the first A3 report experience (SK3).	**0.843**
Acknowledgement of implement the continuous improvement (UCI3).	**0.804**
Measure the continuous improvement impact on the work area (SK2).	**0.780**
Team members worked comfortably during the A3 report program (SK4)	**0.665**

[a]Each item is considered loaded onto a construct if its loading is ≥ 0.500 and all-cross loadings were ≤ than 0.300.

As tab. 5 shows, the loading pattern produced by the factor analysis of the outcome measures of report out questionnaire, suggests only one component underlying dimensions. This component appeared to contain a consistent uniformly focus on the three scales. Thus, this component was called social outcomes (SO).

5 RESULTS

5.1 Identification of direct predictors of outcomes

Multiple regression was used to identify the direct predictors of social outcomes (SO). A candidate model was considered to be viable if all variables had p-values less than 0.05. The social system outcomes model explained approximately 70% of the variance in the outcome. Thus, H1 and H2 were partially supported; in fact, social outcomes were predicted by two input factors and two process factors.

Table 6: Results of a multiple regression analysis for direct predictors of social outcomes (SO).

Variable	Model 1 (y=SO)	
	β	p
Intercept	-0.967	0.024
Goal clarity	0.187	0.026
Team autonomy	0.155	0.004
Affective commitment to change	0.598	0.000
Internal processes	0.264	0.004
R-squared	0.690	
R-squared	0.761	

5.2 Identification of indirect predictors of outcomes

Mediation analysis was used to identify the indirect predictors of social outcomes (SO). Three regression coefficients in two equations were tested (step 1 and step 2). The step III was performed to confirm whether each input variable (x) was a significant unique predictor of the mediator (z).

Internal processes and affective commitment to change are significant mediators of the effect of goal clarity and team autonomy on the social system outcome. Internal process is also a significant mediator of the effect of goal difficulty on the social system outcome. H3 is supported with two significant mediation effect on the social system outcome. Acting indirectly through both affective commitment to change, internal processes, goal clarity and team autonomy are significant predictors of the social outcomes, accounting for 30% and 15% of the direct effect of affective commitment to change and 60% and 20% of internal processes.

Table 7: Results of a mediation analysis for indirect predictors of social outcomes (SO).

Step1	z = ACC A		p		z = IP a		p	
GC	0.282		<0.0001*		0.579		<0.0001*	
GD	0.073		0.143		0.163		0.024	
MS	-0.038		0.060		0.022		0.437	
TA	0.148		0.001*		0.193		0.003	
WAR	0.065		0.072		0.069		0.179	
Step 2	b	p	c’	p	b	p	c’	p
Mediator	0.888	<0.0001*			0.567	<0.0001*		
GC			0.409	<0.0001*			0.330	0.001
Mediator	1.008	<0.0001*			0.635	<0.0001*		
TA			0.244	<0.0001*			0.242	<0.0001
Mediator					0.795	<0.0001*		
GD							-0.026	0.670
Step 3	z = ACC a’		p		z = IP b		p	
GC	0.307	<0.0001*	<0.0001*		0.612		<0.0001*	
TA	0.133	0.003*	0.003*		0.172		0.006*	
GD					0.127		0.049	

6 DISCUSSION AND CONCLUSION

This research demonstrates that the factors determining the success of improvement initiatives in the manufacturing context (goal clarity, team autonomy, affective commitment to change and internal processes) are valid also in the healthcare sector, even though the kaizen mechanisms employed are different. This finding confirms that kaizen mechanisms can vary but, if they are coherent with the learning cycle of continuous improvement [5], their outcomes can be comparable. However, what changes is the relative strength of the predictors. In fact, Farris et al. [21] suggested that internal processes are the strongest predictor of successful social outcomes of kaizen events in manufacturing sector, while the present study identifies in the affective commitment to change the major predictor of social outcomes of A3 reports in healthcare sector. From a practical point of view, this difference warns about the development of *ad hoc* lean implementation strategies for the healthcare sector [24]. Furthermore, this finding is aligned with organizational change literature which sustains to there is a relationship between employee affective commitment [9] to change and change initiative effectiveness [8][21]. In fact, employee affective commitment is determinant when employees develop the improvement programs by themselves independent of management attitudes and supports [8]. Therefore, public healthcare organizations which decide to implement the lean management employing the A3 report should emphasize on creating team buy-in for the kaizen programs. That is, this organization should develop strong interest of employees to implement change [8] in order to achieve successful results (e.g. performing on-job simulations with substantial results). Moreover, the internal processes is also a significant predictor of the social outcomes. This suggests to health care organization should emphasize on the internal harmony, positive group dynamics and team coordination [5][16] during the A3 report development. Finally, this study also confirms the importance of goal clarity and contradicts studies that suggest using loosely goals [1][21]. Likewise, this study supports the importance of team autonomy to accomplish successful social outcomes [3][21]. Thus, health care organizations should emphasize on the clearly understanding of the goals by part of all members of the team and the autonomy to determine the changes to improve the work area.

7 LIMITATIONS AND FUTURE RESEARCH

Future research could focus on testing this framework on other public/private healthcare organizations with longer experience (more than five years) in the use of A3 report and other kaizen mechanism. In addition, this research only investigated the determinants of initial kaizen program outcomes. Future research could focuses on the sustainability of the positive results by employing the A3 report.

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IMPACT OF THE KEY PERFORMANCE INDICATORS ON A MAINTENANCE PROCESS: A LITERATURE OVERVIEW

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Abstract
Many organizations are still considering the maintenance process as a very costly process that adds little value to the organization. The greatest importance of the maintenance process is that, if it is properly developed and well managed, contributes greatly to asset preservation in order to achieve all maintenance objectives (availability, reliability, product quality, etc.). Monitoring the effectiveness of maintenance process can be carried out through the use of key performance indicators (KPIs). Although the concept of KPIs is long known and much research has been carried out regarding that field, the level of application of KPIs in a maintenance process is still low. Therefore, this paper will give answers to the following questions: Why is there a need to measure maintenance performance? How to pick key performance indicators? Why are indicators used in a maintenance process? What are literature gaps regarding the usage of KPIs in a maintenance models / frameworks?

Keywords:
Maintenance, key performance indicators, maintenance performance measurement

1 INTRODUCTION

The main idea of key performance indicators (KPIs) is that they should help organizations to understand how well they are performing in relation to their strategic goals and objectives. In simple terms, they should provide important performance information that will help identify critical areas in the organization that need additional attention.

Although nowadays KPIs are widespread in modern companies, companies that are using KPIs correctly and effectively are not common. KPIs only have an impact on a process if the right ones are identified, measured and analyzed on a regular basis to inform and illuminate decision making in a business.

Measuring performance of the equipment or performance of the maintenance function is of great importance for all organizations where the maintenance process has an impact on other business processes. In the last few years, the number of measurements and collected data in a maintenance process has increased dramatically due to the fact that condition based inspection technology and development of information and communication technology (ICT) have become widely used.

The problem begins when the collected data have to be interpreted and used to ease a decision making process or even predict or prevent breakdowns. To solve this problem and to make benefits from collected data in a maintenance process, a set of performance measurements, called maintenance performance indicators (MPIs) is used.

Much research has been done in the past years regarding the use of the performance measurement in a maintenance process. Due to that, the purpose of this paper is to give an overview of the recent literature which presents the ways of use maintenance performance indicators. The aim is not to give an exhaustive overview on all published articles where maintenance indicators are mentioned, but rather highlight the significance of measuring maintenance performance and give update of the papers that have already provided similar overviews.

This paper is organized as follows. In section 2 there will be a discussion about the maintenance performance and need to measure maintenance performance. In section 3 reasons for use MPIs and ways of selection MPIs are presented. In section 4 overview of the models and frameworks that use MPIs will be given. Finally, in the conclusion, arising questions regarding this field will be discussed and future directions for this research will be given.

2 IMPORTANCE OF MEASURING A MAINTENANCE PERFORMANCE

The most detailed overview on the importance of measuring maintenance performance was given by papers [1], [2], [3], [4] and [5].

Mobley [1] highlights that the measurement and subsequent management of organizational performance is necessary to determine whether goals and objectives are being met. The purpose of measuring performance is to help predict future action and performance based on historical data. Measuring performance helps identifying areas that need management attention. On the other hand, measuring performance also highlights successful areas and accomplishments.

Samat et al. [2] state in their review of maintenance performance measurement that it is important to monitor and improve maintenance activities from time to time to ensure effective operations. Maintenance can be monitored and improved based on its performance. Maintenance performance reflects the capabilities of the maintenance system to ensure continuous production of quality products and to reduce total operating cost at the same time. Management requires performance information to be able to improve their maintenance activities. The absolute value of such performance information can then be compared to a previous situation or a

trend. The value can be used to glean the maintenance performance levels and to ensure a continuous improvement plan.
Based on the literature, Parida [3] first outlines that the reason for measuring performance in general is to provide management and employees with feedback on the work they are performing. The feedback from employees can generate many potentially positive effects, such as improving motivation or launching improvement initiatives, which can support the organization for achieving continuous improvement. Due to that general conclusion, maintenance performance measurement (MPM) linked to performance trends can be utilized to identify business processes, areas, departments and so on, that need to be improved to achieve the organizational goals.
In the future work, Parida and Kumar [4] state that MPM can be effectively utilized for the improvement and the process evaluation and MPM data can also be used as a marketing tool, by providing information, like; quality and delivery time. MPM is also used as a basis for benchmarking, in comparison to other organizations. MPM is a powerful tool for aligning the strategic intent within the hierarchical levels of the entire organization. Thus, it allows the visibility of the company's goals and objectives from the CEO or strategic level to the middle management at tactical level and throughout the organization.
In their overview of maintenance performance metrics, Kumar et al. [5] address the importance on measuring performance due to the next facts:

a. The maintenance of large-investment equipment is considered key for improving the cost-effectiveness of an operation, creating additional value by delivering better services to customers;
b. Due to the increased amount of outsourcing, it is becoming crucial to measure, control and improve the assets' maintenance performance.

To conclude, all authors are implicating that the most important achievements of maintenance performance measurements are the identification of opportunities to improve existing equipment and plants, and improved supplier performance. In the end, this results in positive organizational and structural changes.

3 WHAT ARE KPIs AND HOW TO PICK THEM?

The literature refers that an indicator is 'the measured feature (or set of features) of a phenomenon, according to a specific formula that evaluates its development' [6].
Adamkiewicz and Burnos [7] state that the purpose of the application of the key performance indicators in the maintenance is for:

- The obtainment of the current and historical values of the measures of the operation properties and their mutual relation,

- The diagnostics of the implemented maintenance activities,
- The implementation of the process of the continuous improvement through the search and elimination of any meaningful deviations from the assumed design figures,
- The monitoring of the changes and progress in the operation system.

In addition, Abreu et al. [8] state that the use of indicators is of high importance as these will inform the current status of maintenance in the organization and answer questions related to the:

- Number of breakdowns, availability and unavailability of equipment
- Distribution of human resources and related costs
- Requests from the various departments
- Materials' consumption and inventory management
- Requests for services from external entities
- Needed changes in the infrastructure
- Time to replace equipment

For monitoring effectiveness of a maintenance process, KPIs, i.e. maintenance performance indicators (MPIs) are used as a special metric that covers all aspects of the maintenance (technical, organizational and financial).

MPIs can be described using a set-theoretic model: *P* = <*N, A, Tp, U, P, B, GV, Tr, F, G*>, where *N* is name of indicator, *A* – using area (object, agent or all maintenance process); *Tp* – type of indicator (*Tp* = {quantitative, qualitative}), *U* – indicator's unit of measurement value, *P* – indicator's measurement (monitoring) values frequency (*P* = {noting; day; week; month; quarter; half year; year}), *B* – bordering value, *GV* – indicator's goal value; *Tr* – trend of indicator value; *F* – calculating formula for indicator; *G* – goals associated with indicator [9].

The selection of MPIs depends on the way in which the MPM is developed. MPIs could be used for financial reports, for monitoring the performance of employees, customer satisfaction, the health, safety and environmental (HSE) rating, and overall equipment effectiveness (OEE), as well as many other applications. When developing MPIs, it is important to relate them to both the process inputs and the process outputs [4].

The available literature mainly proposes common lists of MPI but lacks an agreed-upon methodological approach of selecting or deriving business specific MPI from the listed indicators in literature. Therefore, maintenance managers are left to select relevant MPI for their specific business situation [5, 11, and 27].

Goncalves et al. [10] state that establishing a useable set of maintenance performance indicators mainly depends on the maintenance objectives and the company's goals. Maintenance performance measurement is a multidisciplinary process that takes into account multiple aspects of maintenance activities. For that reason, the selection of the best maintenance performance indicators is a complex task, which can be formulated as a multi-criteria decision making (MCDM) problem. They propose a new approach for selecting relevant maintenance KPIs using a methodology based on the original ELECTRE I, which is a multi-criteria decision making method. The proposed methodology, which involves the decision maker's preference information, determines a ranking of possible alternatives following its evaluation according to important criteria.

A step further has been made by van Horenbeek and Pintelon [11]. They developed an MPM framework that aligns the maintenance objectives on all management levels (i.e. strategic, tactical and operational) with the relevant MPI used. For selection of the relevant MPIs they used the analytic network process (ANP) method.

Both research papers had the same outcome, i.e. proposed methodologies were used as an effective tool to aid maintenance managers in the definition and accurate selection of MPIs according to the maintenance and corporate objectives and strategy.

4 USE OF A PERFORMANCE INDICATORS IN A MAINTENANCE PROCESS

The importance of optimizing a maintenance process has been recognized both by academics and industrial / service companies where maintenance process has to support primary process. Due to that, plenty of optimization models and maintenance frameworks have been published over the years.

The most detailed overview of the models applied in maintenance optimization has been given by van Horenbeek et al. [12]. They state that there is a big gap between academic models and application in practice as it is very difficult for industrial companies to adapt these models to their specific business context. To overcome that problem, they developed a generic classification framework of maintenance optimization models, with special focus on the optimization criteria and objectives used. This framework groups all factors that have an influence on the optimization model and links that factors, i.e. inputs, to the specific maintenance objectives, i.e. outputs.

In order to differentiate models and frameworks that use maintenance performance indicators, and that are developed after this thorough research, an overview of the literature is given in tab. 1.

Table 1: Overview of reasons of use MPIs in models, frameworks, methodologies or reviews in different areas of application.

REFERENCE ***Specific industry / Area of application***	**MODEL / FRAMEWORK / METHODOLOGY / REVIEW**	**WHY ARE MPIs USED?**
Muchiri et al. [13] (2010) *Asset / Maintenance management*	Explore the use of performance measurement in maintenance management	As a tool for evaluation of maintenance management state
Nik-Mat et al. [14] (2011) *Facility management*	Methodology for designing Performance Measurement System	As a measure for identifying areas that need improvements
Muchiri et al. [15] (2011) *Manufacturing companies / Asset maintenance*	Conceptual framework that provides guidelines for choosing maintenance performance indicators	For analysis of maintenance effort/process
Bartz et al. [16] (2011) *Metallurgical company / Maintenance management*	Analyzed and identified potential maintenance indicators that may be adopted by enterprise	For evaluation of the performance level
Qingfeng et al. [17] (2011) *Petrochemical company / Maintenance management*	Equipment maintenance and safety integrity management system (MSI)	As a part of a decision-making process for delivering maintenance strategy
Shahin and Attarpour [18] (2011) *A steel manufacturing plant / Maintenance management*	Decision making grid for maintenance policy making	For determining maintenance policy based on the indicators' range
Efthymiou et al. [19] (2012) *Review / Asset maintenance*	A review on the predictive maintenance approaches, methods and tools in manufacturing systems	For visualization of the critical activities
Adamkiewicz and Burnos [7] (2012) *Ship turbines on the floating vessels / Asset maintenance*	Aspects of the application of the maintenance KPIs in the management of the operation	For examination and analysis of the power systems in order to provide desired information to the management

REFERENCE ***Specific industry / Area of application***	**MODEL / FRAMEWORK / METHODOLOGY / REVIEW**	**WHY ARE MPIs USED?**
Malamura and Murata [20] (2012) *Production / Maintenance management*	Simulation model that combines production process and the information flow of maintenance work-orders	For identifying best maintenance strategy and optimization opportunities
Qingfeng and Gao [21] (2012) *Oil transfer stations of PetroChina / Asset maintenance*	Risk and Condition Based Indicator Decision-making System (RCBIDS)	For fault prediction
Abreu et al. [8] (2013) *Business process improvement / Maintenance management*	Framework for improvement of Maintenance Management Procedures	For defining improvement actions
Oliveira et al. [22] (2013) *Industrial Companies / Asset management*	Framework for maturity model	For determining companies' maturity level
Chompu-inwai el al. [9] (2013) *Maintenance management*	Framework for development of maintenance performance measurement model	For equipment Maintenance and Repair Overhaul system optimization
Oliva et al. [23] (2013) *Asset maintenance*	A system based methodology based on an executable unified model built with Probabilistic Relational Model (PRM)	For verification if the objectives of the production and maintenance systems are satisfied
Morad et al. [24] (2013) *Medium / low voltage public distribution substation transformers network / Asset management*	Framework for criticality based maintenance management	As a base for measurement of reliability trends
Jafarnejad et al. [25] (2013) *Electricity Company / Maintenance management*	Framework that aims to design and implement the measurement and improvement system for maintenance	For measuring and defining corrective activities

REFERENCE ***Specific industry / Area of application***	**MODEL / FRAMEWORK / METHODOLOGY / REVIEW**	**WHY ARE MPIs USED?**
Rastegari and Salonen [26] (2013) *Asset management*	A framework for formulating maintenance strategy	As a measure for supervision of organization objectives
Kumar J. et al. [27] (2013) *Manufacturing Industry / Maintenance management*	A conceptual framework that provides the overview of maintenance performance metrics	As a part of analysis for determining groups / similar categories of maintenance metrics
Imam et al. [28] (2013) *Oil and Gas (O&G) industry / Asset management*	Highlighted World Class Maintenance (WCM) indicators for the Oil and Gas (O&G) industry	For comparing the asset performance with world-class standards
Lobna et al. [29] (2013) *Asset management*	A framework for analyzing the problem of performance evaluation in maintenance process using ECOGRAI method	To ensure that strategic objectives of a company are achieved
Nestic et al. [30] (2013) *Metal processing sector / Maintenance management*	Model for assessment of maintenance process quality using the fuzzy set and genetic algorithm approach	For comparing and contrasting assessment of the quality of the maintenance process in different fields.
Meselhy et al. [31] (2014) *Manufacturing systems / Asset maintenance*	Framework for development of a periodicity metric for evaluating maintenance strategies	As an indication when the equipment has to be reset
van Horenbeek et al. [11] (2014) *Asset maintenance*	MPM framework that aligns the maintenance objectives on all management levels with the relevant MPI used	As a goal, i.e. to select KPIs that will ensure that maintenance objectives will be achieved

REFERENCE ***Specific industry / Area of application***	**MODEL / FRAMEWORK / METHODOLOGY / REVIEW**	**WHY ARE MPIs USED?**
Chemweno et al. [32] (2014) *Asset management*	Framework for asset maintenance maturity model (AMMM)	For continuous improvement through re-defining maintenance targets
Lahiani et al. [33] (2014) *Production / Maintenance management*	Combined simulation and Non Dominated Sorting Genetic Algorithm-II (NSGA-II) optimization model	For showing systems' dysfunctions and as a goal for future optimization

After analyzing the papers, it has been noticed that performance indicators in maintenance have been used in various industries where maintenance process is of great importance, but mostly they are used in the area of asset maintenance / management. In addition, the models and frameworks mostly use same known indicators and an attempt for developing complex indicators that would replace multiple indicators has not been found in the overviewed literature. In most of the papers, indicators are used as a starting point, i.e. optimization criteria that will assist in achieving wanted goals / outputs. Another important finding was that the use of application-based maintenance optimization has not been significant in papers.
As mentioned in the section 3, some of the main reasons for the implementation of MPIs are the identification of critical area(s), fault prediction, and the process of continuous improvement. Finally, based on the withdrawn conclusions from the reviewed literature in this paper, other significant reasons for using MPIs are the selection of an appropriate maintenance strategy and comparing quality of a maintenance processes in various industries.

7 CONCLUSION AND FUTURE WORK

The significance of measuring maintenance performance has not only been noticed on operational levels in a company, but also on organizational level. As mentioned in the previous sections, the use of MPIs can depend on various reasons – fault prediction, critical area identification, a starting point in a process of continuous improvement and also comparing quality of a maintenance processes and determining the appropriate maintenance strategy. It is obvious that the impact of the MPIs is of great importance as it can significantly affect the whole organization and lead it towards the

wanted goals (cost minimization, process / service time reduction, etc.). In addition, it is important to understand MPIs and use them correctly as they can be the main influencing factors in a decision making process.
Due to that, data collection plays an important role in the process of calculation and interpretation of MPIs as incorrect data can cause wrong decisions. Data sources that are mainly used in the calculation of MPIs are failure data, cost data and operating data. Without the use of sensors and remote data transfer, data are usually collected by the people who monitor and, in some case, operate the equipment. Afterwards, the collected data are manually entered in the information systems, which is used for managing all maintenance activities. It is obvious that the human factor is a very significant actor in the process of measuring maintenance performance as it affects the accuracy of the collected data. Minimizing the effect of the human factor on data accuracy can be achieved by implementing e-maintenance strategy, which is based on information and communication technology. Using e-maintenance, the right information can be provided at the right time and this will result in the right decision. If correct and complete data are available, optimal solutions of the maintenance problems can be made and correct models for maintenance optimization can be developed.
To conclude, it could be interesting to conduct a research in a company that is making a transition to the e-maintenance, and analyze the accuracy of the collected data, their impact on the results of MPIs and the actions made before and after the implementation of the e-maintenance.

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APPLICATION OF DATA MINING TECHNIQUES IN SMALL-SERIES JOB SHOP

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Abstract
Manufacturing industry has its domain where fast and reliable decision-making is often an exigency. Modern ERP, MRPII and MDC systems accumulate large amounts of data that are stored in databases located on-site or in cloud-based servers. Although these data are valuable for the company as they are, they hide even greater potential value. A large amount of data increases the time required to conclude or make decisions based on that data. Regarding that fact, it can be concluded that the potential value of the data is in the efficient analysis and interpretation which can help in the decision-making process. Nowadays, job shops are an important part of the industry in Croatia, but their decision making process mostly relies on skilled employees whose knowledge and possibilities, faced with high amount of available data, is getting more and more inadequate. This paper considers machine learning algorithms application for data mining in small-series job shop. Some of the data mining techniques are reviewed, applied and evaluated on the manufacturing data with the aim of demonstrating the potential of improving the decision-making process in the job shops using RapidMiner tool.

Keywords:
Data mining, machine learning, job shop

1 INTRODUCTION

Manufacturing companies collect a great amount of various data at different levels of the factory. These data can be stored in a centralized data warehouse, but are of different origins, different types and different sizes.
Manufacturing SMEs require analysis of the available data in order to get a more efficient production system. The available data need to be turned into information and knowledge by organizing them in database(s), transferring and interpreting them for the purpose to be useful in the decision making process.
Data mining stands one of the stages of knowledge database discovery (KDD) process. Data mining is an interdisciplinary field with the general goal of predicting outcomes and uncovering relationships in data. It allows a

search for valuable information in large volumes of data [1]. Its aim is to infer knowledge that is generalized from the data in the database [2].

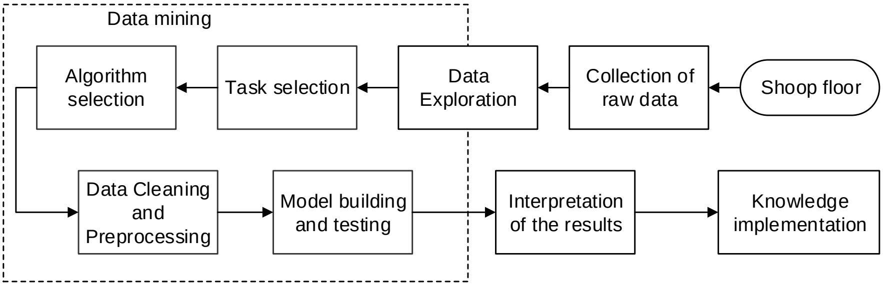

Figure 1: Example of data mining and knowledge discovery in manufacturing data.

Traditionally, statistical techniques were used in order to find patterns in manufacturing data, but with growing complexity of manufacturing systems as well as recent proceedings in information technology, data acquisition systems and storage technology collects more and more data suitable for data mining application. Data mining is already used in many different areas in manufacturing to get the knowledge for use in engineering design, manufacturing systems, shop floor control and layout (production planning and scheduling), decision support systems, fault detection (quality control), maintenance and CRM [3]. Data mining is not specific to one type of data. The approaches and algorithms differ when applied to different types of data. Data in manufacturing SMEs i.e. job-shop to be mined are usually stored in relational databases (ERP, MRP), but also in flat files, CAD drawings, data warehouses, multimedia databases etc.

Fig. 1 presents an example of data mining and knowledge discovery process in job shop. The data mining process starts with an analysis need, a question or a business objective. Without a defined problem, it is very difficult to come up with the right data set and pick the right data mining algorithm. It can be concluded, that the prime step is to understand manufacturing domain and targeted goal of the data mining – where they will be used and how the result should look like. Collection of raw data is mainly subject of the extraction and transformation of the existing data stored in operational databases or data warehouses. With an increasingly growing amount of data, it is important to focus on relevant data i.e. data that have impact on a previously set goal. Data exploration, also known as exploratory data analysis (EDA), provides a set of simple tools to obtain some basic understanding of the data. This is done by two common approaches, descriptive statistics by using measures as mean, standard deviation,

correlation and data visualization, by projecting data in multidimensional space. Data exploration tools are a part of standard data analysis software packages from Microsoft Excel® to advanced data mining software like R, RapidMiner, SAS, IBM SPSS etc.
The data mining task is selected according to the knowledge that we want to get from the data. Data mining algorithm selection is done with the aim of building a better data model and/or better description of the input data set. Cleaning and preprocessing consists of missing value replacement, noise removal or data cleaning. Preprocessing of the data is done after task and algorithm selection because particular task and particular algorithm requires certain type of input data. After this step, data is ready to be mined. Often, practitioners also use data exploration and feature selection during data preprocessing with the aim of visualizing data and/or reducing dimensionality. Construction of the model includes the application of the selected algorithm to the specific task, but also includes cross-validation technique application, optimization of the parameters and optimization of the feature selection. Interpretation of the results gives the answer to the question whether the obtained data can be regarded as newly created knowledge. Based on a survey, it could be said that data mining practitioners today use very powerful techniques to accomplish their objectives: decision trees; regression models and clustering [4]. It can be concluded that even here an 80/20 rule applies: Most of the data mining processes can be accomplished using few techniques. But, as it is known for the very most of the 80/20 processes, the rest of the less-used techniques is very important to reveal all the possible knowledge i.e. value. Leading this trail, premise is that manufacturing companies should get familiar with not only commonly used techniques, but also with rarely used or a combination of several not so commonly used procedures.

2 DATA MINING TECHNIQUES

In general, data mining techniques can be categorized into *supervised* or *unsupervised* learning models. Supervised techniques predict the value of the output variables based on a set of input variables. To do this, a model (i.e. relationship function between input variables) is developed from a *training* data set where the values of input and output are previously known. This model is then used to predict values on datasets where the output variable is not known. Prediction (also named *estimation*) possibility of lead time, costs, maintenance, quality, defects etc. is highly important in manufacturing process. Unsupervised data mining finds hidden patterns in unlabeled data when there are no output variables to predict. The objective of this class of data mining techniques uncovering patterns in data based on the relationship between data points themselves. Two major goals of data mining in manufacturing are prediction, using mostly supervised models, and description, using mostly unsupervised models. The boundaries between

descriptive and predictive data mining are not sharp, e.g. some aspects of the predictive model can be descriptive, to the degree that they are understandable and vice versa [5].
Task and algorithm selection is the next problem that a data analyst deals with. Knowing the differences between common tasks (see fig. 2.) enables faster and more credible decision making (knowledge) while in the same time following knowledge discovery goals.

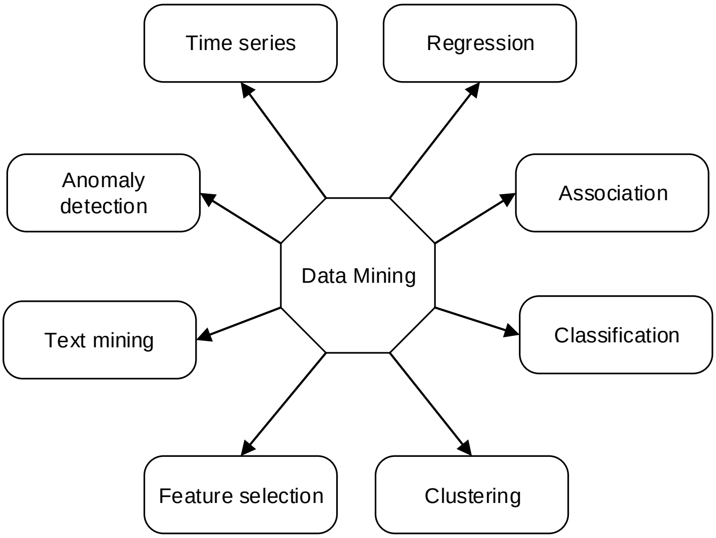

Figure 2: Data mining techniques.

Feature selection
Feature selection in data mining refers to the process of identifying the most important variables or attributes that are essential in a model for an accurate prediction. This is done for several purposes: optimizing the performance of the data mining algorithm, making it easier for the analyst to interpret the outcome of the modelling. This process can be part of the preprocessing data set reduction, which is divided in two categories with relatively subtle differences: dimension reduction and feature selection. While dimension reduction combines actual attributes with the aim of reducing the number of data set columns, the latter works like a filter that eliminate some of the attributes.

Clustering
Clustering is the process of finding meaningful groups in data. In clustering, the objective is not to predict a target class variable, but to simply capture

the possible natural groupings in the data. Clustering is an unsupervised learning problem where one is only given the unlabeled data and the goal is to learn the underlying structure. Regardless of the types of clustering applications, the data mining task of clustering seeks to find the groupings in data in such a way that data points within a cluster are more ‘similar’ to each other than to data points in other clusters.

Classification and regression

Classification is the two-step procedure of assigning labels to unlabeled data by a constructed model that maps (classifies) a data item into one of several predefined categorical classes. First step of this supervised data mining method creates a model representing training set data (contains class attribute), while in the second step this model is applied on a test set or future data (without class attribute). Regression involves many different techniques and the most common ones are *linear regression* for numeric prediction and *logistic regression* for classification. Regression is one of the most used data mining methods applied in practice [4].

Association rules mining

Association rules mining is an unsupervised learning process that discovers hidden patterns in data, in the form of easily recognizable rules. The objective of this class of data mining algorithms is not class or value prediction, but finding usable patterns in the co-occurrences of the items. Usually, this is a three step method:

- Preparation of data in transaction format;
- Generation of the frequent item set;
- Extraction of association rules from the frequent item set.

Anomaly detection

Anomaly detection is the process of finding outliers in the data set. Outliers can be described as the data set records that do not conform to the expected behavior in a data set. For the anomaly detection, both supervised and unsupervised algorithms are used. In general, supervised algorithm are used when a training set has known outliers, while unsupervised anomaly detection algorithms detects outliers without usage of training data or building model.

Text mining

Text mining is the new frontier of predictive analytics and data mining. Text analytics development is driven by the need of processing unstructured data, i.e. data that are not consisted in rows and columns. The basic idea of text mining lays in the converting (preprocessing) of the unstructured text into semi-structured data. After that step, patterns can be found and models can be built.

3 DATA MINING IN MANUFACTURING

In modern manufacturing the reuse of past knowledge constitutes a key factor for improving manufacturing performance, during design, planning and operational phases [5]. The use of data mining techniques in manufacturing began in the 1990s [6, 7] and their use is growing ever since. Industrial applications of data mining techniques have increased between 2000 and 2011 .The process of data mining, however, has not changed since those early days and is not likely to change much in the near future. *CRISP-DM* (Cross Industry Standard Process for Data Mining), *SEMMA*, *SolEuNet* (Data Mining and Decision Support for Business Competitiveness: A European Virtual Enterprise), *Kensington Enterprise Data Mining* (Imperial College, Department of Computing, London, UK) , and *Data Mining Group (DMG)* have established methodologies and developed languages and software tools for the standardization of industrial applications of data mining [3]. Though those products are broadly recognized, they focus on the implementation of data mining algorithms and application development rather than on the ease-of-use, integration, scalability, and portability.

Today, data from almost all the processes of the manufacturing organization are recorded allowing the application of data mining methods to support decision-making.

Data mining problems can also be grouped into classification, regression, association analysis, anomaly detection, time series, and text mining tasks (see fig. 2).

Most of these data mining techniques can be applied in the SME's knowledge discovery process. The paper aims to present how data mining techniques can be applied to small series job shop data using RapidMiner platform. RapidMiner is a software platform developed by the company of the same name that provides an integrated environment for machine learning, data mining, text mining, predictive analytics and business analytics. RapidMiner provides 99% of an advanced analytical solution through template-based frameworks that speed delivery and reduce errors by nearly eliminating the need to write code [9]. In 2014, Gartner Research placed RapidMiner in the leader quadrant of its Magic Quadrant for Advanced Analytics [10].

3.1 Manufacturing data

Integration of the ERP systems into the shop floor is highly important for the continuous improvement of the production process, while gaining visibility into manufacturing operations at all levels of control. Although they understand the benefits, a large proportion of job-shops in Croatia are still struggling with the exploitation of the full potential of ERP systems, which leads to a structured data collection that can be processed by data mining.

Small series job-shops discussed in this paper have already come the long way with the implementation of the ERP+CAPP system (3-10 years of

usage) and currently exploring the possibilities of data mining methods implementation in the hope that it will enable them better decision making.
A manufacturing database is mainly used for storing and collecting data about work orders, products, resources (machines and human) and capacities, production and material planning and tracking, quality control and maintenance.
Modern ERP systems in most cases provides some kind of more traditional business intelligence based on historical data that is stored in various databases, which is then cubed and analyzed, but this BI is mostly based on finance, sales and marketing processes. The basic assumption is that data mining application can fill this gap by providing knowledge from the real time or near real time data.
Datasets are collected from small-series job shop manufacturing tools for a glass container industry. The period of observations starts on 02 January 2013 and ends on 01 March 2015. The whole dataset contains multiple tables with around 200 attributes and more than 200 000 records.

3.2 Data mining techniques in manufacturing

The CRISP-DM methodology belongs to a group of the most widely data mining methodology used for manufacturing data mining. The details of each step of CRISP-DM [11] make it a reliable methodology that is easy to use and fast to implement. Literature reviews such as [3, 8, 12] clearly illustrate the diversity of data mining techniques in a manufacturing applications. However, contrary to the increasing interest in manufacturing related knowledge discovery activities, data miner surveys conducted by [4, 9] annually show that manufacturing related projects are still being implemented significantly less than other areas, e.g. social media, fraud-detection, advertising, banking or CRM.
The purpose of the following sections is to emphasize the way of how certain tasks and algorithms could be used in certain processes by using existing data collected from the small-series job shop. Firstly, association rules are implemented by processing standard parts of the work orders with the aim of finding co-occurrence of specific standard parts that can help in the manufacturing logistics and process flow. Products which have higher metrics values can be stored or manufactured together. Further, prediction capabilities are tested by means of creating a model for evaluating manufacturing costs of standard parts. A trained and tested model with approved performance can be used in the inquiry preparation process as well as for planning activities.

Association rules descripting standard parts of the work orders

By its definition, association analysis process expects transactions (work orders) to be in a particular format, containing different items (standard parts) in columns.
Following that, input grid should have binominal (true or false) data with items in the columns and each transaction as a row. Manufacturing work

orders database object has standard parts (attribute StandardPart) as one-to-many relational sub-table where all standard parts of certain work order (attribute WorkOrder) are stored as rows. The raw table contains 7327 rows. Preprocessing of such data is done in several steps (see fig. 3):

- Pivoting of raw data by converting nominal attribute (Name of the *Standard part*) to numerical binominal value and aggregation (grouping) by WorkOrder number. This sub-process creates CSV files with StandardParts names in columns and WorkOrder number in rows.
- Second step must be done to convert numerical values stored in StandardPart attributes to true/false values and to remove WorkOrder number column. Finally, preprocessed data contains 1196 rows with 70 attributes and no missing values. After this step, the data set is ready to be mined.

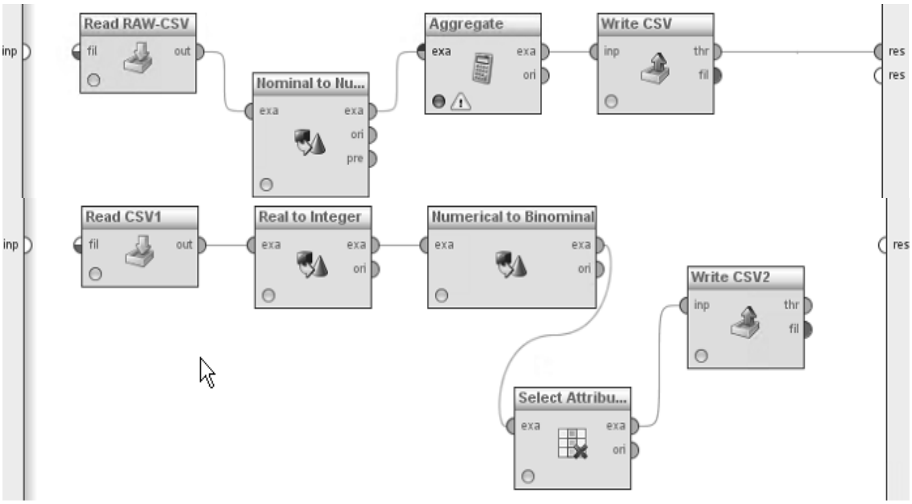

Figure 3: 2-step data preprocessing.

RapidMiner is using two operators for association rules generation: FP-growth and Create Association Rules. Frequent Pattern Growth algorithm generates the so called FP-tree of frequent items that is used for creation association rules.

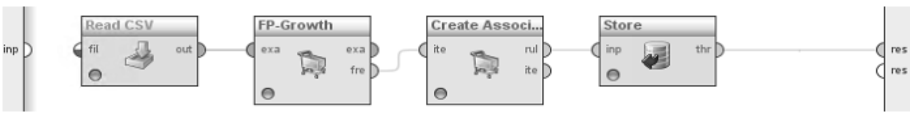

Figure 4.Generating association rules.

Rule support and confidence are two measures of rule interestingness that reflect the usefulness and certainty of discovered rules. A support of 0.2 means that 20% of all the rows under analysis contains premise or conclusion. A confidence of 0.6 means that 60% of the rows with premise also contains conclusion. Typically, association rules are considered interesting if they satisfy both a minimum support threshold and a minimum confidence threshold that are set by analyst. Results show that with the increase of both confidence and support, the number of rules generated is dropping but rules are becoming stronger and more robust.
With the minimum support set to 0.5 and minimum confidence set to 0.9, a total of 100 rules were generated. Those rules present generated knowledge about which standard components appear together on work orders. Having in mind that standard parts are manufactured on CNC machines and then assembled or stored in warehouse, extracted knowledge can be used in manufacturing process optimization, transport route reduction or warehouse optimization of the job shop.

Using neural network in predicting work order parts manufacturing costs
The capacity of the tool-making shop to respond quickly to the inquiry is an important competitive factor. Predicting parts' manufacturing costs based on input information that are available before manufacturing process as the tool price is limited upwards and downwards. The toolmakers cannot afford additional reserves in price, because if the price is too high it is not competitive on the market and the order is not awarded. Conversely, if the price is too low it brings loss to the company, which is not to the interest of the job shop. In the following section, RapidMiner's *NeuralNet* operator as model builder is examined. This operator learns a model by means of a feed-forward neural network trained by a back propagation algorithm (multi-layer perceptron). The training set contains 2310 records where one row presents part (product) on the work order. There are seven numerical variables: number of different parts in work order, total planned machine time of the order, total planned machine time of the part, planned number of the operations on the order, planned number of the operations on the part and number of parts. Additionally, the cost attribute represents the dependent variable. The data set is normalized using Z-transformation contained in the *Normalize* operator.

Backward elimination operator is used to select the most relevant attributes of the given data set through an implementation of the backward elimination scheme. This process indicated *total planned machine time of the part* and *number of different parts in order* as non-relevant. A (Evolutionary) operator for optimizing parameters is included to find the optimal values for a set of parameters using an evolutionary strategies approach. 3-fold cross validation is used to estimate the statistical performance of a learning operator. Finally, a model was generated with attributes selected as relevant and optimized parameters. Model performance testing included calculation of *Pearson correlation coefficient* on the unseen test set with RapidMiner *Performance* operator (fig. 5.).

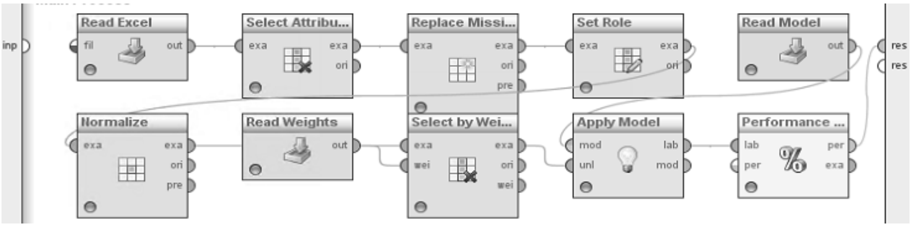

Figure 5.Application of the model on the test set.

The model's performance (fig. 6) on a training set shows a correlation coefficient value of 0.82, which is generally described as *strong positive* relationship between predicted and real value. Test set (1067 records) correlation coefficient value is 0.91, i.e. shows even stronger relationship.

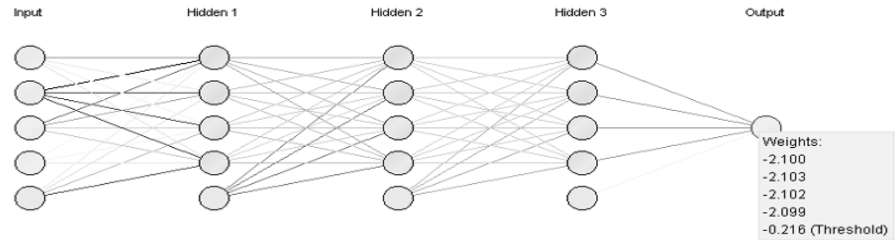

Figure 6.Model built by NeuralNet operator.

The model includes weights in the three hidden layers of neurons for each of the input variables and the threshold. This model now can be used in unseen set predicting costs of the parts while they are still in the pre-manufacturing phase.

In the past 15 years, mining manufacturing data has been the subject of numerous scientific papers. Authors [14, 15] deal with manufacturing scheduling problems using data mining algorithms, while [16, 17], applied data mining to support decision making processes by using different data-mining algorithms to generate rules for a manufacturing system. Based on literature overviews [3, 13], it can be concluded that currently there is no universally best data mining method for all manufacturing contexts. Nowadays, RapidMiner is a relatively mature data mining tool and covers most of the commonly required data mining tasks, especially in the area of structured data mining. Nevertheless, according to the conducted research and authors' knowledge, so far there are no papers that deal with manufacturing data mining using RapidMiner software platform.

4 CONCLUSION

With the increase in the amount of data collected in small and medium-sized manufacturing companies, the scope for the application of modern methods of data analysis, in order to support decision-making, broadens.

The paper presents how data mining techniques can be applied to process small series job shop data using RapidMiner platform. Both supervised and unsupervised techniques are described. The association rules unsupervised technique is applied in order to generate rules of work order parts co-occurrence. Additionally, feed-forward neural network trained by a back propagation algorithm is applied to the manufacturing data in order to build predicting model for the products manufacturing costs.

Model performance evaluation and results show that both techniques are applicable for manufacturing data analysis, and generated knowledge can be used to support decision-making in small and medium-sized manufacturing companies. In this paper, practitioners will find a brief overview of data mining methods that are usable in the processing of manufacturing data, together with the described case study in which the data mining process is described and algorithms applied. The case study showed that RapidMiner has the capacity to process manufacturing data, but for its proper implementation it is necessary to know the basics of the data mining process. Moreover, engineering statistics knowledge as well as the data mining practice are mandatory for proper model performance and results interpretation. Future work will be based on a detailed analysis of the applicability of data mining techniques in the production environments of small and medium-sized enterprises, with a focus on the detecting relationships between specific algorithms and specific production process, which can lead to standardized implementations.

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FLEXIBLE MANUFACTURING SYSTEM DESIGN AND OPTIMIZATION SUPPORTED BY SIMULATION MODEL

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Abstract
FMS (flexible manufacturing system) is an efficient solution for organizing manufacturing processes of complex machined parts. Raw pieces are fixed on pallets in loading stations and from there a transport device picks units and transports them temporarily to internal storage racks or directly to one of the machining centers. FMS utilization reduces production lead times, increases production flexibility, makes unmanned production possible and reduces WIP (work in progress) capital. The integration of a multilevel storage system for raw and semi-finished parts makes space utilization more efficient, reduce WIP handling activities by applying repetitive FIFO and one-piece-flow logic.
Design of a new FMS system requires many competences and a deep analysis of many technical aspects. Most important is the system’s size evaluation.
Evaluation of machine quantity is easily installed and almost limited by budget constrain, space availability, required machine capacity and other.
Other details, such pallet storage system and the number of pallets/fixture, are more difficult to design. This can affect the overall budget utilization (oversizing) or jeopardize the efficiency of the whole system (lack of equipment).
Wartsila Italy is going to invest in a new FMS system for site’s key component production. In this study, results are shown of the analysis performed through simulation model in order to define optimal quantity of pallet storage system and the number of pallets/fixture. The study allowed to optimize CAPEX and increase the system utilization rate.

Keywords:
Simulation, flexible manufacturing system, FMS

1 INTRODUCTION

Wartsila Italy actually produce 4stroke engine for marine and power plant market and ship propulsion machinery such as thrusters, controlled pitch propellers and gearboxes. Part of the Wartsila Corporation, the production plant is located in Trieste, Italy, with 43 years of history in manufacturing & testing of its products.

From the early years of production, when quite all the components were produced in-house, with large and complex machining centers, now the company is dedicated mainly to designing and assembling the engine and propulsion products. Most of the components are purchased from suppliers who are treated as partners.
In this context and facing a changing and competitive market, Wartsila strategy request to keep in-house more than 50% of the production of most critical components of the engines. This choice found its reason in protecting knowhow and production capacity.
Those components are mainly parts of the driving units and actually machined in two flexible machining systems, which are 25 years old.
Renewing these systems with one more efficient and compact is the core of a big transformation project started this year in the factory. Capital expenditure is limited and designing an efficient solution respecting the budget is the objective of the project team.

2 THE FLEXIBLE MANUFACTURING SYSTEM

The definition of FMS is well stated in the manufacturing literature but it could be refined in the context of this article as a group of generic CNC machining center and machinery linked together by an automatic transport system, also numerically controlled. Each center has to be a station with a fully automated system for loading and downloading the pieces to be manufactured and in case of machining also automated tool exchange system. The machine could be dedicated to a single machining operation. However it has to be adapted to the dimension of pieces to be produced and related fixing tools and transportation pallets. The whole system is capable to accept different pieces, randomly loaded and optimized as flow with the use of an integrated storage utilized as automated buffer for raw, semi-finished, finished-good material and work in progress. [1] [2]
Wartsila started developing in practice the concept of FMS since the year 1990, with the actual lines installed in Trieste, Italy and with the newer ones installed in the other factories in Europe, mainly the mother workshop in Vaasa, Finland. The solutions in the different plants are similar but adapted to components' dimensions to be manufactured (up to 2 tons, in Trieste case), to available physical space and to be optimized.
In the case of the new Wartsila Italy system, the storage area will be used also for raw material storage, in order to optimize the area and the volume of the workshop occupied by the FMS system.
The system will be composed (in its initial definition) of four CNC machining centers, one transport system (stacker crane), one washing machine, one robot for deburring and marking, one measuring station, two loading and downloading stations with setup area, two loading and downloading stations for raw material. Fig. 1 shows FMS's layout in its latest version, where it is possible to recognize the above mentioned system components, with the

addition of a measuring machine, a loading and unloading station for raw material (casting or forging) on normal wooden EURO pallet and related racks to store them.

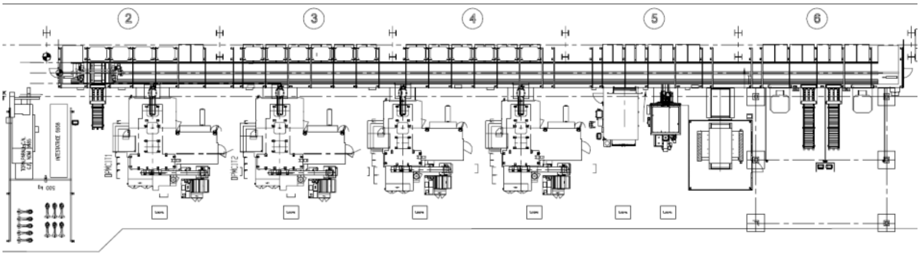

Figure 1: Layout of the Wartsila Italy FMS in the latest version.

All the parts, from raw to finished good stage, have to be moved on pallets. As already mentioned, in case of raw material pallets are normal wooden EURO pallets. Special metallic pallets have to be used to transport the part into FMS: They are designed to fit the transport system. On each of this pallets has to be fixed a tool where the part has to be clamped. Tools are designed and dedicated for part type and machining phase in order to respect predefined machining position and orientation.

3 SIMULATION USE IN SYSTEM DESIGN

3.1 Why a simulation model is useful and which objectives were expected

The new FMS definition for Wartsila Italy was an extended team work, involving technical, economic and strategic aspects. As machine definition, the technological knowledge among manufacturing engineering and machining departments was enough for deep discussions with suppliers in order to select the best solutions to produce the components. Less clear was how to optimize the transport system among the machine, the number of pallets and tools and the need of space in the system for semi-finished parts. Calculations were performed but it was not easy to find the smartest way to investigate all the possible scenarios of number of tools, storage dimension and operator needed to make the new system working in the most efficient way. Developing a calculation tool with standard Excel spreadsheets looked too limiting and not useful for visual checking of solutions and further improvement evaluation.
In this context the need for a simulator model to support the team during system design and optimization was born. From the initial one, many

updates of the model were implemented, with the objective to test and review impact on capacity and machine utilization. Still the latest version is in review and Wartsila Italy's intention is to maintain a simulator model, more and more detailed and complex but useful to support continuous improvement of the new machining system.

3.2 Simulation approach and basic assumptions

Several approaches to simulation definition could arise. As Wartsila Italy has experience in simulation definition for plant and lines, there was not a deep analysis of the possible outcome but it was preferred a learn-by-doing approach from a basic model that grew up with following need of more detailed results.
Main elements of the basic model (fig. 2) consisted in:

- Manufacturing machines
- Transport and support machines
- Set of parameters to be changed and monitored

It was simple as the first request of results: The main focus was to evaluate number of pallets (and tools), the number of WIP storage locations in the system and check for bottle necks or constraints in different resource allocation conditions.

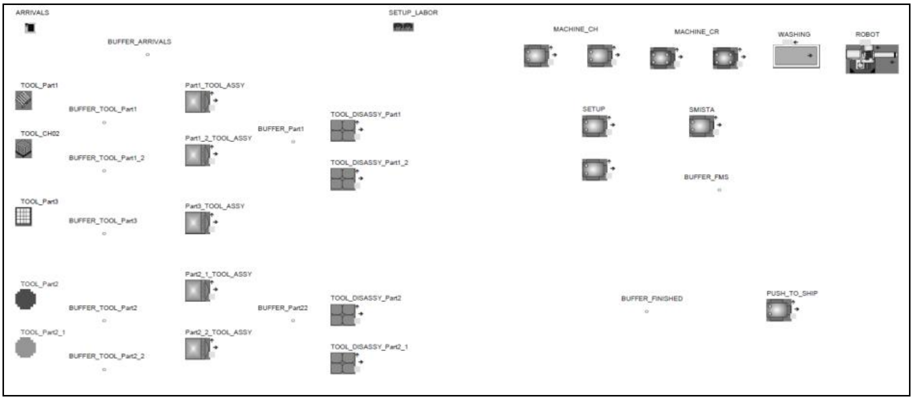

Figure 2: Initial model of FMS, designed with Witness software.

The model was developed to check production output and verify resource optimization in the better condition. No possible machine failure, operators' absenteeism or system break down were considered: The assumption was that the system has to be designed to run with more than 90% of machines

utilization in the optimal condition: Any disruption will affect the efficiency but not have a direct impact on initial system design.
All the efforts were concentrated on transferring the (new) logic of the FMS to the simulator and reconstruct it with the programming language by developing related algorithms.
The software used was 'Witness' (©2014 Lanner Group, http://www.lanner.com/en/witness.cfm) [3] It was easily selected because already licensed to Wartsila Italy and used in previous simulations, therefore software knowledge was already available. In addition the software is in use also in the department of engineering of the University of Trieste and it was planned to get future support and development by a collaboration with the university itself.
The software is a discrete-event and object-based dynamic process simulation tool, easy to program after an initial training to understand basic modelling logic.
It is designed for production simulation of 'classic' lines but also service business. Many examples of possible utilization and business cases are easily available by the software house.
Wartsila FMS simulation case had some special needs and asked for some 'tricks' definition and inventiveness to set up the requested logic to manage parts production cycles.
This simulation software's programming flexibility is good, although the object-based structure and the fact that elements have predefined functions and actions available, limited a bit the smooth and linear appearance of the model. With the limit to accept (at least as beginner in software use) a graphic appearance not like the reality, all the expected logic was successfully simulated.

4 FMS SIMULATION MODEL DESCRIPTION

As a FMS is a system of machines and additional station for loading and downloading of parts, it was very logic to design the simulator model in a similar way starting from a simple group of machines linked with push and pull logic. Witness elements used were 'machine' elements, in 'single' model if it has to change a part (or attribute of) or in 'assembly' in case two parts have to be mounted together (component and related tools).
The first version was so composed by four machines (representative of the CNC machines), two machines (representing respectively the washing machine and the deburring root) and two loading stations (fig. 3). Another 'single' machine acted in the important role of part sorting and moving to the right step. In the 'output rules' of this machine the logic of the FMS (and in particular of the stacker crane) was programmed as it is simulating the main PLC of the system.

In addition a set of two machines for each component to be produced and machining phase was necessary to simulate the mounting and dismounting component from machining support tools (fig. 4).

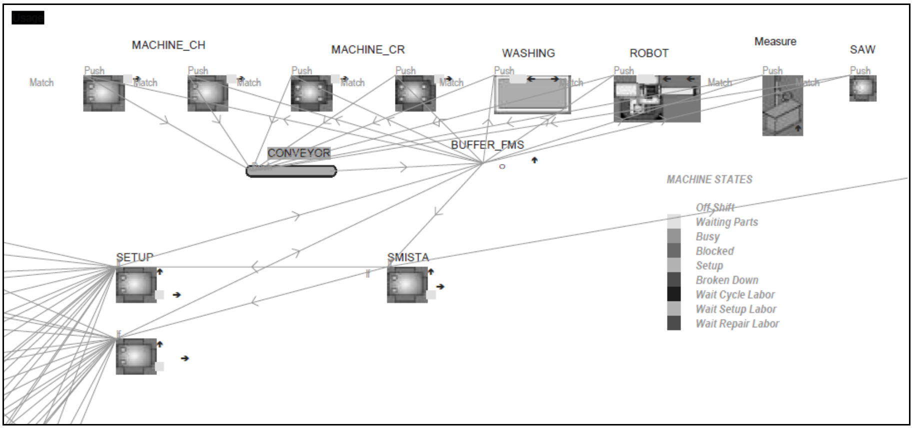

Figure 3: Active machine element layout of the FMS, with flow indication.

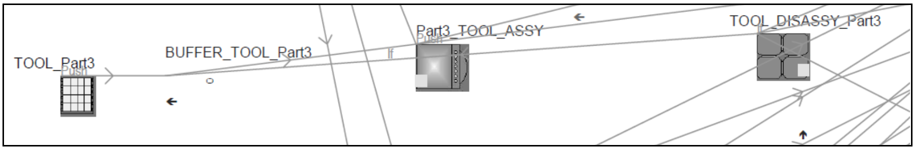

Figure 4: Example of set up of the simulation structure for part assembly to tool (simpler case, Part3).

Before designing the model, three groups of information were defined:

1. The parts (engine components) to be produced, their machining cycle (sequence) as from actual design and machinery know how and the main input data for the model
2. Machinery layout and capability
3. Output data and expected results

Keeping in mind that the objective of the simulator was the optimization of tools and number of pallets, main attention in model design was on functionality and efficiency from this point of view. It has to be studied the condition to avoid inefficiency and stoppage due to too many or too less tools or related storage space. Therefore capital spending optimization at project level and WIP control after production ramp up.

4.1 Input data, parts and related machining cycle

The team working on FMS definition had the task to review actual 'old' FMS machining sequence and define the new one. These people gave the inputs for the simulator design, from its first simple version up to the actual requests for further detailing and optimization.
As initial simplification, only three parts were assigned for machining. They are generally representative of the three main parts to be produced: in a second step different version of parts which have different component fixing tools. Those three have different machining cycles and sequences, and will be mentioned in this paper as part 1, part 2, part 3.
For simulation scope the cycle was divided in groups of activities:

- Set up, as loading and unloading operation from tools.
- Machining phase (Phase 1 o 2) as list of operation performed in a machine without part to be removed from it.
- Washing operations.
- Deburring operation.

In the economy of the simulation, each of this groups of operation was considered as all-comprehensive step of the cycle.
Not all the parts have to pass through the two machining phases (e.g. Part 3 uses only one machining phase to complete the process).

Table 1: Example of machining sequence as per simulation scope.

			Part	
		Part1	Part2	Part3
Process Step	**OPERATION**	**Time [h]**	**Time [h]**	**Time [h]**
1	SETUP 1	0,15	0,10	
2	PHASE 1	3,00	1,25	
3	ROBOT 1	0,75	0,50	
4	WASHING 1	0,50	0,25	
5	SETUP 2		0,10	
6	PHASE 2 (extra FMS)		0,50	
7	SETUP 3	0,15	0,10	0,05
8	PHASE 3	3,00	2,75	1,75
9	ROBOT 3	0,75	0,50	0,50
10	WASHING 3	0,50	0,25	0,15
11	SETUP 4		0,10	
12	MEASURING	0,50	0,50	0,50
13	SETUP 5	0,15	0,10	0,05
14	DELIVERY	0,00	0,00	0,00
	TOTAL HOURS	**9,45**	**7,00**	**3,00**

To manage the different steps in the machining cycle, additional attributes were introduced to the parts that will be changed by the machines after each process step completion.
In order to track lead time and number of parts produced, other specific attributes were added.
Important input of the simulator is the part arrival (or part creation) logic. Different approaches were tested (daily sequence, weekly, annual) and the last agreed ones were a weekly sequence of parts entering the model as idealization of production orders that call raw material from suppliers to warehouse.
Many buffers were defined in the model: Their main scope was to control and limit part and tool storages, by measuring their 'filling rate' during the time. An important example is the semifinished (or WIP) part buffer in the FMS (known as 'buffer_FMS') that is used to measure optimal use of space in the FMS system.

In summary, main information used in the simulator is:

- Input: tools number
- Variables: buffer capacity, cycle time, number of operators and working shift organization

4.2 Machinery layout and capabilities

The machinery detail (number and functionality) were defined by the team and fixed as situation to be simulated.

Mainly there are four machining centers, in theory capable to manufacture all the three types of parts. In fact, two machines were dedicated to Part 1 machining and two for Part 2 and Part 3. This choice is due to dimension and cost optimization.

These CNC center are nearly located and physically connected by an automatic transport system. No predefined element in the simulator software was capable to model it and its logic: Therefore it was simulated by setting input rules in each machine (calling piece from the unique buffer 'fms_buffer' and the 'single' machine ('SMISTA') that sort and move the parts out of the system to the 'setup' machines. The combination of these sets of rules were satisfactory replicating the FIFO logic and the logic of the two dedicated machines and the assembly step to be followed strictly in sequence. This action was possible by an iterative evaluation of the related attributes of each part present in the buffer.

A conveyor element was inserted with the scope to fully simulate the time spent to move the pieces inside the system.

The two setup stations are modelled by machine elements that collect from other 'virtual' machines the assembled part into tools and send to disassemble.

In a scheme, setup activities (as mounting and dismounting the parts from tools) are a combination of two machines types:

- One to assemble the part physically ('…_tool_assy')
- One to let the time pass at the right moment ('setup')

In the last version of the simulation was also a machine out of the system to simulate an operation (cutting) introduced that was later stated to be performed out of FMS. Related buffers and tools were introduced. See fig. 5 for an example of the simulator appearance when working.

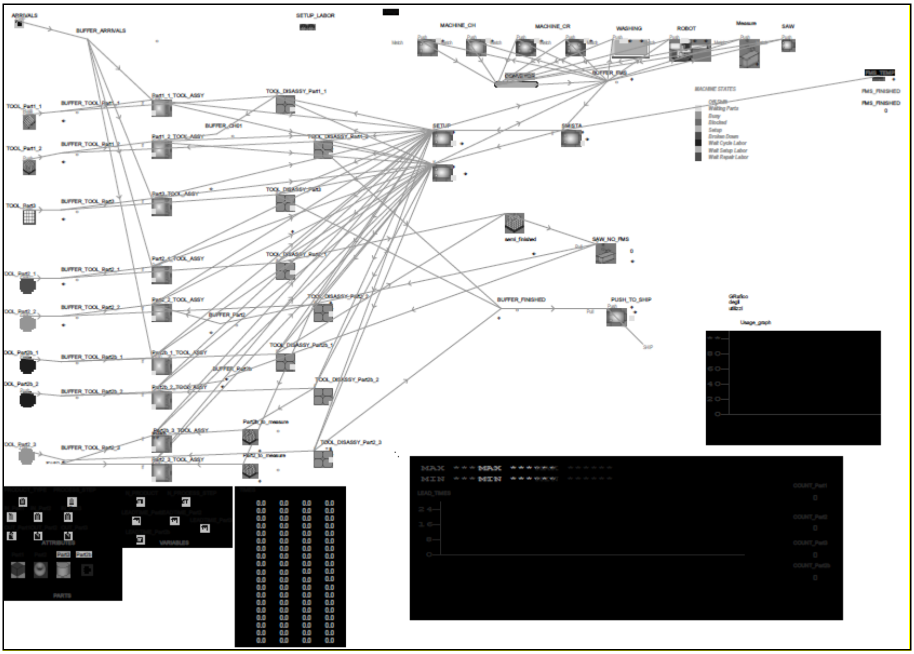

Figure 5: Simulator screen shot, with parts and flow.

5 RESULTS AND PROJECT IMPACT

Model validation was performed through a loop of test simulation runs, with predefined data and expected results to be reached (e.g. mono parts production, unlimited buffer and resource available,…).
Examples of the results are shown in tab. 2:

Table 2: (part 1) Example of simulation results.

Sim run nr	Operator working shift	Parts arrival per day (PART1+ PART2+ PART3)	Storage space inFMS		Number of TOOLs							
			available [Pallet]	Max used [pallet]	Part1Tool1	Part1tool2	Part2tool1	Part2Tool2	Part2bTool1	Part2bTool2	Tool3 (measure)	Part3Tool1
60	5 d 2s, 2 d 2 s	10+10+12	40	*21*	6	4	3	3	3	3	3	3
61	5 d 2s, 2 d 2 s	10+10+12	40	*21*	5	5	3	3	3	3	3	3
62	5 d 2s, 2 d 2 s	10+10+12	40	*21*	6	5	3	3	3	3	2	3
63	5 d 2s, 2 d 2 s	10+10+12	40	*23*	6	3	5	2	5	2	2	3
64	5 d 2s, 2 d 1 s	10+10+12	40	*23*	6	3	5	2	5	2	2	3

Table 2: (part 2) Example of simulation results.

Sim run nr	Annual production [pcs]				Machinery utilization [%]								
	Part1	Part2a	Part2b	Part3	MACHINE_CH(1)	MACHINE_CH(2)	MACHINE_CR(1)	MACHINE_CR(2)	WASHING	ROBOT	MEASURE	SETUP (1)	SETUP (2)
60	2800	1050	1050	2800	100	100	81	77	50	91	46	18	5
61	2450	1143	1132	2975	87	87	86	84	48	88	46	17	6
62	2450	1143	1132	2975	87	87	86	84	48	88	46	17	6
63	2658	1397	1397	3124	95	95	99	99	54	99	51	20	7
64	2483	1354	1354	2816	84	84	94	94	50	93	48	18	7

Results were organized in order to highlight differences in different cases of resources allocation.
It was interesting to discover the following topics:

- More tools available for Phase 1 let have more efficiency in case of not human controlled lines during night shift or weekend.

- Due to queue effect in the FMS, limiting tools of one-phased parts (e.g. Part 3) improve other parts productions.
- Optimized space for WIP in the number of tools minus 15-25% (depending on operator working shift): e.g. in case of 28 tools, it is needed to keep up to 24 pallet spaces in the system.
- Operator saturation seems not to be an issue (less than 50%).
- Risks for line productivity are due to robot (deburring) cycle time: It has to be maintained below the expected value.
- Impact of measuring machine introduction and related pallet was not significant.

These data were used by the project team to set up storage racks and dimension them. Initial number of pallets and tools to be purchased were also defined from the information coming from the simulator (mainly the results of simulation run number 63 and 64).

6 EXPERIENCE AND NEXT STEP

The experience of utilizing the simulator to decide for tools, pallets, storage design and purchasing was clearly described in previous sections. In addition it is important to mention that to develop a simulation model for a system already at its design stage was a very interesting practice. It was possible to cross check expected results versus simulated ones, an interesting opportunity to review project concepts and assumptions during the creation of the virtual one and re-discuss it with the team.

The FMS simulator proved to be an extremely good tool to verify the impact of project/system modification. Further opportunities are in the mind of manufacturing engineering team by maintaining updated the model and studying in details system performance at its start up, when real data will be available. Some other possibilities, taking apart the already presented possibility to test virtually future proposed improvements, are to train technicians and operators on overall system functions by looking at a moving model.

Developing a simulator for a company is of course an extra cost on a project. The cost of the software, related training for the engineer that will develop the model and the hours spent in model definition (in the case of this paper, from nothing to a well functioning simulator were spent something like 200 hours, or more because the resource was not fully dedicated to this job) has to be taken into account.

Simulator design could be outsourced, with possible costs reduction but many of the positive results mentioned by the authors will not be possible because company’ engineers will not own algorithms and logic used.

Wartsila Italy is sure that these costs will be recovered easily with a successful start up of the new FMS, without constraints or disruptions coming from not optimal decisions on number of tools, pallets and storage space.

ACKNOWLEDGMENTS
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INCREASING THE EFFICIENCY OF MANUFACTURING PLANTS BY PROCESS SIMULATION AND LEAN THINKING

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Abstract
In the last few years companies had to manage an increasing number of products and additional services required by the customer; besides, they had to increase their internal process efficiency to be competitive. Since the production efficiency is in general rather low, there is a strong industrial interest in optimization methodologies. In this paper, an innovative approach based on combination of lean manufacturing, process simulation and optimization methods is presented. To validate the approach, an industrial case study was modelled and simulated by using a commercial discrete event simulation (DES) software provided with particle swarm optimization (PSO) algorithm. The results evidenced that the combined approach can be effectively applied for optimization of production plants and strong improvements (>20%) can be obtained.

Keywords:
Manufacturing plant, efficiency, simulation, lean manufacturing

1 INTRODUCTION

In current situation of strong international competitiveness, optimization of manufacturing operations is of fundamental importance [1].
Generally, the degree of optimization of manufacturing processes is rather limited and based on very simple and practical methods. The complexity of the system is generally high and there is a lack of optimization environments which can be practically applied to manufacturing problems. In many cases the optimization is performed manually or by using very basic tools such as experience and spread sheets.
Moreover, in order to reduce the complexity, the overall system is simplified into sub-systems which are optimized individually according to general rules such as minimum cost or processing time. Unfortunately, the general trend towards fully-automated and integrated production systems is reducing the applicability of these approaches.

1.1 Optimization of manufacturing systems

Conventionally, optimization of manufacturing systems is performed on two levels, technical and logistic, as follows:

1. The single production operation is optimized from the technological point of view independently from the rest of the operations. The optimization is performed in order to determine a suitable range of operating parameters which assure the desired quality and the standard time of the operation. This is obtained by using specific software for simulating the process physics or/and direct tests. For instance, an operation on a machining center can be simulated off-line by specific software and the test part program is further refined directly on the CNC machine during production sampling.
2. The whole manufacturing system is modelled as a chain of processes whose processing time is the standard time of the operation determined in the first phase. The operations are considered as indivisible building bricks of the manufacturing chain. Therefore, the optimization is performed only on logistic aspects: batch size, buffers and storage bins size, serial/parallel distribution of machines, number of operators and shifts. The optimization can be performed off-line using specific software (such as discrete event simulators - DES), conventional methods and time measurement and in accordance to efficiency philosophies such as lean thinking.

There are several reasons why the two levels are conventionally decoupled:

- To reduce the complexity of the system and the number of parameters.
- The optimizations are performed independently by operators with different technical competence: strong technical for the first one and managerial for the second.
- There is a different perception of the relative importance: usually the technical optimization is considered less critic. In many companies the first level optimization is not considered important or impossible.
- The optimization is performed using different software tools which are not easy to interface to each other.

Nevertheless, the disjoined optimization introduces a non-linearity in the problem preventing the achievement of a greater level of optimization.
In this paper, an integrated approach for the optimization of complex manufacturing systems based on coupled process and plant simulation is presented. The main concept of the approach is the joint application of state-of-the-art simulation of manufacturing processes including simplified models of technological processes, advanced optimization algorithms and lean thinking – LT.

2 DESCRIPTION OF THE PROPOSED APPROACH

The concept of the proposed approach is illustrated in fig. 1.
Basically, the main idea is the joint optimization of parameters deriving from physical/technological aspects such as speeds, temperatures, pressures – micro part of the picture – and logistic aspects such as batch quantities – macro part of the picture.

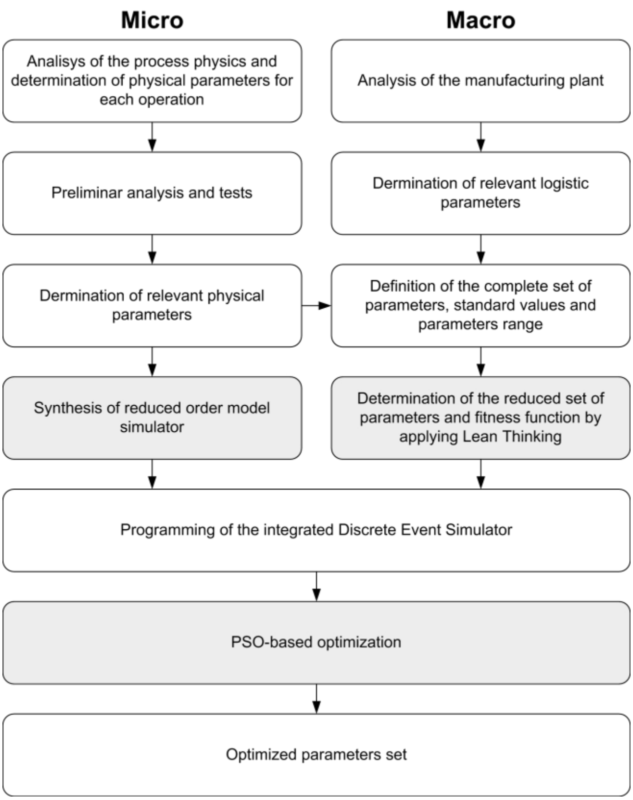

Figure 1: Concept of the proposed approach.

The physical part of the system is first analyzed in order to determine the main parameters, then some tests may be performed in order to assess their influence on the process. Then, different approaches may be applied to determine simplified models of the physical systems which represent the effect of technological parameters on processing time, maintenance time or

mean time to repair – MTTR, mean time between failures – MTBF, quality of production, and so on.
In parallel, the relevant logistic parameters of the factory are determined and combined with the physical ones to determine an overall parameter set. For each parameter a suitable range and standard value is defined.
Lean thinking is applied to determine the optimization criteria – i.e. the fitness function – and accordingly the subset of parameters that will be included in the optimization. All parameters which are not included in the optimization will be set to the standard value.
Combined optimization of logistic and technological parameters could be performed at the same time by integrating both aspects in simulation. In this way, for example, the dimension of the input buffer of a machine tool, the cutting speed of the machining operation, the dimensional control sampling and many other parameters could all be optimized at the same time.
Since the number of parameters tends to be high, suboptimal metaheuristic optimization methods such as evolutionary algorithms or swarm intelligence approaches are applied.
The main aspects of the proposed approach are discussed in detail in the following sections.

2.1 Simplified models of the physical systems

Simplified models of the physical systems are computationally inexpensive mathematical representations that offer the potential for near real-time analysis and are suitable to be included in complex optimization environments.
Simplified models may be determined in several ways:

- Empirically, from experiments and statistical modelling of data
- Analytically, by identifying the coefficients of lumped parameters models
- As ROMs, by simplifying higher order models derived from finite-element-simulation using state-of-the-art approaches

The topic is of great contemporary interest for the efforts of the scientific community of producing reduced order models – ROMs of physical systems by simplification of higher order finite elements models.
The development of these kind of models is crucial in modern conditions for the realization of advanced automation system, whose functioning depends on the prediction of the manufacturing system outputs.

2.2 Discrete event simulation – DES

Discrete event simulation models the operation of a system as a list of events in time [2]. Each event occurs at a particular instant in time and it produces a change of state in the system and the generation of future events. Accordingly, the simulation is performed by executing always the next event in time. In comparison to continuous time simulation systems, they are based on non-constant time intervals.

The application of DES for the simulation of manufacturing systems is quite common and there are several commercial software for the purpose: Siemens Tecnomatix Plant Simulation, Rockwell Automation Arena and many others.

Generally a DES software is composed of an interface – in some cases graphical – for the definition of the model, an engine for the simulation and some reporting functions for the visualization of results.

The main building block for the definition of the model is the single process which is modelled as a set of probability functions for estimating the duration, set-up time, mean time between failures and maintenance time. The most complex commercial DES environments include a high-level language interpreter (for instance: Pascal or Basic) which can be used to model very complex behaviors like those of the human operators.

2.3 Particle swarm optimization – PSO

The particle swarm optimization (PSO) is a family of evolutionary algorithms whose bases were developed by Kennedy and Eberhart [3].

The algorithm is based on the imitation of the social behavior of animals (for example: fish, flocks of birds ...) each of which is represented as a particle, corresponding to a candidate solution for the problem, moving in space; the trajectory and speed of movement of the particle are progressively corrected assessing its past experience and the experiences of other particles of the swarm. The PSO combines the excellent local research with a global search, looking for the right balance between exploration (look around for a good solution) and exploitation (to benefit from the successes of other particles).

The trajectory of each particle (i.e., a candidate solution to the optimization problem) in the search space is adjusted according to the particle own experience and the experience of the other particles in the swarm, as described in the following equations:

$$\begin{cases} \mathbf{v}^{k+1} = w\mathbf{v}^k + c_1 Rand[0,1]\left(\mathbf{x}_p - \mathbf{x}^k\right) + c_2 Rand[0,1]\left(\mathbf{x}_g - \mathbf{x}^k\right) \\ \mathbf{x}^{k+1} = \mathbf{x}^k + \mathbf{v}^{k+1} \end{cases} \tag{1}$$

where $\mathbf{x}^k$ is the D-dimension position of the particle at iteration *k* in the continuous search space and $\mathbf{v}^k$ is its velocity. The positions $\mathbf{x}_p$ and and $\mathbf{x}_g$ are the best known position of the particle and the overall best known position of the swarm, respectively. They are updated at each iteration according to the value of the fitness function, which accounts for the quality of each solution. The parameters w, c_1, and c_2 are, respectively, the inertia weight and two learning factors. *Rand*[0, 1] denote a random number in the range [0, 1].

The maximum velocity of each particle is bounded to prevent the so-called swarm explosion, according to the following formula:

$$v_{j,\max} = \frac{\overline{x}_j - \underline{x}_j}{k_{v_{\max}}}, \qquad j = 1, \ldots, D \tag{2}$$

where $k_{v_{\max}}$ is the velocity restricting coefficient, x_j.

3 EXPERIMENTAL PROCEDURES, RESULTS AND DISCUSSION

3.1 Description of case study

For a preliminary validation, the proposed method was applied to an automated high-productivity line for the manufacturing of electric motor shafts. An example of the final product obtained from the line is given in fig. 2 and the simplified visual stream map is given in fig. 3.

Figure 2: Example of electric motor shaft for automotive application used as case study.

The manufacturing line consisted of the following operations. The forged raw components are fed into an automatic line feeding system which collects and aligns the pieces. Then the workpieces are machined into a double spindle lathe to achieve roughly the final shape.

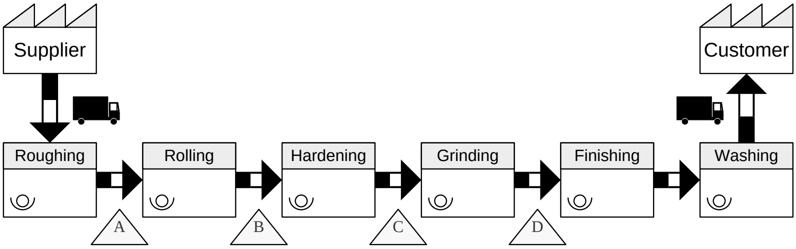

Figure 3: Visual stream map of the selected case study.

After visual inspection by operator, the workpieces are conveyed to a rolling machine for the realization of the gears by plastic deformation. Then, the workpieces are hardened by an automatic rotary table machine. The hardened surfaces are ground to the final dimension. Eventually, the remaining parts are machined by a multi-spindle lathe. The final operations - deburring, washing and packaging – were neglected.
All the movements between different machine tools are performed by automatic magnetic conveyors which are also used as buffers, whereas articulated robots perform loading and unloading of the parts.
Each of the operations was modelled by defining four reference times:

- Set-up time: the time required to start production after a production stop of any kind
- Process time: the time required to transform one workpiece from the input to the output
- Mean time between failure – MTBF: predicted elapsed time between inherent failures of a system during operation
- Mean time to repair – MTTR: the average time required to restore production after a failure

Table 1: Reference times of the operations.

Operations	*1 Roughing*	*2 Rolling*	*3 Hardening*	*4 Grinding*	*5 Finishing*
Set-up time [min]	5	5	10	10	5
MTTR [min]	20	20	25	20	30
Parameters	v_{c11} v_{c12}			v_a	v_{cf}
Processing time	$\frac{960}{v_{c11}}+\frac{840}{v_{c12}}$	11 s	13 s	$\frac{0.11}{v_a}$	$\frac{2400}{v_{cf}}$

The process and MTBF times were expressed as non-linear functions of the process parameters for roughing, grinding and finishing operations.
The relation of process time and cutting speed could be generally expressed as follows:

$$t_A = \frac{H}{v_c} \tag{3}$$

Where t_A is the processing time or active time, H is the reference length of the process derived from geometry and v_c is the cutting speed.
For machining operations, the tool life was taken as a measure of the MTBF, according to the well-known Taylor's tool life equation, which can be expressed as:

$$T = T_0 \left(\frac{v_{c,0}}{v_c} \right)^{\frac{1}{n}} \tag{4}$$

where T is the tool life in minutes, T_0 is the reference tool life (usually 20 minutes), $v_{c,0}$ is the reference cutting speed recommended by the tool producer to achieve the reference tool life, v_c is the actual cutting speed and n is the tool life equation coefficient (usually equal to 0.2).
It can be seen that both process time and MTBF are decreasing for increasing cutting speed thus introducing an optimum cutting speed which maximizes productivity.
The list of parameters selected for the optimization of the process are listed in tab. 2.

Table 2: Optimization parameters.

Factor	*Description*	*Range*
1	Roughing cutting speed – v_{c11}	100-200 m/min
2	Roughing cutting speed – v_{c12}	100-200 m/min
3	Grinding feed speed – v_a	0.05-0.2 mm/rev
4	Finishing cutting speed – v_{cf}	100-200 m/min
5	Buffer A – Lower Threshold $B_{A,L}$	0-50
6	Buffer A – Higher Threshold $B_{A,H}$	0-50
7	Buffer B - Lower Threshold $B_{B,L}$	0-50
8	Buffer B - Higher Threshold $B_{B,H}$	0-50
9	Buffer C - Lower Threshold $B_{C,L}$	0-50
10	Buffer C - Higher Threshold $B_{C,H}$	0-50
11	Buffer D - Lower Threshold $B_{D,L}$	0-50
12	Buffer D - Higher Threshold $B_{D,H}$	0-50

For each buffer two thresholds were selected as parameters: the lower and the higher. The higher threshold defined the maximum dimension of the buffer. When the maximum dimension of the buffer was reached, the preceding operation was stopped. The lower dimension of the buffer determined the trigger to start the preceding operation if stopped.
Each working station had four possible states:

- 0 – idle: machine is completely shut down;
- 1 – starting up: machine is warming up after a shut down;
- 2 – wait for input: machine is ready for operation but there are no workpieces in the input buffer;
- 3 – processing: machine is processing a workpiece;
- 4 – maintenance: machine is under maintenance.

The selected fitness function for optimization was the manufacturing lead time, defined as the sum of queue time and run time [4] from the pick-up of the workpiece from the input buffer, to the release to the final buffer. In accordance to lean thinking, this function was selected since it enables the reduction of the work-in-progress (WIP) and enhances flexibility.
For a given set of parameters, the simulation was performed starting with empty buffers. The simulation was carried on until the absolute difference of average manufacturing lead time calculated for subsequent large batches (2000-5000) of workpieces was lower than 5%. This procedure was selected in order to reduce the effect of the initial transitory in the evaluation of the fitness function.
The optimization of process parameters was replicated 20 times in order to test the robustness of the solution against the random initial population of the particle swarm. The parameters of the PSO algorithm are given in tab. 3.

Table 3: PSO algorithm parameters.

Parameter		*Value*
Learning factor	c_1	2
Learning factor	c_2	2
Inertia weight	w	1
Max. number of iteration	k_{max}	300
Max number of iter. with no improvement	k_{imp}	20
Number of particles	q	24
Velocity bounding effect	k_{vmax}	0.1

3.2 Results and discussion

The characteristic of fitness function against the number of optimization iterations is given in fig. 4.

It can be seen that the best solution found had an average manufacturing lead time lower than 150 s. Some of the optimization tests converged to a fitness value of about 200 s. The number of iterations performed to reach the minimum varied depending on the initial combination of cutting parameters from 50 to 150. The total elaboration time on a 12-core workstation was about five hours.

The great dispersion in the optimal conditions found in the repetitions was interpreted as a measure of the complexity of the fitness function, which was strongly non-linear.

In order to evidence some patterns in the optimal solutions of the 20 replicates, the statistical analysis of the normalized parameters is given in tab. 4. The level 0 represents the minimum value and 1 the maximum value of each normalized parameter.

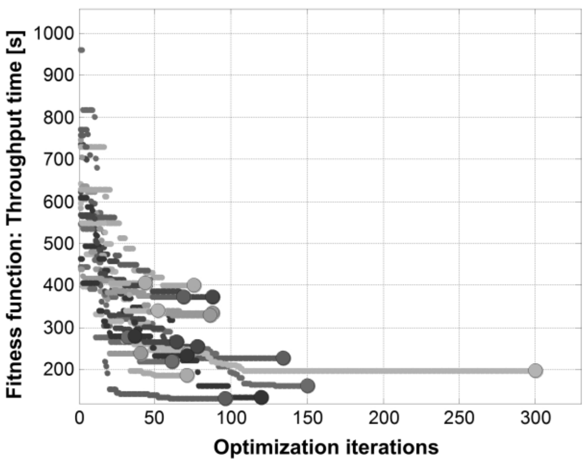

Figure 4: Characteristic of the fitness function against PSO iteration for the 20 replicates.

Table 4: Statistical analysis of optimized parameters.

	Factors											
	v_{c11}	v_{c12}	v_a	v_{cf}	$B_{A,L}$	$B_{A,H}$	$B_{B,L}$	$B_{B,H}$	$B_{C,L}$	$B_{C,H}$	$B_{D,L}$	$B_{D,H}$
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
μ	0.33	0.94	0.56	0.36	0.41	0.33	0.53	0.31	0.56	0.55	0.61	0.58
σ	0.35	0.22	0.17	0.16	0.22	0.31	0.25	0.24	0.18	0.33	0.20	0.27

The statistical analysis evidenced the relative importance of the factors for the optimization. The lower the standard deviation σ, the stronger was the relevance of the parameter. In this case, the most important factors in order of relevance were: cutting speed in finishing v_{cf}, feed speed in grinding v_a, lower buffer C dimension $B_{C,L}$, lower buffer D dimension $B_{D,L}$, lower buffer A dimension $B_{A,L}$, and so on. It is interesting to notice that both technological and logistic parameters had a strong relevance.
A conventional expert-driven optimization of the system was also performed for comparison. In this case, the reference values were chosen without simulation by applying known concepts. For instance, the levels of technological parameters were selected in order to synchronize the total processing time for each station – defined as the sum of processing time and MTTR divided by the number of expected workpieces to be produced in the MTBF. The levels of the buffers were set to 0 in order to minimize the queue time before each operation.
The levels of the parameters for the optimal solution found with the PSO algorithm and simulation and the reference solution is given in table 5.
It can be seen that the fitness function (average manufacturing lead time) for the optimal solution is more than 40% lower in the case of the optimal solution.

Table 5: Optimized parameters.

	Factor	*Opt. sol.*	*Ref. sol.*
1	Roughing cutting speed – v_{c11}	0.39	0.1
2	Roughing cutting speed – v_{c12}	1.00	0.1
3	Grinding feed speed – v_a	0.46	0.1
4	Finishing cutting speed – v_{cf}	0.58	0.5
5	Buffer A – Lower Threshold $B_{A,L}$	0.37	0
6	Buffer A – Higher Threshold $B_{A,H}$	0.22	0
7	Buffer B - Lower Threshold $B_{B,L}$	0.28	0
8	Buffer B - Higher Threshold $B_{B,H}$	0.54	0
9	Buffer C - Lower Threshold $B_{C,L}$	0.43	0
10	Buffer C - Higher Threshold $B_{C,H}$	0.40	0
11	Buffer D - Lower Threshold $B_{D,L}$	0.52	0
12	Buffer D - Higher Threshold $B_{D,H}$	0.32	0
	Fitness function	132.4 s	237.4 s

Table 6: Comparison of times between optimal and reference solutions.

		Rough.	*Roll.*	*Hard.*	*Grind.*	*Fin.*
Optimal solution	t_{Att}	11.1	11	13	12.6	13.7
	MTBF	454	14400	21600	10800	2797
	N_p	41	1309	1662	860	204
	t_{TOT}	47.8	12.1	14.3	14.6	24.0
Reference solution	t_{Att}	16.4	11	13	16.6	14.4
	MTBF	9017	14400	21600	10800	3305
	N_p	551	1309	1662	649	229
	t_{TOT}	19.1	12.1	14.3	19.4	23.6

For reference, a comparison of processing time t_{Att}, MTBF, number of workpieces produced in the MTBF, average lead manufacturing time for each process is provided.
Considering the total manufacturing lead time, the bottleneck for the optimal solution was the finishing operation, whereas previous operations presented an increasing total processing time pattern.
After the analysis of the simulated process states and the number of workpieces in each buffer for the optimal solution, it was possible to notice that the higher threshold of the buffers was effectively applied to shut down the preceding process in the manufacturing chain thus reducing WIP.

4 CONCLUSION

In this paper, an integrated approach for the optimization of complex manufacturing systems is presented. The main concept of the approach is the coupled process and plant simulation by means of discrete event simulation, simplified models of manufacturing process and advanced optimization strategies.
The main components of the method were discussed and validation was performed on a real case study. The results evidence that it is possible to obtain a strong optimization of the process, much stronger than conventional methods due to the high complexity of the system.
Also, there was a strong benefit to optimize at the same time technological and logistic parameters since the optimal solutions presented very sophisticated logic which do not resemble those applied conventionally.
It would be of further interest to continue the research on this field by investigating the influence of other technological (quality of parts, for instance) and logistic (effect of the human operator behavior) parameters on more advanced fitness functions.

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ASSEMBLY LINE MANAGEMENT: MULTI-OBJECTIVE OPTIMIZATION

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Abstract
The aim of the present work is to define and to optimize an assembly line that processes parts of medium/large dimension. As the assembly line processes large parts, some operational constraints arise, which for example are assembly to order production, just-in-time production, etc. The objective functions are minimum earliness and minimum tardiness stated to a given level of working stations saturation. To achieve these purposes we use two industrial software programs: the first is a discrete event simulation (DES) package WITNESS 14 by Lanner Group, the second is a design optimization and process integration package, MODE-FRONTIER by Esteco. The DES software allows us to produce a simulation model for the assembly line. The optimization has been carried out in three steps. First step is a multi-objective optimization cycle with genetic algorithm that generates a Pareto Frontier solutions; second step is a methodology that clusters the Pareto Frontier in different groups. A set of simplifications characterizes this second step with the aim of reducing both the number of inputs and the objective functions. The third step is a mono-objective optimization cycle that allows us to reach a solution by means of a simplex algorithm. This method offers a way to solve scheduling problem of a complex production plant constrained to respect a management policy.

Keywords:
Assembling line, management, multi-objective optimization, simulation

1 INTRODUCTION

Currently, management and investigation on manufacturing systems is a very important aspect for any industry. The inaccurate or defective definition of manufacturing system can affect the real capacity of a company to stay on the market. For this reason several techniques to support the decision making have been developed in the last 20 years in order to evaluate the manufacturing production strategies and the system itself.

The first step of the production system definition is the system production management that generally schedules operations to maximize/minimize one or more performances. The literature shows several methods to solve

problems of this type such as enumerative, heuristic and meta-heuristics methods.
In the first two cases, i.e. enumerative and heuristics, scientific papers examine a wide scenarios' spectrum [13], [8], [15]. Meta-heuristic methods combine heuristic methods searching optimal solution of iterative type.
The basic idea is to couple a random component in a heuristic method to lead to a better solution than the one that can be obtained by a deterministic solution alone [1].
The multi-objective flow shop scheduling problem (MOFSP) [6] has been studied by many researches who considered two or more objectives, such as makespan, flowtime, earliness, tardiness and idle time. The optimization techniques applied include simulated annealing-SA, tabu search-TS, genetic algorithms-GA, ant colony optimization-ACO, neural networks-NN, etc. [14], [15], [16], [17], [18].
The latter methods lend themselves to connect with production systems simulation software, the discrete event simulation tools (DES) that can simulate a wide range of activities and situations that may occur within a production system [11], even if significant computational time is needed [12].
This work, in addition to the direct issue, considers the inverse problem, i.e. using the management method in order to take out useful information to define the production system.
The production system under study is an assembly and testing plant of large mechanical products. It is a hybrid flow shop system, processing a set of *n* jobs in a sequence of *m* stations, each of them can have *k* identical machines [1]; some stations can receive parts from other flow lines.
Given the large size of the parts, it is necessary to impose an assembly-to-order strategy consequently the management of the line follow the just-in-time (JIT) approach. Flexibility is mandatory, since the products differ in completion time and bill of materials (BOM). Evaluation of flexibility can find several proposals in literature and, in this case, adopting the suggestion in [4], where the mix response flexibility is the time that you spend in changing the production of one part with another part type (setting-up). The problem relies on job-based completion time that does not include load-unload and setup times [3]. Assembly stations have a set-up time constant and equal to 1 hour.
The proposed analysis follows the meta-heuristics methods with the difference that the method of analysis itself provides a series of useful information to define the main features of the assembly line. In this way, in addition to optimize one or more performances, the method proves to be a useful tool to manage the resources of the assembly line, also calibrating so appropriate operational constraints to avoid critical conditions that may occur (e.g. bottle neck). Modelling the production system and optimizing mono/multi objectives, two commercial software packages were used: WITNESS 14 and MODE-FRONTIER respectively.
The goal is to find an optimal job scheduling over one year with the definition of number of machines for each machine-group and the definition of shifts

for each machine-group.
Two quantitative performance metrics are given by the minimization of earliness and maximization of tardiness while balancing the saturation levels in all machine-groups. The flow-shop scheduling problem, *n* jobs on *m* machines is stated to:

- Each job *i* can only be processed on one machine at a time;
- Each machine j can process only one job i at any time;
- Pre-emption is allowed, but the job cannot leave the machine until the process is over;
- All jobs aren't available for processing at time zero but the jobs are provide every week;
- The set-up times of the jobs on machines are sequence independent and are included in processing times.

Operational constraints are summarized as follows: the saturation levels of the various activities/work-centers are inside the production time range of the job and never exceed the deadline.
Achieving this goal, the procedure goes through three phases:

- First cycle: multi-objective optimization;
- Clustering and analysis of optimal solutions (Pareto front);
- Second cycle: mono-objective optimization.

These three phases comes from the procedures for multi-objective optimization that usually generates large size sets of optimal solutions. Introducing two more steps increases the quality of the solution bringing to a solution as robust as possible, but limiting the number of excellent solutions.

2 ANALYSIS AND MODELLING OF THE ASSEMBLY LINE

The model is based on a real system used to validate the model. The line can handle the assembly of twelve different product typologies; the final products differ in size and in customization. Each product has its own bill-of-materials (BOM); the twelve final products have arranged into two subgroups depending to the size: *M*-Medium, *H*-High and both subgroups count six products each. The main component identifies the main material flow line, while secondary component parts reach the corresponding station for assembling the main product component. The main component, principal part (PP), identifies the key element of the production process but, due to as BOMs are different there is the need of product customization and therefore sufficient flexibility in the assembly line to limit the setup times [4]. The management of secondary component parts (PS) finds place in two preparation departments, PS1 and PS2.

The production capacity of these departments are considered much higher than that of the main assembly line in order to ensure that the process of the PP never waits for the arrival of secondary parts. The production mix and the production plan are given and it is assumed that during the simulation period, one year, the supply of PP and the corresponding PS be weekly: in total, every week five jobs enter, three of which are *M* type (3-*M*) and two are of *H* type (2-*H*).

Table 1: Starting conditions for variables.

j	**Activity (MCs-group)**	n_j	**shifts**
1	Control/working	2	2
2	First assembly *M*	2	2
3	First assembly *H*	2	2
4	Second assembly *M*	5	2
5	Second assembly *H*	3	2
6	Test *M*	2	2
7	Test *H*	1	2
8	Inspection	2	2
9	Finishing	2	2

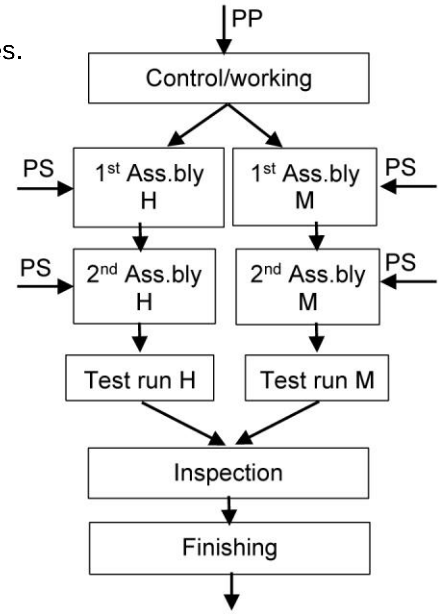

Figure 1: Flow line diagram.

The diagram of fig.1 describes the structure of the flow line by group of machines: the main flow and the secondary parts feeding. The assembly line subdivides itself into two branches that process parts *M* and *H* respectively, with identical machines in each station. For each machines-group station, the maximum number of available machines is known. Transportations between the stations are done by bridge crane, which means that the handling time is not negligible [5].

A zero-buffers line is defined in order to operate as close as possible to the no-wait flow shop scheduling condition [3].

Free variables for the optimization problem are the number of available machines and the shifts for each machine-group (tab. 1) while a further variable, the priority, regulates the entrance of the PPs in the flow-line.

Priority is a numeric quantity that depends on PP component i.e. the finished

product. Its value ranges from 1, lowest priority, to 12, highest priority. Starting assumptions does not allow jobs re-scheduling at an intermediate point of the line, therefore priority has an influence only at the entrance of the line. Three vectors of integers governing variables are the base for parametrisation; the task for the model is to read such vectors and adjust the characteristics of the line.
The first two scheduling performances are completely time dependant and use the following functions: *aarliness*, positive, and *tardiness*, negative.

$$minE = min\sum_{J=1}^{n} E_j \qquad maxT = max\sum_{j=1}^{n} T_j \tag{1}$$

The third requested performance is s*aturation levels* balancing: the ratio between the sum of the actual working time (busy time) and the sum of availability of the machine. Finally, moving to the concept of saturation level of the station, machine-group, just consider the mean among the number of available machines in the group:

$$meanS_j = \frac{\sum_{k=1}^{M_j} P_{k,j}}{M_j}, \tag{2}$$

with:

- *meanS*$_j$: percentage of the *j-th* machine-group utilization, $j=1,\dots,m$;
- $P_{k,j}$: percentage of the *k-th* machine utilization in *j-th* machine-group, $k=1,\dots,M_j$;
- *Mj : number of available machines in the j-th machine-group*.

meanS_j values around 75% are good condition for optimal solutions and assure even a fair distance from overload conditions.
Moreover, using objective functions such as minimization of production unbalance and maximization of throughput you get the following results [10]:

- Idle time reduction by increasing busy time;
- *Maximising total output of the system*;
- *Limiting tardiness*.

The three objective functions are linked between them and generally, optimum of one performance does not coincide with the optimum of the other one, as it happen in multi-objective problems.
Monitoring the annual production volume foresees dividing it into parts *M* and *H* and the *dead*-line function defined as follows:

$$dead = \begin{cases} 1 \textit{ if at least one Job overcomes the dead-line} \\ 0 \textit{ otherwise} \end{cases}$$

After model setting-up, fig.2, monitoring and verification has done. Comparing the real production throughput to the one provided by the model, the prediction error was less than 13%, with an overestimation of the production volumes.
Starting conditions are those of tab. 1.

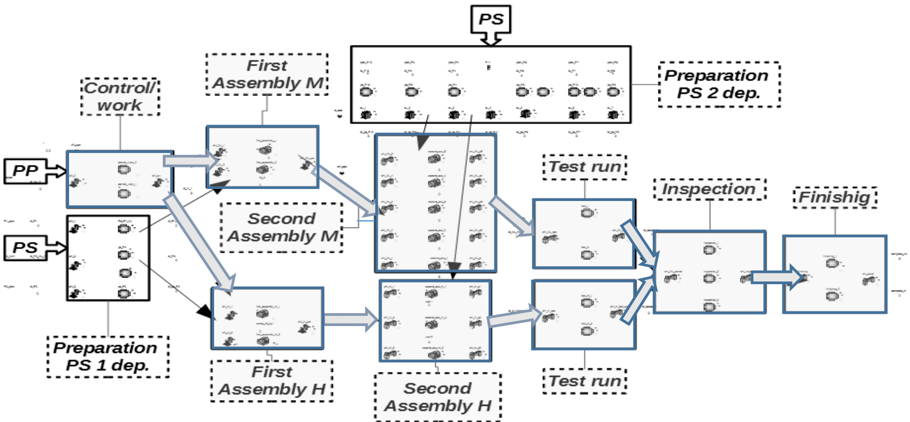

Figure 2: The model schematization by WITNESS 14 and machine-groups.

3 FIRST CYCLE: MULTI-OBJECTIVE OPTIMIZATION

Next step, after a parametric model setting-up of the assembling line, an optimization phase keeps going by means of MODE-FRONTIER. The created workflows allow multi-objective optimization for problems with continuous discrete or mixed variables, respecting limitations/constraints that can evolve in the process. The software allows integration with other commercial programs and/or proprietary software (typical CAD/CAE software and data processing). There is a wide range of algorithms able to cover the most needs; they determine the best possible solutions and post-processing tools allow you to collect a wide range of information: visualization tools, statistical analysis, clustering support and decision-making.
Feeding data input to WITNESS 14 from MODE-FRONTIER was made by a MATLAB script, which properly structures the input vectors into WITNESS' readable files.

3.1 Input variables

The first input rules the precedencies and then pull rules of PP in the line.
There are 12 PP and therefore the priority varies between 1 and 12: defining a vector of integers $\overrightarrow{pMH} = [1,2,3,\dots 12]$ with 12 components; a generic component pMH_i represents the priority of *i-th* part family. For sake of clarity, it means that the part family M1 has priority 1, part family M2 has priority 2 and so on up to part family H6 with priority 12. Assuming that in a week the work load is H5, M1, M3, H2 and M6, the sequence of entry will be H5, H2, M6, M3 and M1. This vector is under control of MODE-FRONTIER, but its input in WITNESS, needs a support program (MATLAB) that generates the part-file.
At this point, the starting buffer of the line has the PPs with descending priority that rules their online entry.
The second input refers the control of active machines. The machine-groups are nine, the aim is to define for each group the number of machines that are required to achieve production goals. The maximum available number $n_{j;max}$ of machines for each group is in tab.1, with j=1,…9. Basically the goals are two, choosing a number of machines in order to avoid a processing time greater than the deadline and having approximately the 75% saturation. The number of active machines is constant in a simulation run. A vector $\vec{n}_j = (n_1, \dots, n_9)$ defines the number of machine for each group: given by MODE-FRONTIER and prepared by MATLAB for WITNESS.
Last input is the management of shifts; the control is on machine-groups avoiding the inactive machines. Shifts are constant during a single simulation run. Define $\overrightarrow{shift}$ a vector of integers with nine components, where the generic *j-th* component represents the number of shifts for the *j-th* group; values of components may be 1, 2 or 3.

3.2 First optimization cycle

The first cycle is the most expensive in computational terms. In consideration of assembly line the chosen performances are inter-related. This means, from a mathematical point of view, that there is not one optimum solution, but there are many optimal solutions with different compromises between the objectives therefore MOGA-II (Multiple Objective Genetic Algorithm) [19] is the selected tool for the first cycle.
The algorithm needs to be initiated by the use of DOE (designs of experiment).
The goal of the DOE is to probe the space of solutions in such a way as to initialize the optimization algorithm. From a practical point of view, it is defining:

- Inputs and variation rules of them
- Objective functions
- Constraints

For given inputs and objective functions, it is necessary to make a clarification on balancing the levels of saturation. In that case one should write:

$$busy = (mean_0 - t_0)^2 + (mean_1 - t_1)^2 + \cdots + (mean_8 - t_8)^2$$

where:
$Mean_j$: the *j-th* vector component of percentages of utilization of machine groups,
t_j : is the *j-th* vector component of requested percentages of use, t_j = 75%, *j*, with the following conditions: *dead*=0 and 50%< $mean_j$ < 85%, *j.*
The constraints have a great importance, becoming them strategies for production management, favoring the saturation levels and respecting the deadline. For this reason, the two conditions will indirectly and strongly constraint the objective functions. All the cited elements are into logical sequential process using the workflow tool by MODE-FRONTIER.
The second cycle of mono-objective optimization also uses the workflow of this stage by making appropriate adjustments.

3.3 Results of first optimization cycle and clustering phase
At this stage, the genetic algorithm GA in MODE-FRONTIER uses variables input priority, number of active machines and shifts for each machine-group. The run has stopped at 14417-*th* design and the GA gives 55% of feasible designs, for which the constraints are respected, and 45% of designs when at least one constraint is violated; *constraint_busy* 88% and *deadline* 12% respectively.
All results are plotted in fig. 3 with tardiness and earliness v/s busy as given by (3). Values in the diagrams, for easy reading, have reduced as mean quantities:

$$SL = \frac{\sum mean_i}{n}\,[\%], \quad mean\_earli = \frac{Earliness}{VP}, \quad mean\_tardi = \frac{Tardiness}{VP} \qquad (3)$$

with *VP* the total production volume and *n* number of machine-group (*n*=9).
The circled zones are the feasible solution dominions.
The purpose of a clustering method is finding a structure arranged in data sets, a cluster is a subgroup of designs that are ‘similar’ and ‘different from designs belonging to other clusters.
The similarity definition uses some metrics, the most common of which is the Euclidean distance by *Hierarchical Clustering* of MODE-FRONTIER package.
The clustering phase provides us with a set of four clusters. The number of elements for each of them is:

- cluster_0 = 44
- cluster_1 = 13
- cluster_2 = 17
- cluster_3 = 160

It is noticeable in the Pareto front that the genetic algorithm shows a unique solution as regards the number of machines and shifts per machine-group. Cluster 1 shows, fig. 4, a *SL* busy function much lower than the other clusters. In fact, in the last machine-group, the number of shift is not optimal in terms of saturation level in comparison with other clusters; for this reason it is excluded from the second cycle of optimization, while the others become *DOE* for the Simplex method. In this way there are three terms of priority.

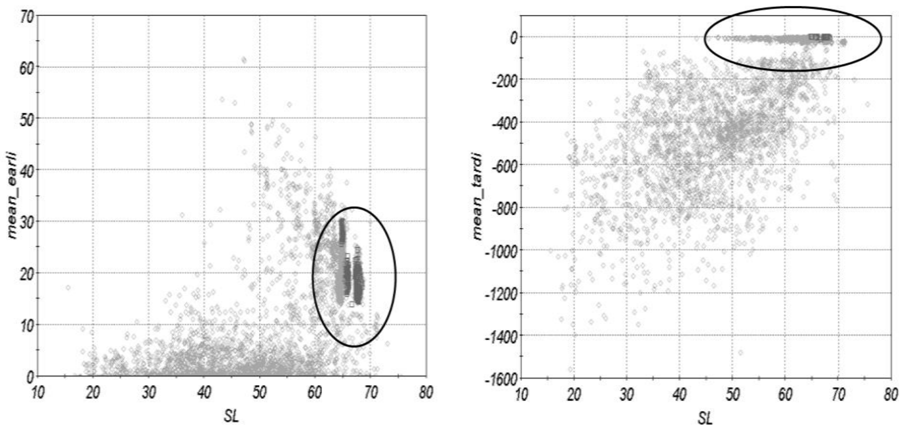

Figure 3: Earliness and tardiness v/s utilization percentage.

4 SECOND CYCLE: MONO OBJECTIVE OPTIMISATION

A cycle of mono-objective optimization, the earliness and tardiness functions will deal with the objective used on saturation levels of machine groups, defines a polynomial:

$$Earli\_Tardi = (Earliness - K)^2 + (Tardiness - K)^2 ,$$

where *K* is set at zero, so minimizing such polynomial tends to reduce the advance/delay of delivery. The number of stations and shifts for each machine-group stated in optimal conditions from *GA* optimization:

$$\vec{n} = [1,1,2,3,2,1,1,2,1] , \quad \overrightarrow{shift} = [3,3,2,3,3,2,3,2,2]$$

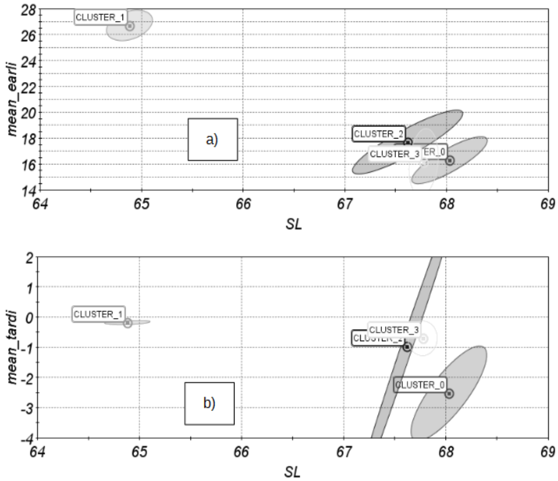

Figure 4: Cluster's fields v/s busy *SL*: a) Earliness, b) Tardiness.

Tab. 2 shows the final results of the procedure and highlights that earliness and tardiness have opposite values due to the fact that constraints for machines saturation levels appears very strong. On the other side, the saturation levels increase of about 10%.

Table 2: Comparison among optimal solutions.

Prio.	Sol_{clu0}	Sol_{clu2}	Sol_{clu3}
M1	12	12	12
M2	1	9	10
M3	12	10	11
M4	8	7	5
M5	9	9	8
M6	3	7	4
H1	10	11	10
H2	6	2	1
H3	4	3	1
H4	2	4	2
H5	1	2	1
H6	5	6	6

	Sol_{clu0}	Sol_{clu2}	Sol_{clu3}	*Sol*
Mean[0]	69	69	69	54
Mean[1]	57	56	56	42
Mean[2]	64	63	63	65
Mean[3]	70	67	68	61
Mean[4]	71	71	71	71
Mean[5]	70	69	70	34
Mean[6]	62	62	62	87
Mean[7]	70	70	71	70
Mean[8]	77	78	78	39
SL	68	67	68	58
Earliness	3508	3357	3275	210
Mean_Earl	15	15	14	1
Tardiness	-662	-227	-255	-4795
Mean_Tard	-3	-1	-1	-21
Prod. Vol. M	138	138	138	137
Prod. Vol. H	90	90	90	88

5 CONCLUSION

Comparing the starting solution, an obvious improvement on the saturation levels of the machines produces a drastic drop of tardiness and increasing earliness. However, the overall process gives valid results in global terms, it is advisable to make a greater effort to priorities control by seeking more effective methods in this regard. The optimization phase is relatively short, using a simple mono-core computer it takes from three to four days.
The critical part of the work is preparing the model WITNESS that requires important knowledge from the industrial side. According to authors, this kind of procedures are interesting from industrial point of view and can be useful decision-making tools. This methodology can also apply to other production systems; in fact, the key to the success of such projects is the study of a valid parametrization setting.

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