Production Engineering and Management

Hochschule Ostwestfalen-Lippe
University of Applied Sciences

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Production Engineering and Management

edited by

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Preface

The International Conference on Production Engineering and Management was this year at its third edition: it can therefore be considered as a consolidated aspect of the collaboration between the Hochschule Ostwestfalen-Lippe and the University of Trieste. The main aim of the three editions of the conference has been to bridge the gap between theory and practice in the field of production engineering and management by offering an occasion where academia and industry could discuss practical and pressing questions. In this respect, the third edition (PEM 2013) is on the same path of the first two successful editions, held in Pordenone (2011) and Lemgo (2012). Furthermore, it had the opportunity to benefit from the contributions of several students who were completing their Double Degree MSc "Production Engineering and Management". Indeed, PEM 2013 was entitled "An active interaction between university and industry" to remark that an active interaction is not only a need for both actors, but also the primary mission of the double degree project as conceived by the two universities: therefore, the presentation of the actual results obtained by the students during their degree studies was particularly welcomed.

PEM 2013 took place between 26 and 27 September 2013 at the University of Trieste (Italy), it was supported by Federlegno Arredo, Friulintagli, Jesse, Palextra and Sabi Group, and sponsored by AIDI, ASDI, Confindustria Trieste and Regione Friuli Venezia Giulia. The program was jointly decided by the organizing and scientific committee and included a plenary session and six scientific sessions. In the plenary session, invited speakers from the industry and the two universities debated on the topic of "Promoting active interactions between university and industry" 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 of the contributions underwent a double-blind refereeing process.
The 23 accepted presentations were assigned, according to their subject, to one of the following sessions: Pathways to the 4th Industrial revolution, Management practices and technologies, Advanced technologies for quality and sustainability, Supply chain management, Product innovation and design and Product development and engineering.

These sessions have been carefully selected by the Organizing and Scientific Committees aimed to highlight some of the foremost discussed topics of today's production industry. The articles therefore cover not only production in a narrower sense, but also new aspects of innovation and product development, of supply chains, of quality improvement, and they address sustainability and revolutionary developments in modern industry.

The proceedings assemble full papers of 21 of the scientific contributions (ordered according to the first author's surname) and the invited talks of the plenary session. The articles were reviewed by the Scientific Committee before their acceptance.

As the editors of the proceedings, we would like to thank all contributors, the referees who accepted the burden of reviewing the extended abstracts and the members of the Organizing Committee and Scientific Committee for planning such an effective conference.

Elio Padoano *Franz-Josef Villmer*

CONTENT

WELCOME SPEECH

Dario Pozzetto
President of the Organizing Committee
University of Trieste

Dear Ladies and Gentlemen,

on behalf of the Organizing and Scientific Committees, I warmly welcome you to the 3rd Conference on Production Engineering and Management.
When in May of this year we were invited by the Academic Council of the Double Degree Master to organize the conference, we felt a shiver, as the available time was very tight at least to replicate the commendable and very successful organization of the second edition of the Conference, which was held at the University of Lippe in September last year.
However, we decided to "roll up our sleeves" and, thanks to the active work of all colleagues, who I thank very much, we are finally able to inaugurate this event.
Europe has been in the grip of an industrial crisis that is linked to changes in the scenarios which we need to undergo. It is in this context that the need of synergy and of a meeting point or mediation between education, research and business emerges clearly.
We are well aware of the limits and constraints, sometimes misunderstandings, that have characterized the past, but it is deeply convinced of the need to overcome them. The issues are clear and well defined, but the options remain open on strategies and tools to choose from to be meaningful and effective.
For all these reasons we decided to start with a Plenary session on "Promoting active interactions between university and industry," which is aimed at receiving a feedback about university education from the industry, on students and graduates' skills and abilities, and at promoting synergy between companies and university in research and technological innovation.
Several research topics, which have been the object of joint activities between academy and industry, will be discussed in the scientific sessions of the afternoon and tomorrow.
Finally, let me thank the partners and sponsorship that have made the realization of this event possible.

I wish you all good work!

WELCOME SPEECH

Michele Pipan
The Deputy Rector for Scientific and Technological Research
University of Trieste

Dear Guests,
It is my pleasure to welcome you at University of Trieste and to this *3rd International Conference on* PRODUCTION ENGINEERING AND MANAGEMENT. We are proud to jointly organize this activity with Hochschule Ostwestfalen-Lippe and we consider this international cooperation an important achievement and an expression of the mission of UNITS.
Academic excellence is a priority at UNITS and international exposure of faculty and students is an essential component of such excellence. The participation of outstanding international speakers into this conference will contribute to our academic life. Your experience and knowledge, dear guests, will enrich and strengthen our cultural atmosphere. It is an important scientific cooperation in a cross-cultural context. Allow me to express, on behalf of the Rector and of the whole scientific community of UNITS, my sincere appreciation for your presence in Italy and at UNITS.

Dear Guests,
The development of production engineering and management can contribute not only to the improvement of industrial processes but also to the enhancement of different aspects of daily life. Your conference today is a step forward in such direction.
This is strictly linked with another dimension of UNITS' mission which is its commitment to community.
A key component of this mission is the cooperation with the industry for a better world and in such perspective, the subtitle of this conference reflects the importance of the event to our community.
The mutual benefits in the cooperation between university and industry is expressed by university research contributing to the development of the industry, and by industry supporting university research. Feedback and assessment of market needs allow joint development of new approaches to improve quality at lower costs, a must in a globalized world.
This is an expression of commitment to community and improvement of welfare, which should be common objectives for university and industry.

Dear Guests,
I would eventually like to thank all people involved in the preparation and organization of this event; the Organizing Committee and all speakers. Their contribution is instrumental in making this conference the fruitful continuation of the series of international events organized by our universities. Enjoy your stay!

WELCOME SPEECH

Daniele Del Santo
The Deputy Rector for Didactic, Policies for students and Right for study
University of Trieste

I'm honored to welcome, on behalf of the Rector of the University of Trieste, the participants to the *3rd International Conference on* PRODUCTION ENGINEERING AND MANAGEMENT an Active Interaction between University and Industry, in particular the group of students and colleagues from Hochschule Ostwestfalen-Lippe.

In these few words of address I want to stress the importance of this initiative from at least two points of view.

In the "Darwinian struggle for life" of Italian Universities the actions of opening to international connections is strategic for survival. This Conference is one of these actions, with the extra benefit of circulation of new ideas and best practices.

Again, in the same struggle for life, it is essential for the Academy to be not separated from the "real world", with particular consideration to the most interesting and active fields existing in the territory: our region, similarly to Ostwestfalen, but also with stimulating differences, has a traditional industrial vocation. This Conference is a small but important step in establishing connections between University and Industry.

Before closing, let me also recall the fact that this Conference is organized in the framework of the Double Degree Agreement between Hochschule Ostwestfalen-Lippe and University of Trieste. The achievement of a new European Citizenship is the fundamental goal toward which all our activities should be oriented. This Agreement goes in this direction.

It remains only to thank the organizers of this Conference, in particular the colleagues Marino Nicolich and Dario Pozzetto, and to wish you good work and good stay in Trieste.

PLENARY SESSION
FEDERLEGNO-ARREDO. OPENING ADDRESS

Andrea Negri
Vice-President, Federlegno-Arredo, Italy

1 Who is Federlegno-Arredo

Founded in 1945, Federlegno-Arredo is the Italian Federation of wood, cork, furniture and furnishing manufacturers. The Federation is an expression of a global supply chain in continuous evolution, the world exports, active witness in the process of economic and social growth of the country. Has over 2,700 member companies.

The federation:

- offers services of interest to companies;
- supports technical and economic development through researches, studies, debates, workshops;
- promotes the industry through exhibitions, professional trade fairs and consortiums;
- promotes and carries out professional training and technical education.

Federlegno-Arredo plans many initiatives of international relevance, is one of the main protagonists in the world of **international trade fairs**, with:

Salone Internazionale del Mobile (the International Furniture Exhibition) and Made Expo , (the international event for projects, architecture and building). It has offices in Milan, Rome and Brussels, and representative offices in Moscow, London and Shanghai.

It contributes to the protection of the environment by **promoting the use of wood products in building**: a simple way to reduce CO2 emissions through the carbon sink and carbon stock effects.

2 Italy: economic activity is still in a critical moment

Economic activity has been declining since the second half of 2011 and real GDP dropped by 2.4% in 2012 as a whole. Private consumption recorded an unprecedented contraction, by more than 4%, as a consequence of the large decline in real disposable income. Government consumption also detracted from growth on the back of the sizeable fiscal consolidation. High uncertainty on demand prospects and tight financing conditions restrained private

investment. The only demand component showing a positive sign was exports, thanks to extra-EU demand. This, together with the collapse in imports, stemmed the decline in GDP.
Italy's recession will continue throughout 2013 as the effects of fiscal tightening and restrictive credit conditions bear down on economic activity. Employment and hours worked will continue to fall, constraining household budgets and consumption spending. Despite recapitalisation, continuing losses hinder the banking sector from supporting investment and consumption, though some relief will come from the government's settlement of its payment arrears. Notwithstanding strengthening exports and less fiscal consolidation, growth will remain low in 2014.

3 Universities and Research Centres relationship

The central idea of the **FederlegnoArredo approach** is that in a world where knowledge is wide-spread, the company cannot rely exclusively on its own internal research and innovation capacity but must know how **to access external sources and know how to work together with other** businesses and research centres, in order to be able to know, acquire and re-orientate the technologies and innovations it produces outwards in an original way. **The policy adopted by Federlegno Arredo was characterised by activities to involve SMEs in the development of joint research and innovation projects together with Universities and Research Centres**.

The fast progress imposed by technological innovations has disrupted the old path that saw basic research, applied research and production as totally separate phases. What is required now is **simultaneous co-participation among these three phases**, necessary not only for a significant reduction in the time it takes to pass from the basic research phase to production of industrial prototypes, but above all because the support of basic know-how is also needed for the so-called applied research.

4 Relaunching research and innovation in the Wood-Furniture sector

The aim of the **1st FORUM DELL'INNOVAZIONE** (Bergamo 21 November 2013) is to fill the gap between the world of research (research centres, technological hubs and universities) and small and medium-sized businesses, historically incapable of approaching this world and relating in a structural and synergetic way with the know-how they produce. The result expected from the Forum is the birth of projects capable of uniting businesses in the system with Universities and Research Centres to develop innovative products, new innovative processes, formulas of dialogue and exchange of know-how between the basic research world and SMEs.

The European Community has set itself the aim of reconciling economic growth targets with the need to protect the environment and improve the social model. In the development of the so-called ‘Sustainable consumption and production', **buildings** emerge as one of the macro-sectors with the most impact on the environment (extracted materials, energy consumption, emissions, demolition waste).

In this scenario, **sustainability** becomes the basic element of social and environmental dynamics and thus of economic-production dynamics also, in view of the creation of a strongly Customer driven and Bio-based European market.

The role played by forestry products, and by the industrial sectors linked to it may turn out to be strongly strategic, and potentially capable of revitalising apparently superseded production sectors through 360° innovation.

FederlegnoArredo supports the **Forest-based Sector Technology Platform** and encourage new initiatives, such as private-public partnerships, e.g. in the bio-based sector, which foster research and innovation for various resource- and energy-efficient products and processes.

The forest sector is more present in **Horizon 2020**. The goal is to enhance the sector’s sustainability and develop better forestry production systems and products

INTERNSHIP: A NEW WAY TO ESTABLISH A CONTACT BETWEEN COMPANY AND UNIVERSITY

Alessandro Jesse
President, Jesse S.p.A., Italy

This presentation, as well as bring a direct evidence, aims to raise awareness to those who do not already have been aware of the opportunities that the DDMSC offers not only to the students but rather to firms and university. After a short introduction about the company, I will discuss the benefits and the basic steps needed to establish this relationship and finally I will give an evaluation about it by also giving some personal proposals.
Jesse S.p.A is a SME that operates in the field of 'furniture industry. It was founded in the early twenty-first century, and is currently located in Francenigo, in the province of Treviso. The number of employees is approximately equal to 150 and the current turnover is about 25 million Euros (Figure 1).

Figure 1

But what Jesse really wants to be and what it meant to represent? Jesse is:
"…An outlook on living. Jesse is a company with over eighty years of experience and history in furniture manufacturing. Its design and manufacturing techniques are aimed to define a collection of furnishing system and accessories reflecting a strongly contemporary concept of living, where every home is a unique dimension in which functional needs combine with feelings, affinities, different tastes…" (Figure 2).

After having spent few words about the company, we will now turn to the main subject of this presentation: the internship in the company and the company's collaboration with the university. Which are the most important benefits obtained from this symmetrical relationship?

Figure 2

The mandatory internship not only helps the student to approach the companies but is also able to align the knowledge given by the university courses to the specific needs of the labour market.
The most important benefits from the mandatory internship therefore are:

- the comparison between the company's needs and the student's knowledge and skills;
- the calibration of the DDMSC courses to the real expectations of the labour market;
- Training for the achievement of the figure of “managers” that the Double Degree Master in "Production Engineering and Management" aims to train.

All of these main goals are pursued in order to reach a common goal:
the combination of the training phase and the internship in the company provides both knowledge and methods that give to the young manager, starting from his "mind-set", the ability to effectively and efficiently solve problems in which the traditional managers have difficulty in finding the right solution.
For those who are not aware of, let's now briefly retrace all the necessary steps to establish the relationship between company, university and the student:

- contact between entrepreneur and program coordinator of the DDMSc;
- identification of the issues, objectives and timing of the internship, and signing of an agreement between the Company and the University;
- interview with prospective trainees;
- candidate's choice;
- continuous check-up between corporate and academic tutor;
- conclusion of the training and preparation of the final report;
- Customer satisfaction from the company tutor to be sent to the University.

So let's finally see which are the provocations and proposals that I'm suggesting in order to possibly improve this project:

- why not invite more frequently experts from the furniture field directly in the university courses in order to supplement the professors? Doing so, would approach further the university to the working life;
- why not include an internship also for the first year of the degree course?

Finally let's have an overview on my final impressions and considerations about this project:

Conclusions:

- it was a new and innovative experience for the company, because it was the first University who has proposed this possibility to my company;
- I was rather sceptical at first, but I'm convinced to continue on this path in the future;
- for the company, it was a good investment because the trainee after an initial period of coaching has been able to fully respond with effective solutions to business problems, both from the theoretical point of view, that applications;
- I will seriously consider the possibility of hiring the student at the end of the training period because in the company there is a lack of such a professional figure;
- I would also suggest this positive experience to other companies;
- I propose to the Industrial Association to divulge this specific and new initiative of the DDMSc.

My short presentation is now concluded. I really thank you all for the kind attention and if there is any question I will be glad to answer. Thank you again and come to visit us!

PROMOTING ACTIVE INTERACTION BETWEEN UNIVERSITY AND INDUSTRY

Fabio Sacilotto
CEO, SA.BI GROUP; Plant Manager, FONDERIA SA.BI S.p.A., Italy

The basic idea of this speech is to bring the experience of my company, FONDERIA SA.BI part of SA.BI GROUP, towards the students of the course "Production Engineering and Management" and to do with you some considerations about the relationship between companies and university. SA.BI GROUP grew out of a total manufacturing project, an innovative industrial undertaking shared by the three companies making up the group:

- FONDERIA SA.BI, heart of the group responsible for the production of small, medium and large series of castings in gray and ductile iron (Figure 1);

Figure 1

- LAF responsible for the production of cores, finishing, painting and the delivery of the products (Figure 2);

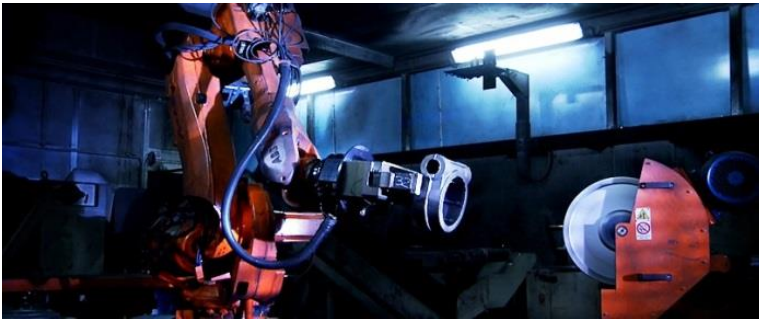

Figure 2

- MEC SYSTEM, responsible for the mechanical machining (Figure 3).

Figure 3

The SA.BI GROUP has a turnover of € 38 million, an annual production of 16,400 tons of cast iron and a total of about 260 employees divided in the three companies of the group. Our production is directed more to the transmission sector and earth moving machines and some of our major customers around the world are Atlas Copco, Caterpillar, Liebherr, Bosch, Parker and Bonfiglioli.

In recent years in the world of small and medium enterprises there has been a lack of the figure of middle manager, that is a figure able: to interface with the top management and the working area by creating a link between them, to coordinate the development of the processes and the innovation of technologies and products, to manage the company operations and to interface at the same time with the globalized market.

What small and medium enterprises expect from the university is that it is able to train middle managers who have a good knowledge of the English language, skills, knowledge and transversal competences on technologies, industrial processes and the management of small and medium enterprises, leadership skills, high quality of theoretical and practical education and have experience of compulsory internship in the company since the early years of university.

Why so did we choose a student of the Double Degree Master and why do I recommend it to other companies? Because we found students close to graduate with a good knowledge of the English language, a good general preparation on industrialization, management and control of the supply chain, students who had practical experience of company management in the different university courses and because during the internship there has been continuous partnership between company and university aimed at building an opportunity to enter the world of work, and, last but not least, for the predisposition to abroad experiences demonstrated by the students in the choice of such curriculum, which is an increasingly dominant factor given by the openness to foreign markets.

To finish my speech I would like to express some reflections about what has been said until now: through the internship in a company it is possible to reduce the insertion time of new middle managers in the companies, there was a high satisfaction with the educational activities carried out by the Double Degree Master in Production Engineering and Management, it is also important to emphasize the importance of the relationship between entrepreneur and university lecturers in order to further facilitate the integration of students in the world of work and finally the hope that this idea is spreading to other entrepreneurs in our area to try to give new expectations in the future to those who wish to take this route.

BIOFILTRATION FOR SUSTAINABLE PRODUCTION

Egidio Babuin [1], Marcello Civilini [1,2], Giovanni Cortella [1,2]
[1] S.E.R.E.S., Udine, Italy
[2] Università degli Studi di Udine, Italy

Abstract
The problem of Volatile Organic Compounds (VOC) emissions due to coating processes in manufacturing afflicts enterprises because of strict regulations. A few companies of the wood district in Northern Italy financed a project aiming at the investigation on the use of biofiltration to reduce the emission of VOCs. Three prototypes at increasing scale have been built and tested, with promising outcomes. The project is now ready for scaling-up at industrial level.

Keywords:
Biofiltration, VOC, emission

1 INTRODUCTION

The problem of Volatile Organic Compounds (VOC) emissions due to coating processes in wood manufacture afflicts furniture enterprises because of the complex requirements of current regulation.
Expensive investments and management costs are required, in addition to usual costs already burdening industrial accounts.
Virtuous companies research into and improve their varnishing processes in order to decrease the VOC emission rate into air by means of:

- new coats with higher dry residual
- transfer efficiency improvement
- introduction of waterborne products
- innovative technology to capture solvents by physical overspray processing.

Nevertheless, customers require a final product with a high quality/price ratio which the present technology can only satisfy by using coats with huge solvent mixture.
Although the real target is to radically solve the problem acting directly on products and processes, companies are often forced to reduce VOC emissions by installing standard plants at the emission point, based on [1,2,3]:

- absorption by active coals
- catalytic combustion
- combustion by heat recovery.

Four companies, two chair producers and two manufactures of wood furniture components in the Northern Italy decided to finance a research project aiming at the industrial use of bio-filtering, involving also a plant engineering company and an university spin-off.
They exploited a recent Italian law, which was created by the central government to facilitate the enterprise networking oriented to achieve a common objective by realizing a technical program.
This way, in 2010 SERES was founded, whose task is to coordinate and support the project, with a lean management organization, by analyzing its technical and economic feasibility and by evaluating a new business opportunity (Fig. 1).

S.E.R.E.S.
Sistemi Ecologici per la Riduzione Emissioni Solventi

IDEALSEDIA S.r.l. chair and furniture manufacturer

PALMA S.p.A. chair manufacturer

Carpenteria Manzanese S.n.c. aeraulic systems manufacturer

BIOSISTEMI S.r.l. spin-off from University of Udine for research activity

L.A.V. S.r.l. wood furniture painting

SNAIDERO Rino S.p.A. modular kitchen manufacturer

Figure 1. Enterprise networking for the biofiltration project.

Furthermore, public institutions participate with financial and technical support:

- Friuli Venezia Giulia regional government
- ASDI sedia
- CATAS.

The bio-filtering system is a clever solution for the reduction of VOC emissions, avoiding the additional CO_2 emissions from non-renewable energy sources due to combustion processes, and it is an important and effective complementary action to other initiatives currently adopted to achieve the same goal.
To better understand the development of the project, it can be split into three phases, depending upon the scale of the prototypes which have been setup: laboratory scale, small and industrial scale prototype.

2 LABORATORY SCALE INVESTIGATION

Lab scale tests were performed to verify the VOC speciation of air pollutants within emissions and to look for agents for their biodegradation. Preliminary tests to quantify the bioconversion to CO_2 of each single VOC were performed. Traditional and advanced techniques were used to discover catabolic properties in each isolated strain with particular attention to the strains with multiple catabolic pathways in the target compounds. At the end more than 98% of the VOCs tested showed to be biodegradable. Successive tests made it possible to demonstrate the ability of microorganisms to use each VOC as energy source even in the presence of other organic compounds when they were added on a solid support.

3 SMALL SCALE PROTOTYPE

Following the promising results of the laboratory tests, a small prototype was setup, consisting in a container filled with inorganic and organic material [4]. (Fig. 2) This biofilter was fed with 100 m^3/h air flow rate, at controlled composition. When investigating the removal efficiency of VOCs mixtures, the composition reported in Table 1 was considered as typical of the wood painting processes.

Table 1: Composition of the VOCs mixture investigated in the small scale prototype.

Compound		% mass
Ethyl Acetate	EA	11,5%
MethylEthylKetone	MEK	17 %
Methyl IsoButyl Ketone	MIBK	1,5 %
Toluene	TOL	5 %
n Butyl Acetate	BA	16 %
Xylene	XYL	38 %
EthoxyPropylAcetate	EPA	6 %
Diaceton Alcohol	DA	5 %

Figure 2: The small scale prototype.

Tests at small scale demonstrated the ability of microorganisms to use the VOCs in the mixture as an energy source. Different elimination capacities of each VOC of the mixture were evaluated showing which compounds were more likely to be degraded. The results of experiments performed at small scale biofilter allowed to gain essential expertise on the processes previously investigated only theoretically or at lab scale, and were the basis for the design of a larger system.

4 INDUSTRIAL SCALE PROTOTYPE

A new prototype at industrial scale was designed and built, to control a fraction of the emissions from a wood furniture manufacturer. The biofilter has a working volume of 25 m^3 and a max capacity to treat 6000 $m^3\ h^{-1}$ of exhausted air coming from the working on and painting of the wooden components (Fig. 3). The drying zone emissions were chosen to feed the biofilter with the polluted air. A system of pipes and valves on vent holes was designed to allow for a possible control of the VOCs' concentration at the inlet of the biofilter, by dilution with clean air. The system is also equipped with an air recirculation circuit which has been activated in very few cases (Fig. 4). The air flow rate was regulated controlling the velocity of the air extractor by means of an electronic inverter.

Figure 3. Industrial scale prototype

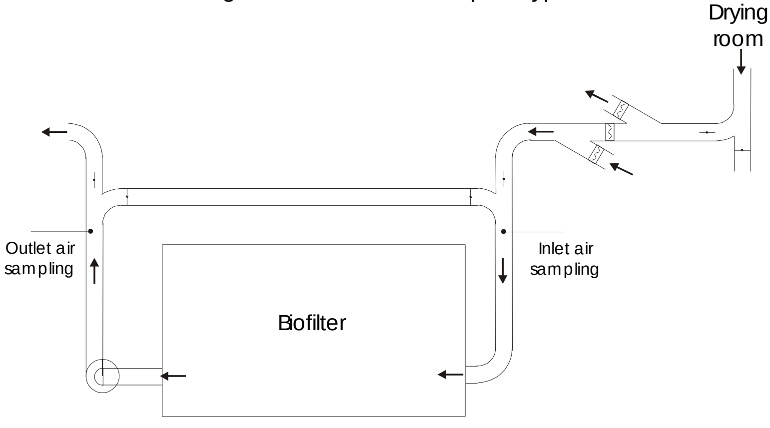

Figure 4. Sketch of the industrial scale prototype

Sensors were installed to control the thermo-fluid-dynamic aspects of the system. In particular, pressure values (and consequently pressure drops), air velocity (and consequently flow rate) and temperature of both air and filling material were monitored at several points.

4.1 Monitoring of emissions

On line monitoring of emissions were performed in both continuous and discontinuous mode at both the inlet and outlet of the biofilter (Fig. 4) [5].
CEE CEN264 n.326 and EN 13526 standards [6] to determine TOC, VOC and CH_4 in emissions were applied for continuous monitoring. By means of alternate (3 min^{-1}) online sampling between inlet and outlet air flows, air samples were continuously withdrawn and supplied to a F.I.D. analyzer.
VOC concentrations were evaluated in discontinuous mode by gas chromatographic (GC) analysis. Coconut charcoal tubes were used for sampling in compliance with the EN 13649 standard [7]. Compounds were identified and separated thus allowing for the speciation of the emission.

4.2 Results

The system start up was in July 2009, with preliminary operations in the absence of any filling material to check the absence of dilution and to optimize the equilibrium flow conditions between the biofilter, the blower and the line connections to the drying room. After filling the material, physical, chemical, microbiological, and fluid dynamic parameters were optimized to guarantee the optimal performance related to working conditions. Full operation was then achieved in September 2009.
During the whole testing period the composition of emissions at the inlet of the biofilter was periodically evaluated. Figure 5 reports the average composition (mass %) and reveals a significant concentration of aromatic substances. At such conditions, organic loads (OL) of VOCs were between 10 and 50 g C $m^{-3}h^{-1}$ and the resulting removal efficiency ranging constantly between 55 to 70%. Further tests were conducted at OL up to 100 g $Cm^{3}h^{-1}$, measuring a removal efficiency around 50 %. As an example, Figure 6 reports the values of concentration continuously measured by F.I.D. at the inlet and outlet during three typical days of operation. Emissions for both 8 hours/day and 16 hours/day working periods have been treated, on a 5 days per week basis.

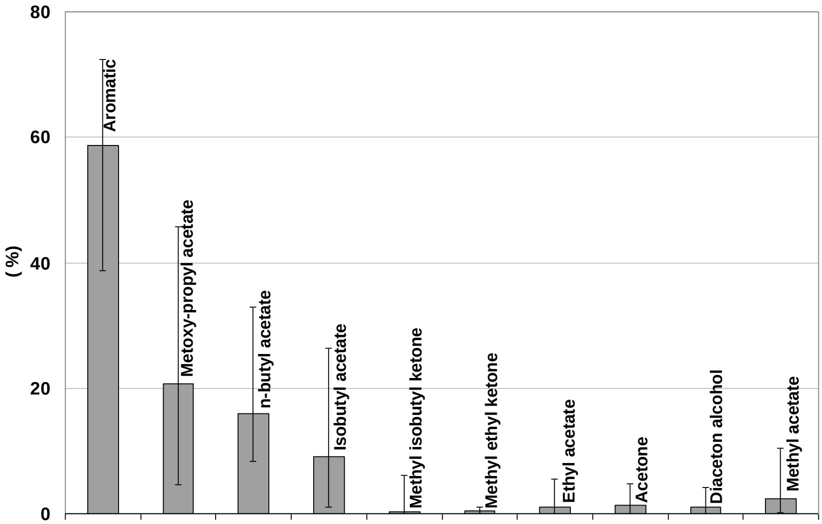

Figure 5. Average composition of emissions at the inlet of the biofilter during the whole testing period

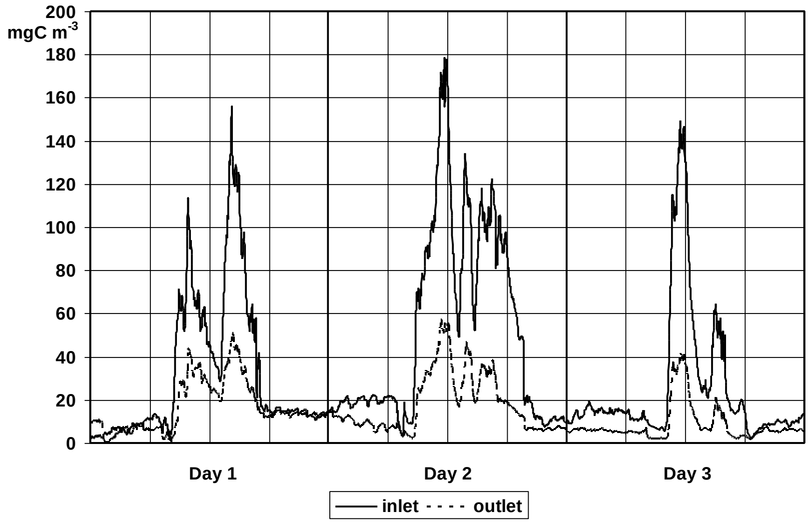

Figure 6. Concentration measured by F.I.D. at the inlet and outlet during three typical days.

The speciation of emissions at both the inlet and outlet of the biofilter allowed a thorough evaluation of its capability to remove single compounds,

and revealed a high concentration of aromatic compounds at the outlet. It was then decided to ask paint suppliers to consider a new paint formulation with low aromatic content (from about 60 % to 30 % in the average). Tests performed with this improved formulation showed a significant increase in removal efficiency at OL greater than 50 g C $m^{-3}h^{-1}$, thus extending the operating range of the system.
No VOCs accumulation was found during the daily and weekly cycles. Particular attention was paid to the latter. The daily cycles have been thoroughly investigated and for this purpose the plant was designed to test, measure and treat the daily residual carbon. Temperature in the biofilter was effectively controlled thanks to a proper thermal insulation and to the heat released by emissions.
The prototype is still working continuously without any modification and no solid or liquid waste has been produced in 4 years.

4.3 Microbiological monitoring

Particular attention was paid to the aspect of microbial safety, to investigate pollution due to possible microbial fall out. Numerous indoor and outdoor samples were harvested in the factory, to detect any presence of microbial contaminations.
There are no standardized procedures or protocols for the evaluation of the microbial contamination in gaseous industrial emissions. Thus sampling at the emission point was performed by the “active method” using a Surface Air System (SAS) single stage impactor sampler (Fig. 7). On the contrary, sampling of the environment was performed by passive monitoring following the procedures described by the Italian Workers Compensation Authority (INAIL) [8].

Figure 7. Apparatus for active sampling at the emission point

Values of microbial contaminations (bacteria and fungi) measured with active sampling at various distances from the emission point (0 cm, 50 cm,

200 cm) showed “very low” bacterial load when compared with the European Collaborative Action limits.
Quality of air in the proximity of the emission point, evaluated with the passive method, was judged “in the average” when compared with indoor limits.
Microbial contamination was checked several times, always with similar results, which confirmed that emissions don’t affect the microbiological quality of environment.

5 CONCLUSIONS

A long term theoretical and experimental investigation was carried out on a biofilter for VOC industrial emissions. A prototype at industrial scale was finally built and installed to control emissions from wood painting processes. Monitoring the prototype operation showed a very low energy consumption, a minimum of maintenance requirements and a steady functioning. These features in addition to the absence of CO_2 emissions from combustion make the biofilter very competitive compared to the traditional VOC reduction systems and a sustainable solution for the environmental improvement policy by virtuous Companies.

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SUSTAINABILITY FOR A BALANCED INDUSTRIAL GROWTH

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Abstract
Friulintagli believes that a medium/long-term company growth is simply not possible without sustainability.
To keep its market shares, the Company needs to reduce marginality and, in consideration of the fact that the prices for raw materials are already high, efficiency and reduction of material consumption per sold unit of product is considered as the main solution. Lighter materials, more recycling, less energy consumption, use of by-products, also in terms of cogeneration, introduction of “green economy” in every company activity at a global level, this is the Company's answer to the markets' new challenges.
At present, there is **no standard index to measure product sustainability.** FriulIntagli aims at the definition of a **specific product sustainability index for every product,** by analysing new solutions concerning new materials and raw materials, energy consumption including cogeneration, the use of recycled material, the recyclability of finished products and recycling of wood waste.

Keywords:
Energy saving, recyclability of finished product, sustainability, economic and environmental intervention for the sustainability, sustainability index, efficiency, renewable energy.

1 INTRODUCTION

The attention paid by the public opinion and by companies to environmental sustainability and social responsibility has been increasing steadily over the past few years. Meeting customers' requirements and evolving the relations with the companies with all the figures it interacts with are the variables onto which innovation should be focused.

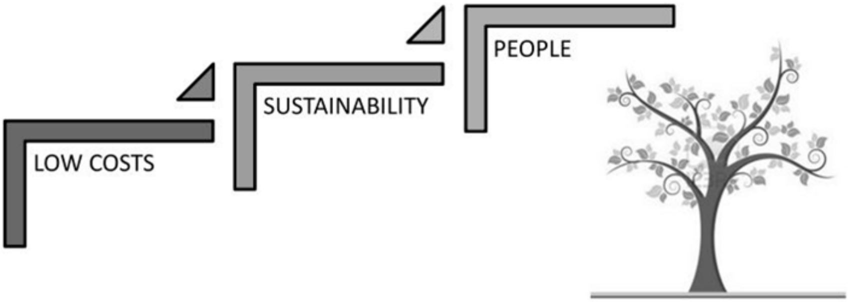


Figure 1: Company basis for GROWTH

To keep its market shares, the Company needs to reduce marginality and, in consideration of the fact that the pressure on prices for raw materials are already high, efficiency and reduction of material consumption per sold unit of product is considered as the main solution.

500 000 m³	• Total raw particleboard/MDF / year
41 055 tons	• Total waste, of which **96 %** are **recycled**
65 GWh	• Energy consumption/year
16 356 tons	• Estimated CO_2 emissions including other GHG/year
28 %	• Renewable share
16 560 m³	• Water consumption/year
90 trucks	• Internal logistics/day
80 trucks	• of finished product/day
150 trucks	• Raw material/day

Figure 2: Company footprint

Lighter materials, more recycling, less energy consumption, use of by-products, also in terms of cogeneration, introduction of “green economy” in every company activity at a global level, this is the Company's answer to the markets' new challenges.

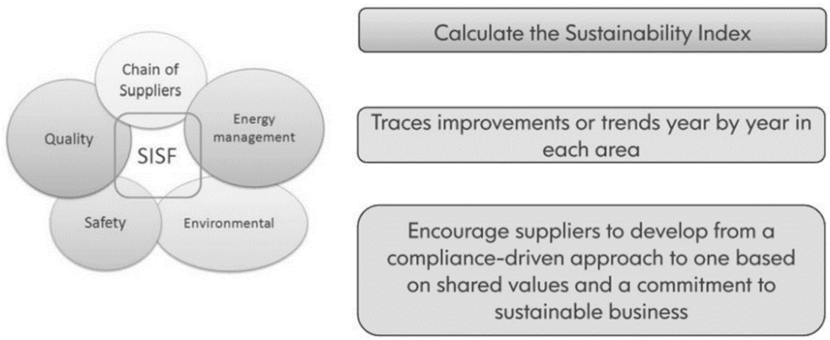


Figure 3: The Sustainability Integrated System Friulintagli

At present, there is **no standard index to measure product sustainability**. However, there are large multinational groups that have defined or are defining their own indices.

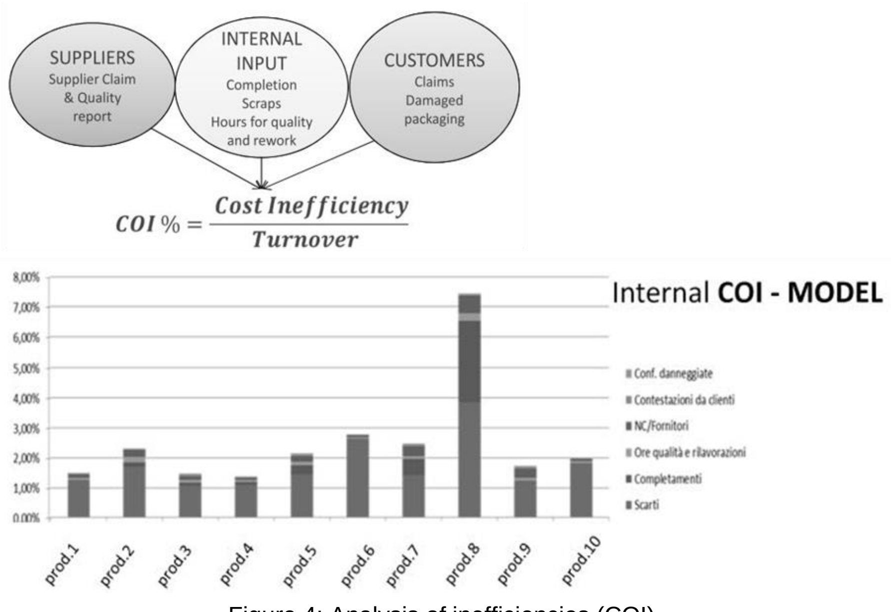
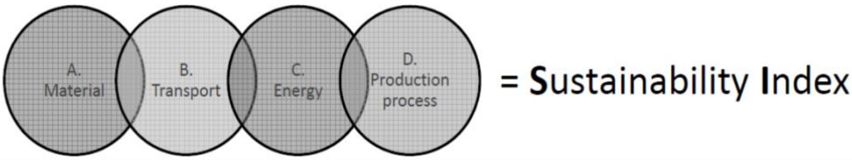


Figure 4: Analysis of inefficiencies (COI)

Friulintagli aims at the definition of a **specific product sustainability index for every product**, by analysing new solutions concerning new materials and raw materials, energy consumption and its impact, including cogeneration, the use of recycled material, the recyclability of finished products and recycling of wood waste.



SCORE 2013

Criteria	Weight	Grade	Score
Material	5,5	2	11
Transport	5	2	10
Energy	6,2	3	18,6
Production Process	6,5	3	19,5
TOTAL			59,1
SUSTAINABILITY INDEX			**64%**

Figure 5: Sustainability Index

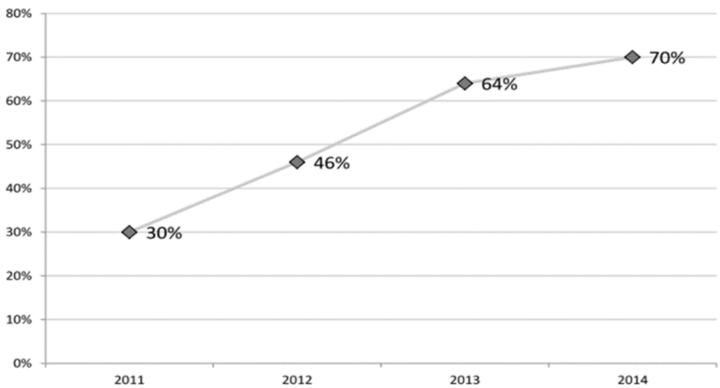


Figure 6: Trend Sustainability Index: goal 2014

This sustainability project includes the following research areas:

New materials and raw materials: panels made with wood substitutes have a density that is frequently higher than wood's, especially if they are made with recycled materials.

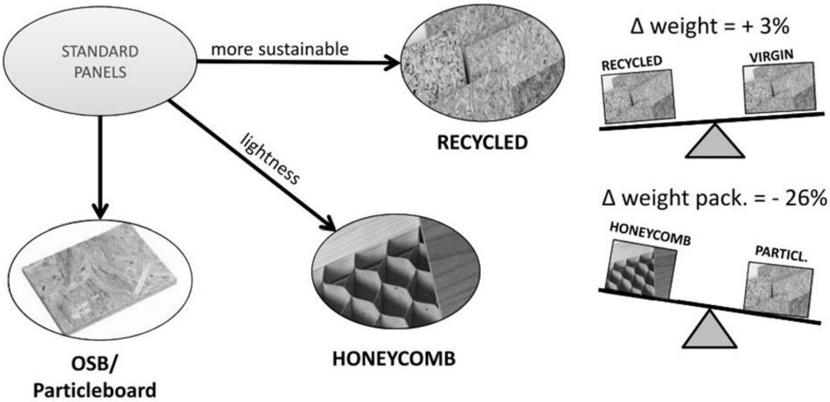


Figure 7: New materials

As a result, the first negative impact is related to the fast wear of the tools used to make them. The second negative impact is related to logistics and transport. For example, lorries that transport them travel at full load in terms of weight, but not in terms of volume. Another negative consequence is a higher weight, given the same performance, of the furniture mounting kits. The end user finds operations more difficult without enjoying any benefit. Some raw material companies are currently carrying out research on lighter materials, which, however, cannot be developed without the close collaboration of users and an in-depth knowledge of the various applications.

Consumption and energy impact: the cogeneration plants currently using wood-based waste material have been designed to heat environments using scraps. This type of system does not meet Friulintagli's requirements. Therefore, at present, there is no cogeneration system that ensures poor use of the thermal part and maximum yield from the electrical part, which is optimised for the use of recycled materials and powders, and not pieces of wood, as raw material Finally, the system that FriulIntagli is studying about the sustainability project shall ensure full efficiency all year long, whereas the solutions that are currently available have been designed for seasonal operation.

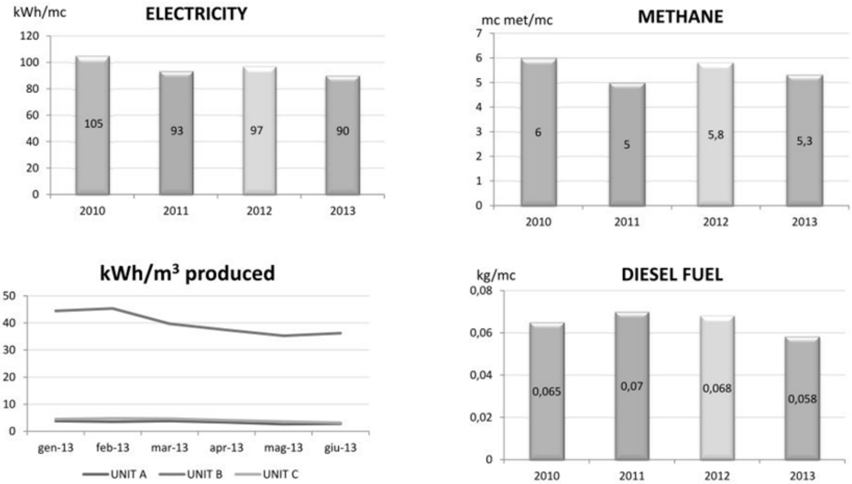


Figure 8: Efficiency indicators

Use of recycled material: it is not about improving recycling, which is already 100% for chipboard panels. The problem here is to obtain lighter panels that are easier to process. The current situation is exactly the same as the one described above for "New materials and raw materials".

Recyclability of finished products: the problem here is to identify harmful or carcinogenic materials and to phase out non-recyclable materials from the manufacturing process of finished products and their packaging.

Recycling of wood waste: the current maximum limit for recycling scrap and waste resulting from company activities is 96%. This sustainability project aims at exceeding this limit, preventing, at least partly, the creation of waste sent to landfill. There are two problems: the first is related to the optimisation of the processes and the use of recyclable materials in the design of the products.
It is clear how, in this industrial context, a small fraction of waste (4%) represents a large amount to be disposed of, which cannot be recycled.
Moreover, sawdust outside of the company becomes waste. It is originated from the panel cutting and perforation processes. The main production unit in Friuli, Unit 1, currently produces 16,500 tonnes/year of sawdust, which means 44,100 km/year covered by 735 lorries and 38 tonnes of CO2 released into the atmosphere.

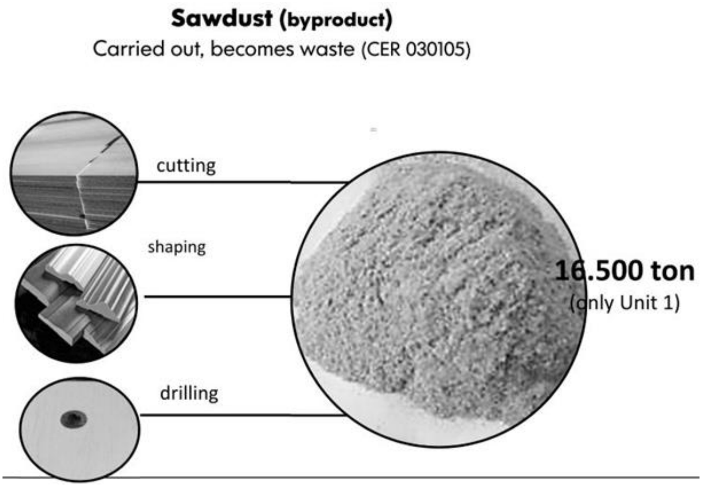


Figure 9: Sawdust production

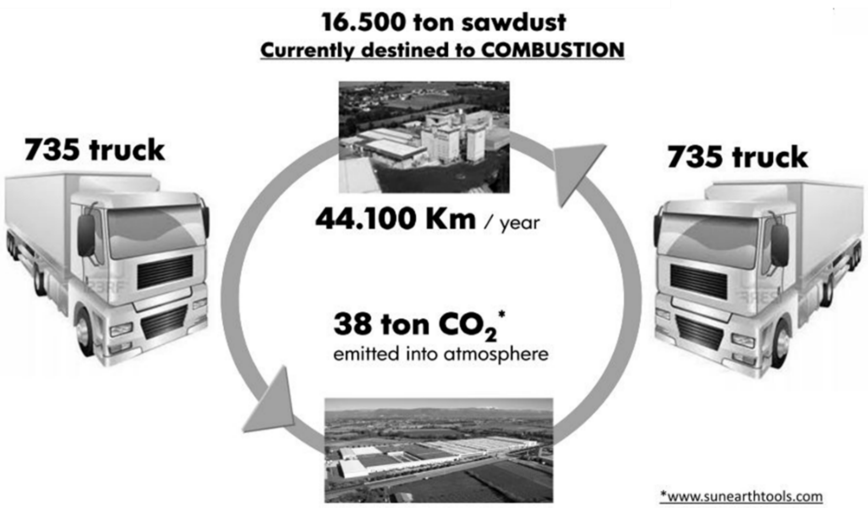


Figure 10: Current sawdust cycle

The main goals described for every area

1) Definition of a sustainability index

The Company want to establish a new index based on raw materials, meeting all legal requirements whilst respecting the sources; in other words, raw materials should come from sustainable sources with certified materials or verified at the source.
To do so, we need to extend our verifications to suppliers.
The index will refer to the single product and will no longer be generic as the current one, which produced these values. This new index will be applied and parameterised for every raw material used in the manufacturing process, thereby referring not only to wood, glue, and paper, but also to thermal energy and electricity.

2) Research and development of new products.

2.1) New materials and raw materials
The goal is to analyse prototypes and verify the use of new materials developed by suppliers, newly developed wood-based panels featuring very low density and made using state of the art technology. The Company also aim at developing new solutions to reduce density. This part of the research is closely linked to the study of honeycomb panels (BOS - Board On Style). In both cases, the impact on the production cycle and the technical solutions used must be verified to establish how to adapt them to the use of these new materials. A typical case is given by handling via suction cups, which strongly depend on the nature of the material as well as on cutting systems.

2.2) Consumption and energy impact
The goal is to develop a new cogeneration system optimised to use recycled material and generate electricity.
Moreover, this system must be fully efficient all year round and must be sized according to its specific features and use.
The company is moving towards on-site electricity production and consumption to prevent any loss during transport. Moreover, the raw material used to power the system should be conveyed directly from the place of generation to the place of incineration through conduits that exclude the use of vehicles inside or outside the plant. From a functional point of view, the goal is to achieve full thermal autonomy in the Prata plant by replacing the current natural gas boilers, and to obtain maximum electrical efficiency as consumption is so high that it does not allow for full self-generation.
In any event, this significant investment will add up to the investment we have made on solar panels. The global goal is to reach 60% of electricity from renewable sources.

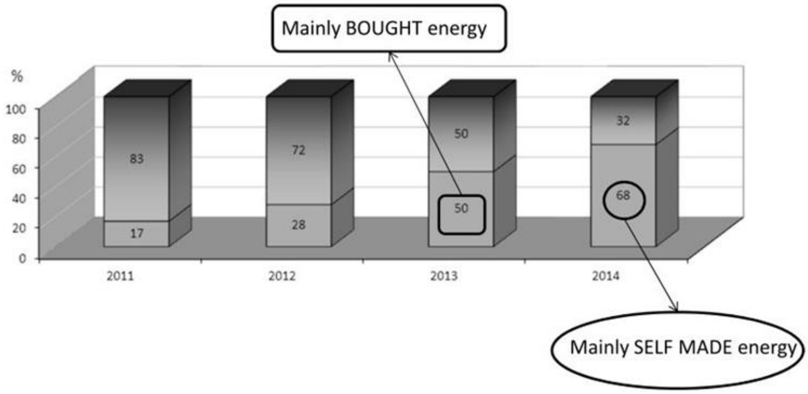


Figure 11: Trend renewable energy

This research takes only a small fraction of the activities into account, both from a quantitative and an economic point of view, and focuses only on the critical aspects of the project, which require a lot of research. In particular, the goal is to design and develop a new combustion chamber prototype and its subsystem, including the fumes line, which is considered the most innovative and critical aspect of the entire system.

2.3) Use of recycled material

The aim is to improve the composition of chipboard panels and to identify solutions for critical processes in order to obtain panels that are increasingly lighter and easier to process. Italian manufacturers have developed processes that can use 100% recycled materials. However, these panels do have some limitations, as they have a higher density and are more difficult to process.

Friulintagli is also a supplier of scraps used to make panels and, simultaneously, a user of these panels. Therefore, we are in a privileged position that allows us to enhance the value of these products by analysing the use of glue and paper, as well as particular processing cycles, in order to achieve the best performance with the highest use of recycled material. Moreover, being in contact with major retailers, we can provide these materials to Mass Distribution and spread their use on a global level.

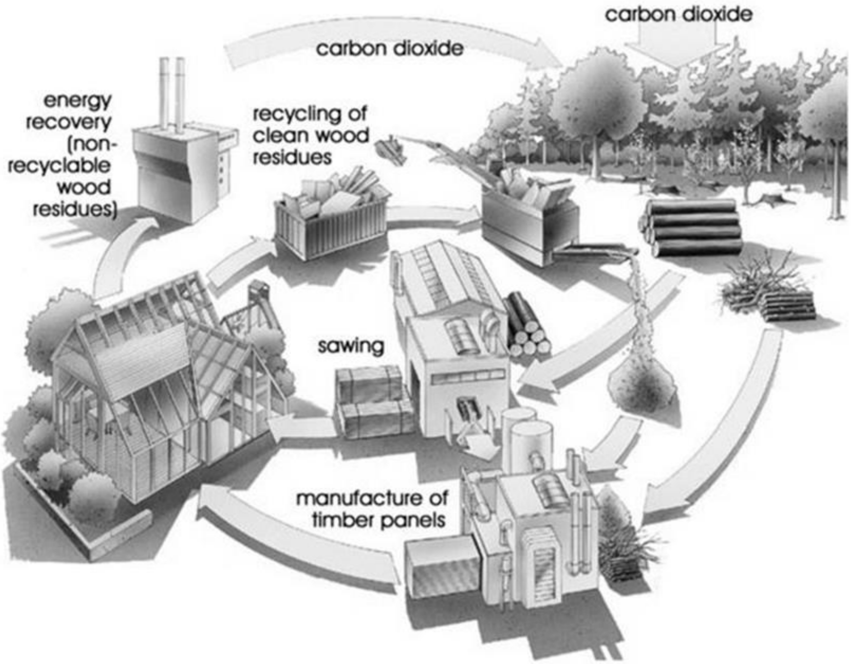


Figure 12: Wood cycle [5]

2.4) Recyclability of finished products
The first goal is to identify techniques to analyse incoming production factors to ensure that the materials use do not contain harmful or carcinogenic elements. This refers to both the finished products and the packaging. To this end, Friulintagli intends to carry out a research aiming at replacing expanded polystyrene used for packaging, with other sustainable materials, such as honeycomb cardboard or similar solutions, using vegetable or recycled fibres. We also wish to investigate the issue related to the selection of the adhesive, which can impact recyclability.

2.5) Recycling of wood waste.
The European Commission has defined the wood cycle according to the following representation and FriulIntagli following this cycle will produce energy only from the non-recyclable wood residues (particleboard and MDF wood dust)*2 blank lines 10 Pt*

People

It is very important create and implement a full communication package as part of overall marketing strategy determined to all stakeholders (customers as well as suppliers).
It's also necessary identify the specific training needs of each position in the factory in order to contribute maximising savings and performance and conduct these trainings continuously.

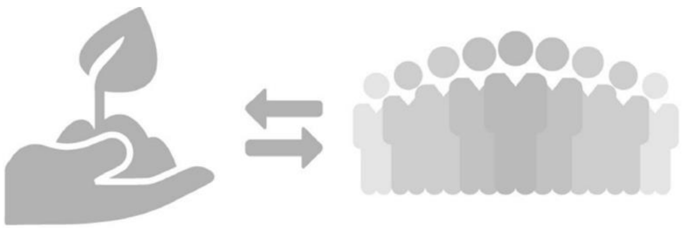


Figure 14: It's necessary everyone's help

Economic and ecological crisis are giving growing importance to the so called "fourth industrial revolution". Efficiency, quality, innovation that all together we summarize as "sustainability" are for us the key of success.

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PROCESS CHAIN SIMULATION: VIRTUAL REALITY TO MACHINE-VR2M

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Abstract
The networking of production processes by means of information technologies (IT) has become a major field of development within industry and research. The main target is to interlink autonomous production systems to an intelligent production line, where products itself organise and control their manufacturing. This new attempt in production is – actual in Germany – described under the definition "Industry 4.0", the fourth industrial revolution. Basically, the essential hardware and software to meet this objectives has been developed in other branches and is able to upgrade machines and handling systems to cyber-physical systems. The crucial issue to design an autonomous, intelligent production line is to generate the exact process data for each production step, to verify this data and to transfer it into the individual machine control. The characteristics of this main problem increases with the degree of interactions between the processes in the production line. In the woodworking industry, the process chain of profiling has a high degree of interactions. The individual production steps are strictly based on another and the result of a process effects the subsequent one respectively. To network these processes and add IT, an integrated IT system with individual CAD/CAM system for each process type is needed. The estimation of the interactions is done by the simulation of the whole process chain in a virtual reality before the real production. This enables to verify the process data, and to benefit from simultaneous engineering. Besides the essential algorithms to calculate the process data for the different process types and estimate the geometry corruptions due to systematic errors and manufacturing tolerances, the consideration of the material behaviour during the production is the determining factor to get valid data for the process chain. The shrinking and swelling of wood and wood-based materials due to a change of moisture content causes a geometry corruption and requires algorithms to simulate this behaviour in the virtual reality. The result of these algorithms for the processes and the material behaviour are the exact process data for a specific profile. The database for the calculations and the data storage is a developed product data model. This product data model forms the gateway for the simulation in the virtual reality to the machine controls.

Keywords: process simulation, process chain of profiling, CAD/CAM, virtual reality, product data model, simulation of shrinking and swelling of wood.

1 INTRODUCTION

The international current economic situation forces all companies to increase their efficiency to stay competitive. The development and production of products must be accelerated, due to shorter product life cycles and an increased pricing pressure. [1]
The main component for this acceleration is the integration of information technology (IT) in all divisions of companies to automatize processes and save resources. Whereas the integration of IT in administrative areas such as finances, personnel, purchasing and logistics has progressed considerably, the production area is operating in large extend without intelligent IT systems. This arises from the complexity of production systems and the diversity of manufacturing possibilities respectively. Thus, a large area of research has been created to develop the software and hardware to enable the potentials of IT in production. The German term “Industry 4.0” covers in this context the networking of production process and the creation of intelligent autonomous production units by means of integration of IT. The basic elements for this approach are cyber-physical systems with the ability to communicate with other technical systems. This communication is described as the “internet of thinks” and the machine-to-machine (M2M) communication respectively. [2]
To upgrade machines and production systems to cyber physical systems in the sense of “Industry 4.0” one essential part is to generate the correct process data and to create an interface to the machine control – in general a standard – to enable the M2M communication [3]. An effective way to generate the process data for a process or connected processes in a production chain is to simulate the processes in advance before the real production in a virtual reality. This leads to a reduction in time, as simultaneous engineering is possible and leads to a revised error prevention because of the simulation [4].
Also the wood working industry can benefit from this potentiality, especially in areas with a minimum of integrated IT systems, due to the complexity of a process chain. The process chain of profiling for the production of profiled elements as components for the flooring, furniture, kitchen, doors, and windows industry is such an intricate process chain. The product range includes solid wood profiles with or without coating and wrapped wood based material profiles in different shapes. For the production of these elements, the basic processes sizing, moulding, sanding, wrapping and coating are directly involved in the manufacturing. Processes like tool grinding, tool manufacturing quality control etc. are sub process in this chain and indirect involved in the production (Fig. 1).
The complexity of the process chain of profiling occurs from the interdependence of the individual processes. The processes are strictly based on another and each process must be adapted to the result of the previous one and modified to achieve by the end of the process chain the correct result. Thus, the generation of process data for these interlinked

processes is only possible if the whole process chain is taken into account during the calculation and simulation. A single CAD/CAM system to calculate the process data for an individual process – like CAD/CAM modules for the carcass furniture production is inadequate as effects of sub and previous processes are not considered and the calculated data do not fit the real and necessary data to run the process [5].

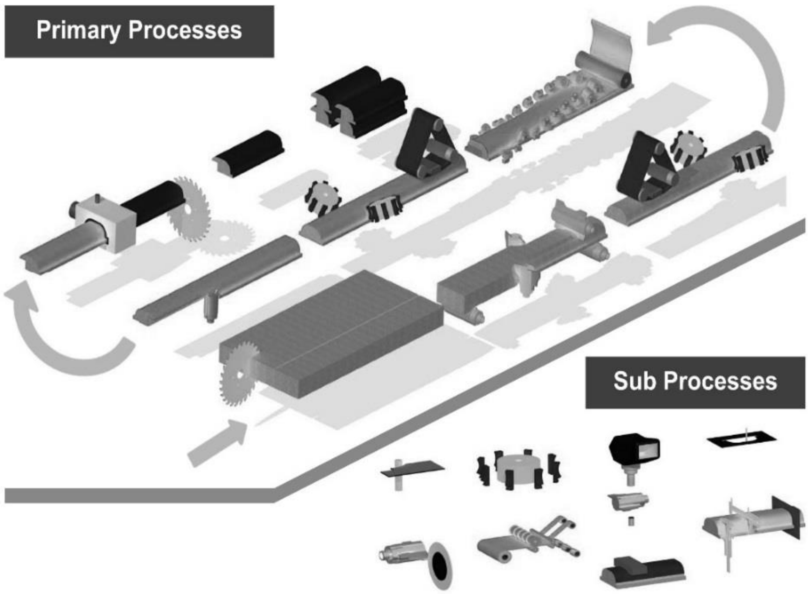

Figure 1: Process chain of profiling with connected process steps [5]

To solve this problem only the simulation of the whole process chain with all effects of primary processes and sub processes will lead to correct process data. However, also the simulation of the material behaviour during the production and storage is necessary because of the hygroscopic properties of wood and wood based materials that lead to a shrinking and swelling in case of a change in the temperature and humidity of the surrounding atmosphere.

2 MODELING AND FOUNDATIONS FOR THE SIMULATION

The foundation for all calculation in a virtual reality are accurate data that describe the properties and the behaviour of the product – the profile – and the processes, which transform the profile. In general, any simulation requires a model either to describe the system in a static way or to describe the behaviour and effects on a system that appear due to interactions within the system or with other systems [6]. The simulation in the virtual reality is carried out by a simulator, which is a software tool able to calculate all interaction.

2.1 The product and process data models

The first step to instantiate the simulation of the process chain of profiling was the development of a product data model to store and handle all information for the profile definition. The product data model was designed using the XML format. The basic element for the profile definition is the profile geometry, which is integrated as DXF data within the XML file. All other semantic information for the profile definition are linked to the geometry and represented by XML datasets. This semantic data includes the materials of the profile, quantities, qualities and tolerances and the definition of the process chain for the manufacturing. To avoid any redundancies all individual elements like a material with its definition and properties were modelled in separate XML files and databases respectively.

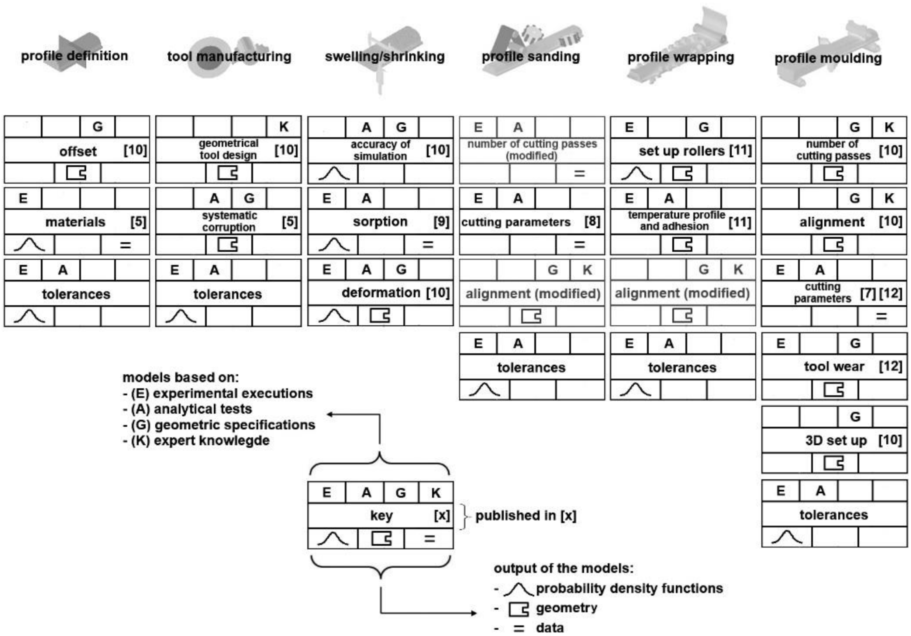

Figure 2: Models for the simulation of the process chain of profiling

For the simulation, also the modelling of the process chain with the machines, tools and other components was part of the research work. The definition of the processes is done with the same data structure than the profile definition. The XML files of the machines, tools etc. include all parameters to build a 3D model with all necessary process data [5].
The next step of modelling was the calculation of the process data and the interactions of different processes and the material behaviour. Therefore, existing models regarding the cutting force for moulding [7], the process data for sanding [8], the sorption of water by wood [9] etc. where used and in some parts enhanced. Other effects with no existing model were investigated and describe with algorithms to build up a model. The existing and developed models to simulate each process and sub process with its effects are presented in Fig. 2.

2.2 Modelling of the deformation of wood

The shrinking and swelling of wood and wood based materials due to a change of moisture content leads to a corruption of the geometry. This effect must also be simulated in the virtual reality with algorithms to predict the deformation and get correct process data.
There are mainly two kinds of methods to simulate the material behaviour as the numerical and the analytical approaches. The numerical methods as the FEA requires a high number of input data and a software for perform the simulation [13] [14]. Furthermore, all the finite element studies do not consider the influences of different shapes in the cross sectional deformation. In contrast, the analytical methods have an immediate application in the solution of problems because they are simple and they require few input data. The intrinsic problem in the analytical methods is that they consider certain assumptions in the calculation that lead to errors or inaccurate results because most of them consider the annual rings as straight lines and the profile shape is always considered rectangular [10][14][15]. There is no presence in literature of any calculation tool, forecasting the behaviour of the cross sectional wood with respect to the profile shape and it is necessary to develop an analytical calculation system.

Development of the new algorithm

The standard analytical approaches consider the deformation of a rectangular cross section considered as a transformation of coordinates or a transformation of external points but they do not consider the internal influences causing the deformation. The innovation in this approach is the consideration of the deformation as a mechanism happening due to linear expansion or contraction of latewood. The input data needed for calculate the deformations of a wood cross sectional shape with the graphical method are the tangential and radial differential shrinkage and swelling parameter, the difference between the initial moisture content and the end moisture content in the cross sectional piece and a picture of the profile cross section.

The series of steps needed to perform the calculation of the deformation start with a picture of the profile cross section.

1. The picture has to be transferred in a program for analyse images, for example a CAD system.
2. The perimeter around the shape of the profile has to be traced with some lines or arcs of circle.
3. With the perimeter of the profile in a vector image, the centre of area has to be calculated and identified in the figure.
4. After that the outline shape is traced it is important to analyse carefully the image searching the biggest latewood arcs of circle present in the image, because they represent the annual rings subjected to more deformation in the wood profile and are the major cause of deformation of the overall profile shape. Also the position of the latewood in each side of the contour of the wood profile has to be considered, because for simplify the process of graphical calculation it is crucial to determine at least two annual rings connecting one side of the board and assuming further that between two points only one segment can pass through. A selection of more latewood annual rings leads to a longer process for calculate the shape deformation.
5. The selected latewood annual rings have to be traced as done for the profile shape contour. Subsequently the nearest latewood annual ring passing through the centre of area has to be traced and this is then considered as the annual ring used to define the pith position of the fitted trunk in respect to the cross section of the board.
6. From the centre of the pith a radius connecting the centre of area of the profile has to be drawn as represented in Fig 3. The segment intersecting the centre of area of the board from the pith of the fitted trunk is considered as the equilibrium segment for the profile cross section where the tangential stresses are acting opposite each other in respect to this segment.
7. For calculate the tangential shrinkage and swelling of the profile it is necessary to draw a radius from the centre of the pith to the profile board sides intersected by the latewood annual rings. The radius has to be quoted for permit the subsequent calculations. Subsequently the angle between the radius and the equilibrium segment passing through the centre of area has to be quoted as represented in Fig 3.
8. For every intersection between the selected latewood annual rings and the profile shape, the radius and the angle with the equilibrium segment as represented in Fig. 3 have to be reported. The tangential displacement is computed with the subsequent formulation 1:

$$\Delta l_{latewood} = \vartheta \cdot r \cdot \beta_t \cdot \Delta u \quad (1)$$

Where r is the radius from the latewood intersection whit the board sides to the pith; ϑ is the angle between the radius and the equilibrium segment, converted in radians; β_t is the tangential differential shrinkage and swelling factor and Δu is the difference between the initial moisture content and the final moisture content state.

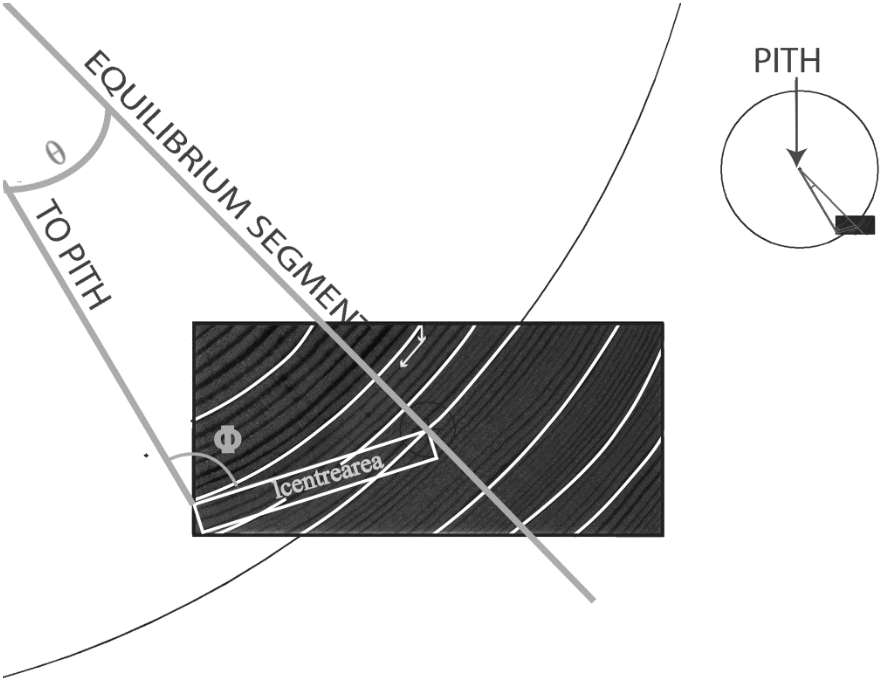

Figure 3: Procedure for calculate deformation of a board

For calculate the deformation in the radial direction the process is similar:

9. For every intersection between the selected latewood annual rings and the profile shape, it is necessary to draw and quote segments, connecting the intersections to the centre of area of the board cross section as represented in Fig 3. Subsequently the angle between the radius and the segment connecting the centre of area of the board as represented in Fig. 3 has to be determined.
10. The remaining length after the deformation of the segment connecting the latewood intersections to the centre of area of the profile is calculated by the subsequent formulation:

$$l_{new} = l_{centrearea} \cdot \left[1 - (\cos\phi \cdot \beta_{r\cdot} \cdot \Delta u)\right] \quad (2)$$

Where $l_{centrearea}$ is the length of the subsidiary line connecting the centre of area, $\emptyset$ is the angle measured in step 9, β_r is the differential shrinkage parameter in the radial direction, Δu is the difference in the moisture content states, l_{new} is the new calculated distance between the segment connecting the centre of area to the latewood intersection in the shape of the profile. The segment l_{new} is computed from the centre of area.

For compute the results originated in the calculation the direction of the deformation movements is oriented with some rules.
The first deformations applied are the deformations due to the radial strains and all the vectors are calculated with the direction against the centre of area as represented in Fig. 3, because the components of the radial stresses seek to be in balance in respect to the centre of area. The calculated length l_{new} after the deformation has to be computed from the centre of area along the segment. Subsequently, the reported deformations in the radial direction, it is necessary to report the deformation due to a tangential deformation and apply the deformed vector in an arc of circle parallel to the arc of circle representing the latewood, with the origin in the cusp of the vector of the radial movements and with the direction towards the equilibrium segment as represented in Fig. 3. In Fig. 4 is represented an example of application of the algorithm in a profile shape.

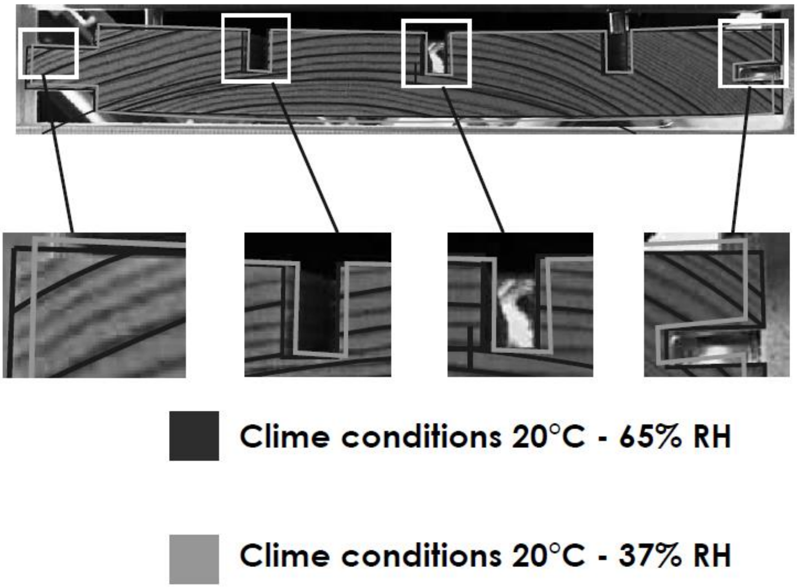

Figure 4: Example of application in the algorithm

The results of this algorithm were investigated with experiments showing a good agreement with the reality.

2.3 The software system for the simulation

The simulation of the process chain in the virtual reality must be divided into two main parts. On the one hand, there is the graphical simulation, which simulates the corruption and changing of the profile geometry. In special cases it is also used to generate process data for single process steps. The graphical simulation is done by using the 3D CAD program Autodesk Inventor. To achieve the functionalities, which are needed for the simulation, Autodesk Inventor is extended by using its API. On the other hand, there is the mathematical and statistical simulation. For the statistical calculation, Matlab with the integrated statistical analysis library is used. Other simulations are done by using a self-developed C# program. This program is also handles and controls Autodesk Inventor via the API and works as an interface to handle the communication and data between the product data model and all other programs that are used.

3 SIMULATION OF THE PROCESS CHAIN

For the simulation of the processes in the production chain it is necessary to simulate first the systematic effects and in the next step to simulate the effects with a variation in a statistic way.

3.1 Systematic effects of processes

The model for the simulation is generated from the product data model and starts with a CAD-sketch of the raw part. Also the process data for the simulation comes from the data model. These process data is used in the model to simulate changings of geometric characteristics. Some of these changes will occur always, are predictable and will be summarized under the name systematic errors. Since these changes occur always and they have a direct influence on the further production on the profile they will be simulated first. Before the simulation it is necessary to split the whole process chain into its single process steps, because every step will change the geometry in a different way. Every process step will also have a direct influence of the following process steps. Therefore the generated data for a single process from the simulation will always be related to the preceding process steps. Still there are two types of systematic errors. On the one hand there are general systematic errors and on the other hand profile specific systematic errors that need to be handled. General systematic errors are the ones that occur before the simulation of a process step. An example for a general systematic error could be the addition and subtraction of material of a profile (Fig.5).

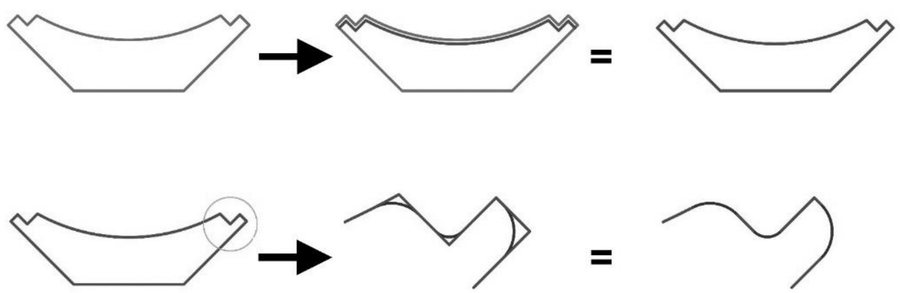

Figure 5: Examples for systematics effects on the profile

Especially in the profiling and the process step of profile wrapping it is necessary to include this in the simulation. The CAD-sketch is in the most cases the optimal profile specification of the finished product, but to get the right process data from the model we need to have the profile geometry without the thickness of the foil or paper, which is added during the profile wrapping. The thickness of the foil or paper is stored in the material database, which is part of the product data model. Therefore it is necessary to change the geometry and subtract material from one point to another, where the foil should be added. This also leads to another problem. If for example the profile geometry has round corners with a small radius and material will be subtracted, it can happen that these corner will disappear and the model of the profile will have a sharp corner at this point. Profile specific systematic errors could be for example the positioning of the profile in a machine of a single process step. The positioning has a big influence of the following process steps because different tools can lead to a different changing of the geometry at the part of the profile they edit. The algorithm which is able to simulate the automatic positioning in a machine works in the meaning of giving the operator a suggestion. The operator will be always the last instance to crosscheck the results, since there is an infinite amount of different profiles with their own special geometrical specifications that might need to be specially handled. Also the positioning is important when it comes to the process step of profile moulding. Especially profile moulding comes with a lot of systematic errors, which comes from the fact that it includes a lot of sub-processes. Already the milling of the tools includes a systematic error because the grinding wheel, which is forming the tool has a radius at the edge. These radius will lead to round external corners of the profile because the internal corners of the tool will have at least the radius of the grinding wheel [5] (Fig.5). Another big influence of the profile moulding is the number of cutting passes. The number of cutting passes specifies which tool will edit which part of the profile. As mentioned before the algorithm which is executing the automatic number of cutting passes is highly influenced by the positioning of the profile, since the positioning defines which part of the profile is moulded by which side of the machine. Another part of the simulation is testing the tools after the number of cutting passes are defined. Some parts of the profile might have undercuts or the profile geometry is too deep and the desired machine can't mould it. In some cases these errors can be erased by a different number of cutting passes or by a different positioning of the profile in the machine. Therefore testing of different positions and set ups are a big part of the simulation. But there are not only systematic changes of the profile geometry, there are a lot of influences which won't always behave in the same way and which can't be easily handled. In that case it is necessary to observe a process step over a long time to predict his behaviour by using statistics.

3.2 Variations of effects in production

The engineer designs the geometry of a profile for example as a CAD-Sketch. This sketch is in the most cases the ideal geometry specification of the part. Manufacturing processes are not capable of producing the part exactly as it is specified, which means they can't produce the part without variation in his geometric characteristics. Therefore, in the most cases also tolerances will be specified, which give limits to the allowable variation [16]. Statistics are a tool with great power to handle these tolerances. Since almost every process in a well-defined process chain can be investigated, also their behaviour over a long time can be obtained. This behaviour can be transferred into the form of probability density functions. The correct estimation of the specific behaviour for single processes and sub-processes is very important since wrong probability density functions will lead to a wrong or insufficient result [17]. For example the accurateness of the positioning of a part in a machine would be more likely an exponential distribution than a normal or rectangular distribution because most of the times the part will be on the right/left guidance element of the machine as desired. Only in a few cases, due to vibrations of the machine for example the part will move away from the guidance element. For processes and sub-processes that cannot be investigated properly rectangular distribution are expected. Rectangular distributions are preferred because it has shown that normal distributions are not suitable for processes in a real environment [18]. [19] says that under the assumption that the probability density function fills out the whole tolerance field, the rectangular distribution has two advantages. In the first place it makes sure the result is "save" and secondly the probability density function won't has to be verified. The probability density function for a single tolerance along a whole process chain is calculated by the convolution of the probability density functions of all sub-processes for a single process step and afterwards of the convolution of the resulted probability density functions along the whole process chain (Fig.6).

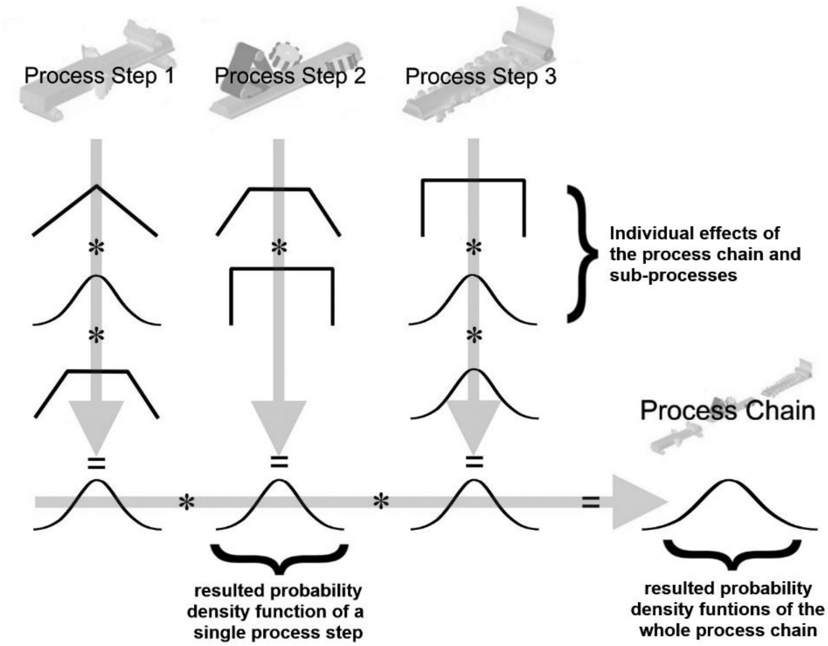

Figure 6: Consideration of statistical influences in the process chain

To simulate and integrate the functionality of statistics with probability density functions into the research project, Simulink Matlab is used. Matlab provides all the basic functionalities that are necessary to convolute distributions and to receive the desired data out of the resulted distribution. This ability opens up another benefit of the statistical approach. With the convoluted probability density function over the whole process chain the percentage of all parts that will probably be inside the tolerances are given by quantiles [20]. These quantiles are calculated using the cumulative distribution function of the resulted probability density function. A further benefit is that for each distribution function the standard deviation can be calculated. When the standard deviations are summed up, the share of each of these values to the summed up value can be calculated, which gives us the influence of each single process and sub-process to the whole process chain.

4 CONNECTION TO THE MACHINES

The calculated process data as the result of the simulation is for each process stored in the product data model, in general as XML data. To enable

the communication from the virtual reality to the individual machine and to allow the M2M communication there are two basic approaches.
The first approach is to use existing interfaces to the machine controls and transfer the process data from the product data model by means of a postprocessor into valid machine data. For the testing of the presented data models and the simulation the control of the profile moulding machine (type: Weinig Powermat 1000) has been enhanced to read directly the XML datasets in the model. This is a marginal different approach to avoid the development of external postprocessors. As the control of the Powermat 1000 does not cover all the set up options of the machine, which are done manually, but were also simulated with the system, the set up data was provided by a modified tablet pc to the operator.
The second approach and the objective target of the research work to enable the communication from the virtual reality to the machine (VR2M) is to develop a standard for the exchange of process data in the process chain of profiling.

5 CONCLUSIONS

The simulation of the process chain of profiling in a virtual reality increases the efficiency of the process design and set up to produce a new profile. Therefore, it is necessary to have models describing the effects of all involved processes to get correct process data. The use and enhancement of existing models together with the development of new algorithms to simulate the individual effects of the process have shown that the research approach is working and simultaneous engineering provokes a reduction in time.
One key factor in the simulation this the consideration of the shrinking and swelling of wood, as it can effect a large profile corruption. The presented algorithms is able to determine the deformation of the profile taking into account the profile shape and ensures a correct simulation.
The developed product data model forms the foundation for the simulation and provides the data exchange from the virtual reality to the real systems and machines in the process chain of profiling.

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IMPROVING THE FURNITURE SUPPLY CHAIN BY LEARNING FROM OTHER INDUSTRIES

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Abstract
Based on literature research, this paper tries to identify supply chain relevant trends in the furniture industry. Also, the situation in the furniture industry is compared to that of the automotive and the Fast Moving Consumer Goods industry in order to see if some of the successful supply chain strategies in these industries can be transferred. Key findings are that supply chain measures are often underestimated, both on the retail and on the manufacturer side. The furniture industry is found to lack standards in IT, processes and handling equipment. However, there is growing consensus that integrated processes are extremely important for a company's business success.

Keywords:
Supply chain management, process and IT integration, cooperation concepts

1 INTRODUCTION: BACKGROUND / AIM OF THE PAPER / METHODOLOGY

The objective of this paper is to identify trends and areas of improvement with regard to the supply chain of the furniture industry. The aim is to benefit by learning from proven successful models in the fast moving consumer goods and the automotive sector. Therefore, first, a standardised set-up for analysing markets and the concept of supply chain management – often controversially discussed - are clarified. Next, general trends affecting logistics are shown, before the current situation of the European markets for fast moving consumer goods, automotive products and furniture are analysed. Finally, the findings are compared to an empiric study of the furniture industry and conclusions are drawn.
Figure 1 shows the dimensions used for **analysing** all the relevant **markets**: First, the relevant **products** and related **services** are defined, before **customer** requirements and demand specifics/customer behaviour are described. Next, the **manufacturers** and then their **suppliers** are analysed, taking into account relevant **general conditions** for the market (e.g. legal restrictions or trends).

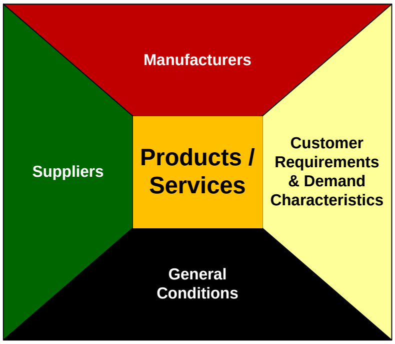

Figure 1: Framework to analyse market related dimensions

Logistics in its basic form can be seen as executing some or all of the four following **basic logistics tasks**: Cross Docking, Order Picking, Storing and/or Transport (abbreviation "COST", see figure 2). Flow and transformation objects for these physical or administrative basic tasks are the following (abbreviation "VIP"):

- Values and Authorisations
- Information and
- Physical goods (e.g. e.g. finished goods, semi-finished goods, raw materials and utilities)

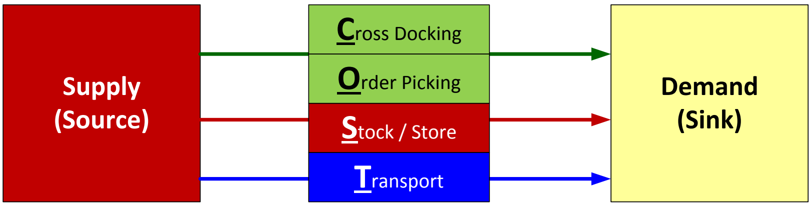

Figure 2: Basic logistics execution tasks

However, efficiently managing logistics processes and structures requires planning, decision making and control activities. Based on the respective time-frame, these may range from long-term process and structure Design, via mid-term Optimisation to short-term everyday Management in addition to the physical and administrative Exectution activities (abbreviation DOME see figure 3).

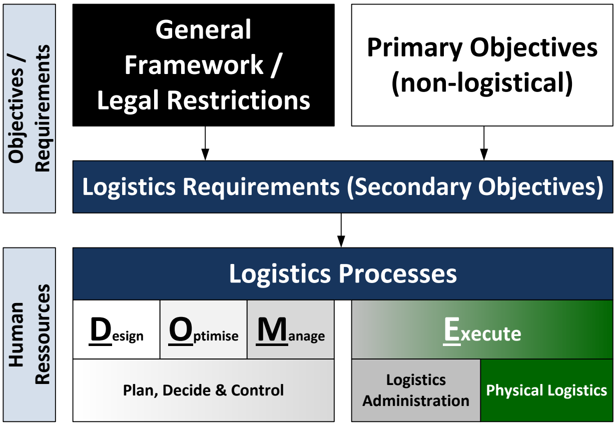

Figure 3: Logistics planning and execution tasks

Often, authors like to differentiate between logistics and supply chain management (cf. for instance [1, 2, 3]). This paper does not do that, as the logistics concept embraced here includes not only physical and information flows but also values. Furthermore, this paper assumes that a reasonable, (i.e. non-basic) logistics approach ought to include an integration of processes and structures, making use of cooperation benefits between both internal participants (e.g. different departments or subsidiaries) and external participants such as customers and suppliers in the respective markets (also see figure 4). Therefore, this paper typically uses **logistics** and **supply chain management** as **synonyms**.

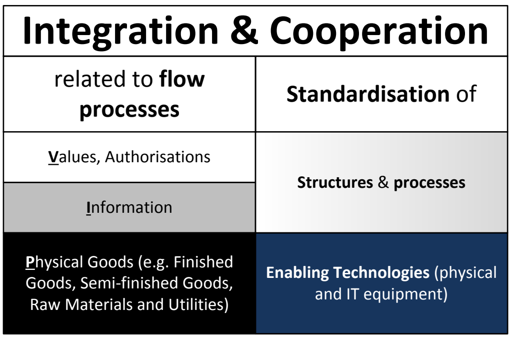

Figure 4: Important Logistics planning and execution tasks

Integration is strongly supported by use of standardised enabling technologies or, at least, use of standardised interfaces. Enabling technologies in this sense include physical and informational systems (abbreviation TWO ITEMS, see figure 5):

- **T**ransport systems: Trucks, terminals, conveyors etc.
- **W**arehouse systems: Storage space, order picking & packing systems

- **O**ther physical systems: Production machinery, repair systems etc.
- **I**dentification and standards terms: Barcode or rfid standards, INCOTERMS, good engineering principles etc.
- **E**xchange systems for communication: Anything from paper, fax to EDI or wireless communication
- **S**upport systems for Design, Optimisation, Management and Execution: ERP systems like SAP, ORACLE etc.

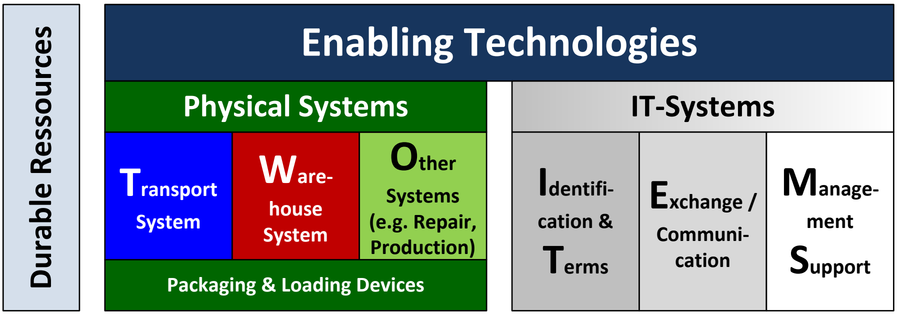

Figure 5: Enabling Technologies

A **simplified, generic supply chain structure** is given in figures 6, starting from the potential private or corporate end customers, their immediate vendors (e.g. retailers or MRO (Maintenance, Repair and Overhaul) companies via the manufacturers to their 1st-tier suppliers. (Cf. [4] for a detailed model of the value chain in the furniture industry.)

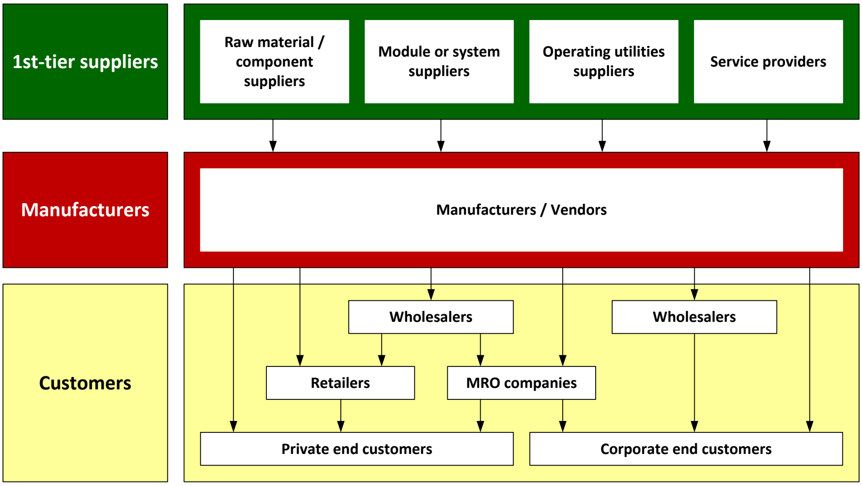

Figure 6: Framework to analyse supply chain structures

While analysing the customers' perspective, the following distinctions are made: Looking at the phases of a sales & usage cycle of a given product, one can distinguish between the pre-sales phase, the sales fulfilment and the after sales phase (cf. for instance [5]):

- Customers' activities in the pre-sales phase include gathering information, comparing offers and/or negotiating with the vendor.
- The sales fulfilment phase is characterised by relevant logistics processes e.g. order picking and transport as well as payment and booking activities.
- Finally, depending on the nature of the product, the after sales phase can be a long phase of up to many years (e.g. car) or not (e.g. chewing gum). During this period, the product might produce further costs of usage or require inspections and/or MRO services.

The amount of time and money invested in all three phases by the customer depends strongly on both the financial and emotional meaning the product has for the customer and can roughly be differentiated into convenience, shopping and specialty goods (cf. [5, 6]):

- **Convenience** or **low interest products** are goods which are more or less regularly purchased for a low price without too much consideration in the pre-sales phase. Accordingly, customers are not prepared to wait for these items, but expect immediate availability or are prepared to substitute them. Purchase and fulfilment require little effort and cost by the customer. Typically, there is almost no measurable cost for the customer in the after sales phase (except for waste removal e.g. of packaging).
- In comparison, **shopping goods** refer to products that customers are prepared to wait for and may spend a considerable time in the pre-sales phase comparing alternative items and/or vendors. The useful lifetime of these goods is longer than that of convenience goods, and the financial and/or emotional meaning to the customer is much higher.
- Finally, **specialty goods** are typically high-value items with a strong emotional bond and substantial financial investment by the customer. Often, these goods are in use for many years and, therefore require MRO services.

2 GENERAL OVERALL LOGISTICS TRENDS

When analysing markets, it is important not only to look at the current situation but also to identify relevant development trends related to market participants and/or general conditions (see figure 7).

Development trends	
related to **market participants**	related to **general conditions**
End Customers	**P**olitical
Commercial Customers	**E**conomic
Manufacturers	**S**ocio-cultural
Suppliers	**T**echnological

Figure 7: Dimensions to analyse development trends

A recent survey analyses global trends and strategies in logistics and supply chain management. (cf. [7]) Some of the key findings are:

- **Customer** related trends: Customers become increasingly more demanding and critical. Therefore, fulfilling their expectation was ranked highest.
- **Retail** related trends: Globally, the single most important trend for retailers is an increased cost pressure. Some retailers are trying to pursue so-called omni-channel logistics, offering both stationary stores and e-commerce with customised delivery services.
- **Manufacturer** related trends: Many manufacturers have in the past undertaken significant efforts to reduce their working capital and reduce inventories in their increasingly globalised and fragmented supply chains. This makes them very dependent on reliable logistics processes.
- Development trends regarding the **general conditions** (political, economic, socio-cultural and technological): Globalisation of businesses and information, talent shortfalls across many regions and, increasingly, sustainability pressure from many different peer groups need to be considered.

Furthermore, companies in many areas need to **collaborate** with horizontal or vertical partners in their supply chain network (cf. [7]). Therefore, the study predicts, key areas of success for the future will be talent management, improving processes, pursuing long-term technology roadmaps and creating successful network partnerships. Finally, trends such as reducing the carbon footprint or, in general, “green” business models are becoming more and more important.

3 CURRENT SITUATION WITH REGARD TO SUCCESSFUL SUPPLY CHAINS IN DIFFERENT INDUSTRIES

3.1 Current situation in the European automotive industry

In the case of **cars & trucks**, there is a large European market for both new and used trucks. Long-term usage of the cars & trucks also requires a large aftermarket for spare parts and related MRO services (cf. e.g. [8]. The functionality of a car or truck is strongly dependent on many parts working. Due to the strong interdependencies, even the failure of simple or small components can cause a total system failure. The possibility to have cars repaired and overhauled wherever they are in use requires a high availability of standard parts and (standard) repair and inspection procedures over a long period of time.

For **end customers**, cars are typically considered to be at least **shopping** or even **speciality goods**, often with a strong emotional bond (status symbol). Depending on their personal situation – typically, cars require a significant financial investment by their owners. Customers may spend a lot of time (and, possibly, money) in the pre-sales phase to gather information, compare offers and negotiate. The sales fulfilment phase is characterised by costly transport and extensive documentation. Finally, the after sales phase can be a very long phase up to many years. During this period, a car not only produces further cost of usage (fuel, tires, etc.), but due to regular inspections and/or defects MRO related costs are incurred. Therefore, sensible end customers should try to take into account the Total Cost of Ownership of the car over all three phases just as corporate customers typically do.

The **sales channels** are diverse for **new** and for **used cars & trucks** as well as for spare parts: Appointed dealerships, manufacturer owned subsidiaries and importers sell new and/or used cars as well as spare parts. Furthermore, a large variety of companies specialises in selling used cars and/or parts. For instance, these can be small, single location companies or large (so-called) fast-fit MRO-chains.

On a turnover base, there are a few very large international **manufacturers** that combine a large proportion of the overall market. This is – among other things – due to the large invest required for developing cars & trucks and the strong economies of scale and scope in manufacturing them. Compared to both their customers and their many suppliers these manufacturers are typically much larger, with a **very strong negotiation and purchasing power**.

The latter enables them to "convince" their supply chain partners to adapt to their processes, thus integrating their supply chain: They are able to implement a **high level of standardisation** both with regard to structures & processes, as well as with regard to equipment (e.g. pallet cages, standard boxes) and parts employed. Analysing existing and defining to-be-processes between the participants of complex supply chains can be facilitated by approaches that are wide-spread in the industry such as using the Supply Chain Operations Reference Model (SCOR-model, also see figure 8 and cf. for instance [9]).

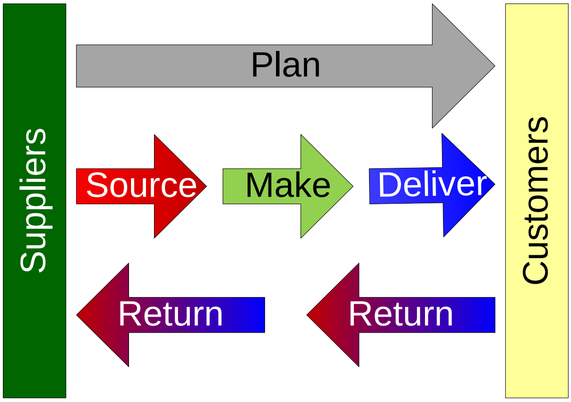

Figure 8: SCOR-model level 1 of 4, describing the basic process types

Powerful automotive **industry associations** and political lobby groups played an important role and continue to do so with regard to developing process and IT standards as well as **shaping engineering standards** and **legislation**.

Many large manufacturers have managed to implement **integrated supply chains** from 2nd- or even 3rd-tier suppliers to the end customers in Europe. All in all, the automotive industry with its high level of IT integration and sharing of sales/forecast data throughout the supply chain is often considered one of the "**showcases**" **of collaborative Supply Chain Management**.

Current developments, however, suggest that the strong domination of the traditional Japanese, US and Europe based manufacturers will decline while Chinese and Indian manufactures are strongly growing (cf. for instance [10]). Also, the domestic European market for new cars & trucks has not been growing strongly over the last years, whereas other areas of the world (e.g. BRIC countries) are catching up fast. What this means with regard to a shift in supply chain structures and processes remains to be seen.

3.2 Current situation in the European Fast Moving Consumer Goods (FMCG) industry

The term fast moving consumer goods (**FMCG**) refers mainly to finished goods that are available almost everywhere and are for short-term use or immediate consumption (cf. for instance [5]). They include, but are not restricted to items such as foodstuffs, drinks and tobacco, hygiene products, laundry & cleaning or even cheap textiles such as socks or underpants. Due to their short useful life between purchase and final consumption (sometimes only days or even minutes) there is no market for used FMCG, “spare” parts or MRO services.

Note: More expensive and long-term usage items such as TV/audio equipment are not considered to be FMCG in the sense of this paper, but rather shopping goods. (In official statistics, however, they often are classified as FMCG.)

For **end customers**, FMCC are typically considered to be **low interest / convenience goods**. Purchase and fulfilment require little effort and cost by the customer. Consumption of legal FMCC incurs almost no measurable cost in the after sales phase (except for waste removal e.g. of packaging).

On a turnover base, there are a **few very large international manufacturers** that combine a large proportion of the overall market in certain sectors. However, in many sectors, there are **many SME** (small or medium sized enterprises) often only supplying regional consumer products to the retailers.

Due to the specifics of low interest products, FMCG need to be easily available almost everywhere. Therefore, they are sold anywhere from large food and non-food retail chains or petrol stations to kiosks and even automats. However, in European countries, the largest proportion of FMCG sales is achieved by the huge **food and drugstore retail chains**. Compared to both their end customers and their many suppliers the European FMCG retail chains are typically much larger, with a very **strong negotiation and purchasing power**.

This in turn, enables them to “convince” their immediate suppliers to adapt to their processes, thus leading to an **integration** of at least the **final part of the supply chain**: They are able to implement a high level of **standardisation** not only with regard to structures & processes, but also with regard to the logistics handling equipment. The collaborative planning & forecasting concept called efficient consumer response (**ECR**) uses, among others, so-called **Efficient Unit Loads** with regard to standard heights and sizes of sales units, boxes, pallets and truck capacities (cf. for instance [2]).

ECR also requires standard EDI messages and barcode labelling or RFID tagging (e.g. see the **GS1/EAN standards**) (cf. for instance [2, 3]). Many large food retail chains also managed to implement successful logistics approaches with regard to retailer driven pickup as opposed to manufacturer driven distribution and/or cross docking or vendor managed inventory (**VMI**) processes. These have been copied by many smaller food retailers and by other retail industries, e.g. do-it-yourself or drug stores.

All in all, many large retail chains have managed to implement integrated supply chains from FMCG-manufacturer to the end customers in Europe by means of what is often considered a “cooperative integration” approach. In some cases, the ECR approach has even been driven even further to a concept that includes (and is, therefore, also called) **Collaborative Forecasting, Planning and Replenishment** (cf. for instance [2, 11]). What increasing trends for “green retail” models will lead to, is not yet clear.

3.3 Current situation in the European furniture industry

The term **furniture** in the sense of this paper is used to include furnishings in offices or homes (e.g. kitchen cupboards, office chairs or upholstery) as well as “furniture-related” accessory like carpets, lamps or decoration material (cf. for instance [12, 13]). Depending on the specific type and brand of furniture, elements can be **anything from low cost / low interest items** (e.g. decoration candles or shoe cabinets) **to high value / specialty goods** (e.g. expensive designer kitchens), depending on their financial and emotional value to the private end customer. (This paper does not focus on corporate furniture end customers or large non-profit organisation like hotels, universities, public administration etc., as this market follows other rules.)

Even though furniture elements often have a **long useful life**, only **few** of them are usually **repaired** and **overhauled**. This is partly due to the fact that personal taste may change strongly over such a period of time and partly due to the cost of repairing compared to the purchase of a new furniture element. Typically, repaired elements are either high value-furniture system elements (e.g. kitchens and/or shelving systems) and/or easy to repair goods, often made of wood that only require, for instance, new hinges or can be glued. In total, the market for used furniture is not that large, as is not that for related MRO services.

In Germany, specialised furniture-only **retailers** are facing a tough competition (cf. for instance [12]): Increasing sales via food or do-it-yourself retail chains and e-commerce of furniture lead to new competitors in the market, but, especially, to a high level of price transparency for the consumers. Due to over-stocks and many retail outlets close to each other, traditionally, German furniture retailers are engaged in a ‘**price war’**. The result on the retail side is that more and more retailers are **merging** or acquiring former competitors. Also, large retail chains are both **expanding** their own **networks** and **taking more control** of supply chain processes.

The **manufacturer** side of the furniture industry is traditionally comprised of SMEs. Most retailers are organised in **large purchasing associations** that represent a huge purchasing power unmatched by the manufacturers. Therefore, the price pressure in the end customer market has traditionally been passed on to the manufacturers, leading to a strong wave of **bankruptcies** and mergers in this part of the industry, too.

In the past, most manufacturers have focussed mainly on several of the following options (cf. for instance [14]): improving marketing & design, expanding sales to new markets, globalising their procurement, automising their production processes or moving production to low-cost countries. Supply chain management has, however, not been a key focus, even though many see that the transportation and inventory costs have increased strongly.

Raw material cost has spiralled, especially due to the price increase of oil and wood. Moving production to low-cost countries and/or utilising global sourcing strategies further increases the importance of supply chain management.

In total, both manufacturers and retailers are suffering from **low profit margins** but, currently, do not systematically exploit the potential benefits of integrated supply chain processes.

An empiric study in 2009 found that, furniture manufacturers understand that both integrated logistics and IT processes and cooperative approaches with suppliers and customers are crucial to improve their business (cf. [15]). Nevertheless, cooperative concepts that have successfully been implemented in e.g. the automotive industry and in the FMCG industry have mostly been ignored up to now. This paper assumes that it is the apparent lack of key “standardisation drivers” as within the automotive or FMCG industry that leads to there being no widely established IT, process or handling equipment standards.

4 CONCLUSIONS

Based on their profitability, both the retailers and the manufacturers would benefit strongly from trying to adapt some of the process, IT and equipment standards that – outside of the furniture industry – are often considered to be an off-the-shelf basic requirement for success. Especially considering the goods and information flow in a more holistic, integrated approach with an improved demand and supply management should strongly improve the situation for all parties involved while at the same time offering a better customer service to the end customers.

Nevertheless, cooperative integration / standardisation approaches from other industries show the benefits of supply chain collaboration possible. It, therefore, seems very likely that the retail chains and purchasing associations will sooner or later try to implement similar concepts and standards like in other industries. Here, using standardisation approaches such as the SCOR-model could help the communication and integration between partners of complex supply chains.

Already, a few of the larger retail chains are beginning to adapt some of the concepts. This is leading to an increase of retailer driven pick-up logistics or even a backward integration into the manufacturing industry. Other retailers are broadening their service and customer base by also offering specialised service as a logistics service provider. Those manufacturers and their industry associations that are best prepared to participate in developing these standards will also be best prepared to face the future challenges.

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NEW CHALLENGES FOR WOOD COATINGS

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Abstract
The health and safety of people in indoor environments are influenced not only by climate and biological agents (bacteria, virus) but also by the potential presence of air pollutants.
Pollutants can come from many sources, such as cigarette smoke, fireplaces, preparation of foods, traffic, etc. Even furniture and building materials used in constructions (floorings, ceilings, walls, etc.) can emit harmful substances for the health of the occupants. Such emissions mainly derive from the coatings applied on the surfaces of the finished products and consequently a special attention shall be paid to the formulation and to the use of such products. This paper presents a summary about the legislative and normative scenario on indoor emissions with the evidence of some data referred to parquet floorings coated with different coating materials.

Keywords:
VOC emission, indoor, coatings

1 INTRODUCTION

Every human roughly inspire 5 million litres of air every year being mainly composed of nitrogen and oxygen. It is possible to estimate that around 50.000 litres of other gases (carbon dioxide, argon, etc.) are introduced in our organism every year with potential effects on our metabolism depending on their composition. The majority of the human life is spent inside buildings (houses, offices, schools, hospitals and so on) and consequently a particular attention to the indoor air quality should be paid.
Formaldehyde is certainly the best-known example of a substance that can be released from the materials present inside houses, offices, schools and other indoor living environments. Test methods and limits for this substance had already been developed, allowing the market to verify the conformity of the products [1].
Nevertheless, formaldehyde is not the only substance that can be emitted from furniture or construction products as the materials with which they are made of, can contain several other volatile compounds. These substances tend, during time, to gradually be released in the environment in which finished products are placed.

All of these substances, may have a negative impact on air quality and consequently on the health of the users living in indoor environments where they are present.
The knowledge of VOC emissions from finished products and their control is becoming a particularly sensitive subject for the market because of the increased attention to the safety of finished products mentioned above [2].
Moreover the increasing need of energy saving buildings determines a considerable evolution in insulating systems and devices reducing, on the other side, the air exchange in houses, offices schools and so on, with a potential increase of the concentration of polluting substances in indoor air.
At EU level, following the publication of the EU regulation n.305/2011 including indoor emissions among the basic requirements for construction materials, the technical committee TC351 of CEN is responsible for establishing test methods and limits for harmful substances released from building materials.
Two Member States, France [3] and Germany [4], have recently published specific regulations on this matter that producers must know and respect in order to freely export their products. Also Belgium is going to publish a similar law coming in to force in 2014 [5].
As coating materials are the main sources of VOC emissions from the finished products, such subject represent a “new challenge” for the coating market among all the other requests in terms of performance and environmental protection.

2 SUBSTANCES POTENTIALLY EMITTED FROM FINISHED PRODUCTS

Many different volatile substances can be emitted from furniture and construction products.
Formaldehyde represents a particular case as it mainly derives from the hydrolysis of the urea-formaldehyde adhesives used for the production of wood based panels like particleboards, fibreboards and plywoods.
Hydrolysis is a continuous process caused by the presence of moisture and accelerated by temperature. Consequently, formaldehyde emission is a continuous process as this substance is ever generated inside panels.
On the contrary, the emission of other volatile organic compounds is an irreversible process, as they are not produced again inside the materials. Such emissions are mainly due to coatings applied to the surfaces of walls, floorings, doors, furniture and so on. Organic solvents and other volatile substances present in the coating formulation do not completely evaporate during drying and consequently they slowly evaporate inside the buildings where the final product is placed.

2.1 Measuring methods

The international reference test method for measuring VOC emissions from raw materials and finished products is defined by the standard EN ISO 16000-9 *Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber method*.

This method consists of an empty chamber of different volume (normally from 0,1 m^3 to 40 m^3) with internal conditions similar to those normally found in indoor environments (23°C, 50 % r.h., 0,5 air exchanges/hour).

The sample is place inside the chamber with a surface area normally corresponding to the real situations.

The air inside the chamber is continuously mixed and sampled at regular intervals (usually after 72 hours and 28 days). The qualitative and quantitative analysis is then performed by a gaschromatograph coupled with a Mass Spectrometer detector because of its high sensitivity and analytical specificity.

It shall be mentioned that the Working Group 2 of CEN committee 351 has defined a new method (presently in the form of Technical Specification CEN/TS 16516), based on the above mentioned ISO standard, to be specific for the CE marking inside the EU.

Another method, to be necessarily mentioned here, is the *FprEN 16402 Paints and varnishes — Assessment of emissions of substances from coatings into indoor air — Sampling, conditioning and testing developed by* CEN TC139 to be used to assess the VOC emissions from applied coatings. The latter standard is also based on the basic principles of EN ISO 16000, but it contains specific instructions to deal with liquid coating materials.

2.2 Health evaluation

Unfortunately, science has not yet been able to elucidate all substances and mechanisms causing a negative effect on health in the exposure conditions of indoor environments [2]. A lot of data is presently available only for substances in the workplaces but sufficient data to enable a full risk assessment in indoor places exists only for a few substances.

One of the main differences with workplaces is the evidence that the period of time to which the population is exposed to indoor pollution is considerably longer. Moreover, the healthy conditions of the people involved can be totally different: infants, older people and disabled people (asthmatics, allergic, convalescents and so on) shall be then considered in the definition of the exposure limits.

Another difference in the case of indoor pollution is that health cannot just be considered as an absence of illnesses, but it shall be also related to the term “comfort”. Consequently it will not be enough to reduce the exposure to the healthy-related substances, but the overall effects from other substances need to be reduced as well. This considerations lead to a development of a complex criteria to fix limits for indoor pollution based of different parameters which normally are even combined together.

Carcinogen substances
In spite of a few exceptions, there are usually no safe limit values for carcinogenic substances, even the smallest amounts of carcinogens can, in theory, cause cancer mutations in cells. Therefore the usual practice to fix very low limits (0,1 µg/m^3) for the amount of carcinogens (Cat. 1 and 2 according to EU-carcinogens classification). In emission testing of indoor products, if carcinogens are detected after 3 days, the test shall be stopped.
Such criteria normally incorporate also Mutagens (substances able to modify the DNA thus increasing the risk of cancer) and Reprotoxic (substances causing abnormal prenatal development resulting in birth defects).

LCI
The LCI (Lowest Concentration of Interest) approach is currently the most feasible strategy to assess the health effects of individual compounds from raw materials and finished products.
The harmonisation process of LCI values has recently started in Europe (EU-LCI project led by the European Commission's Joint Research Centre on behalf of DG SANCO) [2].
The definition of the LCI limits is based on different criteria as, for example, the use of the workplaces values divided by safety values (e.g. 100).
LCI's are limits for the single substances, but also the sum of all substances with an LCI can be considered (e.g. $\sum (C_i/LCI_I \leq 1$ where Ci is the concentration of each singe substance).
Criteria are also set for substances which LCI values are not already established. For example the German specification prescribes a limit of 0,1 mg/m^3 for the sum of all these VOCs.

Total volatile organic compounds (TVOC)
The sum of all VOC's, indicated as Total VOC (TVOC) is normally combined with the limitation of CMR (Carcinogenic, Mutagenic or Reprotoxic) substances and with the LCI concept. This general limit considers the potential "combination" effect of the presence of more substances in indoor air and their cumulative effect on the comfort of the people.

3 STANDARDISATION AND LEGISLATION

3.1 EU
The Construction Product Regulation (EU 2011/305) since 1st July 2013 defines the basic requirements for construction materials [6]. This Regulation replaces the directive 89/106/EEC. Among the seven requirements number three, already present in the old directive, is dedicated to: hygiene, health and environment. Then the regulation prescribes that any construction work

must not be harmful to the health of occupants, meaning that no dangerous particles or gases shall be emitted in the air.
The purpose of this regulation is to harmonize the technical and healthy description of products including also indoor emissions thus facilitating their marketing in the EU area. The goal is that the CE label applied on building materials and products will contain performance classes that cover all national regulations in Europe. Then each EU member state can specify which performance classes a product shall fulfil for being accepted on that national market. For indoor emissions and other types of releases, CEN has established a technical committee (TC 351) to undertake the work of developing the harmonised standards. A specific working group (WG 2) is dealing with indoor air. At the moment, WG2 has produced a test method (CEN/TS 16516) for indoor emissions based on the ISO 16000 series of standards concerning determination of emissions of VOCs from building products.

3.2 Germany

The German regulation on volatile substances emission from building materials has its origin in the European Directive 89/106/EEC for CE marking of construction products recently replaced by the Regulation 305/2011. As written above, the directive established that any construction product should not be harmful to the occupants of a building with specific reference to substances potentially emitted in indoor air. As both the EU documents do not detail this requirement with respect to emission limits, Germany decided to establish a special task force set up by government authorities that deal with health and safety. This working group, called AgBB, has consequently defined a regulation, which sets test methods, limits and procedure of control for VOC emissions from building materials.
The consequence is that building materials (e.g. flooring) marketed in Germany, besides the CE mark, must be further approved by the DIBt (a technical body that deals with the German Federal Building) to be installed in German buildings.
The process of obtaining approval is called Allgemeine Bauaufsichtliche Zulassung (ABZ) and consists of two steps.
The manufacturer must initially provide to DiBt all the technical data about the product including the complete chemical composition of the coating used.
The chemical composition is needed for the identification of the product excluding the presence of dangerous substances. If dangerous substances are present (e.g. carcinogens) the request is rejected.
Is the first step is positively passed, the process can proceed with an inspection to the production site followed by a test of VOC emission according to the standard EN ISO 16000-9.
Tests and inspections are conducted by an organization officially recognized and authorized by DIBt. If the two steps are all successful, products can be

marked with a "U", which in German means "Übereinstimmung" 'compliance'.
The surveillance of the product is maintained during the following years.
The emissions of the sample is analysed within the test chamber (EN ISO 16000-9), after 3 days, and after 28 days. The requirements to be met are those of table 1.

Table 1: The German limits on VOC emissions

Substance	*Limit*
Carcinogenic compounds (3 days)	10 µg/m^3
Sum of all VOCs (3 days)	10 mg/ m^3
Carcinogenic compounds (28 days)	1 µg/m^3
Sum of all VOCs (28 days)	1 mg/ m^3
Ri = C_i/LCI_i *	1
∑ Ri	1
Sum of all VOC without LCI	0,1 mg/ m^3

(*) The list of LCI is reported in the AGBB protocol

3.3 France

In 2007, the French Government launched a concerted action (so-called Le Grenelle Environnement) for the identification and improvement of environment and health conditions in France. Such programme involves also the definition of a mandatory labelling for VOC emissions from building products including the ban of carcinogenic, mutagenic and toxic for reproduction substances category 1 and 2 (according to 67/548/CEE directive classification).
Such objective has been transposed into French regulation by Decree n° 2011-321 (March 23, 2011) relating to the labelling of construction products, floorings, wall coverings, paints and varnishes regarding their VOC emissions.
The above mentioned Decree prescribes a mandatory labelling scheme indicating the emission classes of volatile compounds for every product on the market. The French Decree defines the list of volatile compounds to be considered (10 individual substances and the sum of total VOCs (TVOC) and four emissions classes ranging from A+ (very low emissions) to C (high emissions).

Table 2: The French limits on VOC emissions

Substance	*Class C ($\mu g/m^3$)*	*Class B ($\mu g/m^3$)*	*Class A ($\mu g/m^3$)*	*Class A+ ($\mu g/m^3$)*
Formaldehyde	> 120	< 120	< 60	< 10
Acetaldehyde	> 400	< 400	< 300	< 200
Toluene	> 600	< 600	< 450	< 300
Tetrachloroethylene	> 500	< 500	< 350	< 150
Xylene	> 400	< 400	< 300	< 200
1,2,4 Trimethyl benzene	> 2000	< 2000	< 1500	< 1000
1,4 Dichloro benzene	> 120	< 120	< 90	< 60
Ethyl benzene	> 1500	< 1500	< 1000	< 750
2 Butoxy ethanol	> 2000	< 2000	< 1500	< 1000
Styrene	> 500	< 500	< 350	< 250
COVT	> 2000	< 2000	< 1500	< 1000

3.4 Belgium

Belgium has also prepared a National regulation for the indoor emission of covered construction products (covers floorings, floor coverings, floor coatings, underlays, flooring installation products adhesives, finishing, coatings). The law will come into force in 2014.

Products consisting of 100% natural stone, ceramic, glass, or steel represent exemptions.

VOC emissions shall be assessed by a laboratory accredited according to EN ISO 17025 after 28 days. The method prescribed is the chamber test according to EN ISO 16000 until the method prepared by CEN/TC351 will be published.

Limits are established for specific substances and for the sum of total VOCs. Belgium has adopted also the LCI criteria prescribing to temporary use the German LCI values until the European will be published (JRC).

Table 3: The Belgian limits on VOC emissions

Substance	*Limit (mg/m^3)*
Formaldehyde	0,1
Acetaldehyde	0,2
Toluene	0,3
TVOC	1
TSVOC	0,1
Carcinogen substances	0,001
$R = \sum (Ci/LCi)$	1

4 THE CATAS RESEARCH ON VOC EMISSIONS

VOC emissions from furniture and construction products mainly derive from the coating materials with which they are finished [11].
Nevertheless other materials may contribute to this effect first of all wood and its derivate. It is well known that the various wood species contain different types of organic extractives, some of which are characterized by a certain volatility such as terpenes, certain acids and aldehydes including the same formaldehyde. It is interesting to note, in this regard, that the odour of some softwoods, often considered pleasant, is due to the emission of such natural substances.
Considering the substrate, it shall be mentioned that the heating of wood at high temperature in the production processes of wood based panels or in the case of thermo treated wood [1], determines the formation of volatile by-products (e.g. acids, aldehydes) as a consequence of the thermal degradation of some wood components.
With reference to coating materials, it can be summarized that the main factors associated to the final indoor emission of the finished product are the following:

- The amounts and types of solvents present, also as thinners, in the specific coating systems adopted.
- The weights applied.
- The procedures used for the drying phase: systems, conditions (e.g. temperature, ventilation) and time.

We must remember that the emissions of solvents are irreversible, thus tending to decrease progressively over time as a function of the conditions in which the material is located, even during storage or shipping.
The following are some results of a specific research programme carried out by CATAS on different parquet floorings directly sampled from the market and coated with different coating systems. The goal of this study was to get some information about the emissions derived by the different type of coatings used.
Tests were carried out according the EN ISO 16000-9 standard.

1. Parquet coated with a solvent based coating system (PU-1)

VOC	*Concentration 72 hours (µg/m^3)*	*Concentration 28 days (µg/m^3)*
Toluene	12	9
Xylene	48	27
Ethyl benzene	5	4
Butoxy ethanol	16	14
n Butyl acetate	72	34
Methoxy propanol acetate	40	32
Ethoxy propanol acetate	116	87
Di propylen glycol mono propyl ether	27	6
Acetic acid	58	49
Others	19	5
Total	413	267

2. Parquet coated with water based coatings (WB-1)

VOC	*Concentration – 72 hours (µg/m^3)*	*Concentration – 28 days (µg/m^3)*
Aldehydes	38	38
Terpenes	28	28
Acetic acid	265	265
Propandiol	66	66
Acetone	53	53
Diethylene glycol monomethyl ether	309	309
Butoxy propanol	166	166
Dietylene glycol mono butyl ether	248	248
Dipropylene glycol mono methyl ether	28	28
N Methyl pyrrolidone	231	231
N Ethyl pyrrolidone	11	11
Benzophenon	196	196
Others	42	42
Total	1.681	1.681

3. Parquet coated with oils (Oil-1)

VOC	*Concentration 72 hours (µg/m^3)*	*Concentration 28 days (µg/m^3)*
Aldehydes	85	72
Carboxylic acids	812	725
Acetamide	37	22
Acetone	41	32
Toluene	5	3
Others	7	4
Total	987	858

4. Parquet coated with radiation curing coatings (UV-1)

VOC	*Concentration 72 hours (µg/m^3)*	*Concentration 28 days (µg/m^3)*
Aldehydes	32	11
Acetic acid	84	57
Methyl acetate	37	10
Ethyl acetate	12	5
Toluene	17	8
Benzophenone	3	2
Benzaldehyde	3	2
Di methyl hydroxy acetophenone	7	2
Aromatic hydrocarbons	27	13
Others	15	7
Total	220	117

5. Parquet coated with radiation curing coatings (UV-2)

VOC	*Concentration 72 hours (µg/m^3)*	*Concentration 28 days (µg/m^3)*
Aldehydes	2	2
Acetic acid	99	70
i-Propanol	157	71
DPGDA	42	13
HDDA	1.120	594 (LCI = 380) *
Benzophenone	21	13
Benzaldehyde	8	2
Di methyl hydroxy acetophenone	40	20
Hydroxy cyclohexyl phenyl ketone	63	23
Others	88	34
Total	1.640	842

(*) Limit derived from the official German list of LCI

5 CONCLUSIONS

The data reported above reveal considerable evidences of the subject of indoor emissions which can be summarized in the following points:

- New construction material can emit considerable amounts of organic volatile substance especially immediately after their installation.
- The levels of VOC emissions derived from the data reported above are generally below the limits (see in particular the German and French laws) but close to them in many cases.
- From the qualitative point of view the substances emitted are generally those normally used as solvents in the coating systems typically used: esters, ketones, alcohols, aliphatic hydrocarbons, and aromatic hydrocarbons. Glycol ethers, which are slow evaporating solvents, are mainly present in water-based coatings. In the case of radiation curing coatings (see samples 5 and 6) it can be noted the emission of acrylic monomers or of substances such as benzaldehyde and methyl benzoate resulting from chemical reactions involving some special additives called photo initiators
- A high content of solvents in the liquid coating material is not directly related to a high emission of VOC from the finished product.
- The indoor emissions depend on the VOC present in the liquid coating but the chemical nature is fundamental

- The “natural” treatments are not free from indoor emissions
- The selection of the coating system is important but application rate and drying are also fundamental. Sample n. 6 in particular reveal a high emission of an acrylic monomer probably due to a deficiency in the UV curing system.

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DESIGN OF AN ENVIRONMENTALLY FRIENDLY PVC-PVC COATING CYCLE

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Abstract

The world of windows, historically dominated by wood, has undergone to significant changes during the recent years: this is due to the introduction into the market of aluminium, wood/aluminium and rigid PVC products. The success of these new materials is based on the durability that the corresponding wooden doors and windows can guarantee only with a periodic maintenance of the protective coating layer.

This study, carried out with a collaboration among: University of Trieste, CATAS, Taka srl and WPR srl, concerns PVC frames laminated with polymeric foils made of PVC and PMMA. The state of the art of the production process is based on two different steps:

1. Adhesion promotion through the use of solvent-based primers.
2. Bonding of the two materials by means of a HMPUR isocyanate adhesive (Hot Melt Polyurethane).

The North Europe market (Germany in particular) prescribes a specific protocol for the assessment of the performance both of the adhesives and of the finished product. The manufacturers of window profiles are virtually obliged to follow such rules and certifications being required and expected by the overall market.

The current market situation therefore requires special attention to these requirements which importance has reached the same level of economic aspects.

Alongside these two parameters, a third factor with an increasing extent, currently affects the industrial production. This factor is the safety and the protection of the environment.

This paper presents a study carried out with the goal of substituting solvent-based adhesion primers with new products or processes capable to reproduce the overall effects of the traditional treatments.

Keywords:

Coating, Environment, Adhesion, PVC

1 AIM OF THE PAPER

This study derives from the need to modify the production process due to the presence of high amounts of harmful substances in the formulation of the primers used to promote the adhesion on PVC: examples of such substances are Dichloromethane which is a suspected carcinogen and mutagen agent, Methyl Ethyl Ketone (also known as MEK) which is a VOC (Volatile Organic Compound), and High Boiling Organic Compounds.
VOCs are subjected to a European directive (99/13/CE) that requires the adoption of proper treatment plants to reduce VOC emissions below certain limits [1]. This constraint leads to significant additional operating costs because of the direct high investment needed for installing such plants and those derived by their continuous operation (e.g. energy consumption). Moreover their effectiveness toward environment protection (propellant consumption) and the employees' health in working places shall be considered in the view of a global approach to process safety. In addition, these plants cannot lead to any environmental certification, which is almost mandatory to be accepted into specific markets of North Europe.
Dichloromethane, like all suspected carcinogen and mutagen agents, is subjected to two European directives: 67/548/CEE and CE n. 1272/2008 which force the employment of personal protection devices not really compatible with the industrial processes.
Nowadays there are no directives, which specifically regulate the use of High Boiling Organic Compounds. These substances are not declared VOCs and consequently treatment plants are not needed in principle, but in reality the 99/13/CE European Directive states that the definition of a VOC depends also on the temperature at which the substances are used. In such perspective the high boiling point substances shall be conversely considered as VOCs due to their particular condition of use (they are forced to evaporate by IR lamp or heat convectors).
It is really important to get ready for this change with new effective laminating technologies which can guarantee environmental protection, certifications, employees' health and better performances.

2 METHODOLOGY

2.1 Analysis of the solvent based-primer technology

The first step to carry out in order to replace an obsolete process with a new one is a deep understanding of the mechanisms involved in the traditional technology. The analysis was conducted starting from literature but also carrying out specific surface analysis to investigate the effects of primers. PVC surfaces were then analysed by IR spectroscopy, optical microscopy and atomic force microscopy before and after the treatments.

IR analysis

IR spectroscopy is a suitable way to analyse the surfaces composition. In this case the goal was to investigate the potential surface contamination due to the production process of PVC profiles, their transport or handling. PVC profiles are obtained by an extrusion process where release substances are normally used to facilitate profile sliding through extruder's head. Such compounds can be very dangerous for lamination processes as they can represent a weak boundary layer for the adhesion process.

Fehler! Verweisquelle konnte nicht gefunden werden. shows the IR spectrum obtained by a surface extraction using n-hexane. The IR signals are:

- 3000 cm^{-1} Strongest signals due to the stretching of the C-H bonds in long carbon chains.
- 1700 cm^{-1} C=O stretching signal of esters.
- 1450 cm^{-1} C-H bending signals.

This spectrum reveal the presence of vegetable oils being considered as a typical example of release substances.

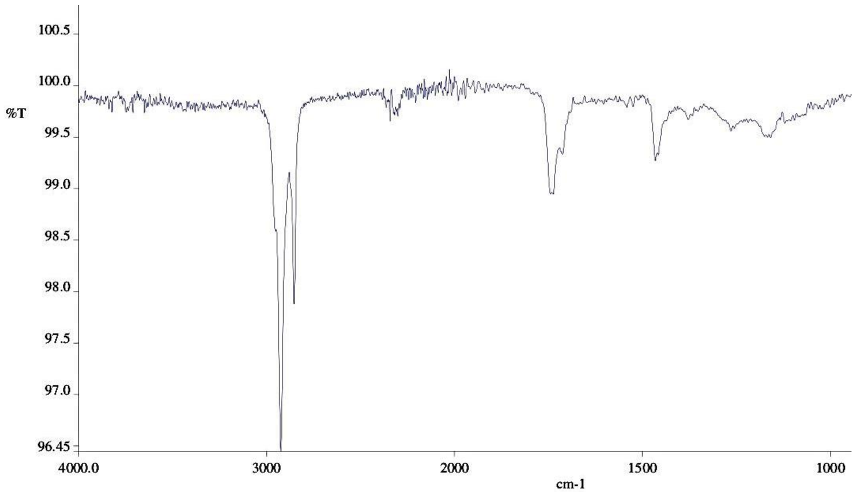

Figure 1: IR spectrum obtained by surface extraction using n-hexane

The same analysis carried out on the PVC surface treated with a solvent-based primer no longer shows the evidence of the oil due to its "cleaning" effect.

Optical microscopy and atomic force microscopy
Primer effects were evaluated by optical microscopy and atomic force microscopy. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows a sample treated with a dichloromethane-based primer where three zones can be identified starting from the left:

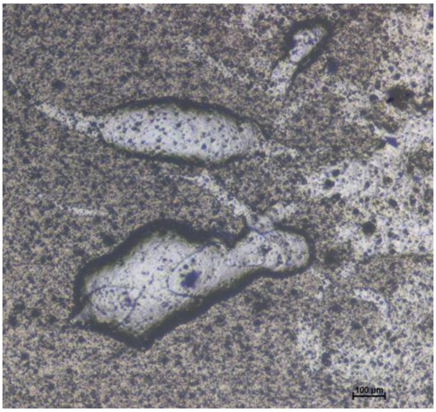
Figure 2: Optical microscopy image

1. Untreated area: primer did not wet this zone which is still dirty (grey).
2. Swellings: in this area there an excess of primer was presumably applied due to the felt landing. Swelling is a well-known phenomenon: a lot of polymeric materials swell in presence of solvents and PVC is one of them.
3. Treated area: in this zone the right amount of primer is present and consequently no swelling can be appreciated by optical microscopy. In any case it is clear that this area was properly cleaned (from dirt and release substances) by dichloromethane because it appear lighter than the left part.

Swellings on treated zone can be also observed in **Fehler! Verweisquelle konnte nicht gefunden werden.** which is obtained by atomic force microscopy. Looking at untreated PVC (**Fehler! Verweisquelle konnte nicht gefunden werden.**) it is evident that primers are capable to raise the PVC surface area as a result of the swelling effect. The increase in the specific area is consequently a benefit for the following adhesion process considering the theories explaining the adhesion phenomenon.

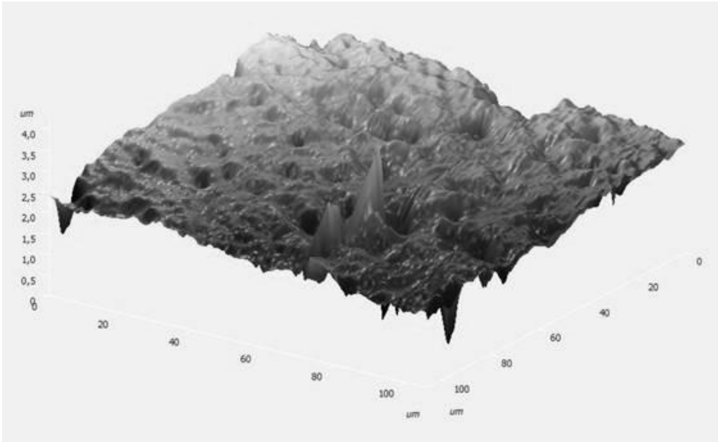

Figure 3: Untreated PVC

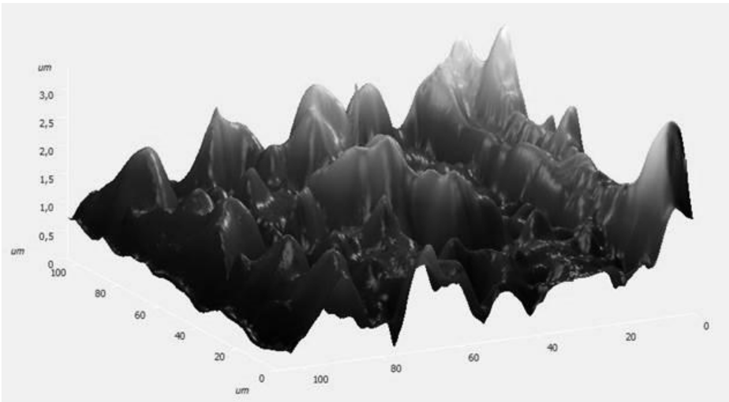

Figure 4: Dichloromethane treated PVC

Finally, primer effects can be summarized as:
1. Surface cleaning: solvents facilitate the removal of dirt, oils and other possible release substances.
2. Swellings: solvents increase the specific area leading also to a sort of surface plasticization which improves the possible inter-diffusion of the PVC polymeric chains with those of the adhesive (HMPUR).
3. Surface energy: primers contain resins which increase the substrate energy and consequently its wettability

3 ALTERNATIVE PROCESSES

The main physical and chemical mechanisms involved in the traditional solvent-based treatments were then analysed and it was consequently possible to search new alternative processes reproducing the same effects on the PVC surface. Flame Ionization and Air Plasma treatments which are well-known processes in literature were considered as possible alternative.

3.1 Flame ionization TREATMENT

Flame Ionization (FI) is a well-known process: the high temperatures reached into the flame promote the formation of chemical active species as radicals. The contact of these active chemical species with the substrate produce a chemical change of the first layers of its surface with a clear increase of the presence of oxygen atoms (see the result of a chemical analysis in Figure and Figure) [2]. In addition the flame is also able to clean the surface from oils.

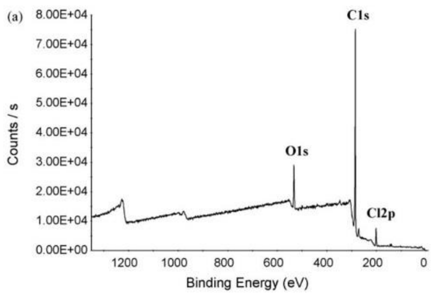

Figure 5: Untreated PVC

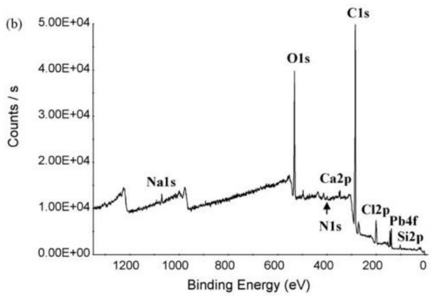

Figure 6: Flame Ionization treated PVC

It must be considered that the FI technique involves the use of free flames which needs a lot of safety devices: for this reason this process was not considered a possible alternative to the traditional primers.

3.2 Air plasma treatment

The second alternative process is the Air Plasma Treatment (APT). Often used on polypropylene, this process can increase the concentration of oxygen on the surface likewise the FI. Plasma treatment is however a safer and simpler system which does not use free flames and dangerous fuel feeds but it needs only electricity and compressed air usually available into the companies. Furthermore, APT provides a better surface cleaning compared to FI. On the other hand it is more expensive.
A pilot APT plant was built in order to evaluate its effects on PVC profiles.

Plasma effects evaluation

The first analysis, carried out by IR spectroscopy, was oriented to verify if APT is really capable to increase the concentration of oxygen on the surface. Several samples were prepared at different treatment speeds leaving unchanged the other parameters: results are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The main PVC chemical modifications were found in these typical ranges:

- 3600 ÷ 3700 cm^{-1} - formation of hydroxyl groups
- 1550 ÷ 1750 cm^{-1} - formation of carboxyl groups

The formation of oxygen-based groups confirms that APT can really raise the surface energy of PVC being a pre-requisite for every adhesion process. It was also found a correlation between the treatment speed and the surface functionalization: samples treated at lower speeds and consequently for a longer time, were the most functionalised ones.

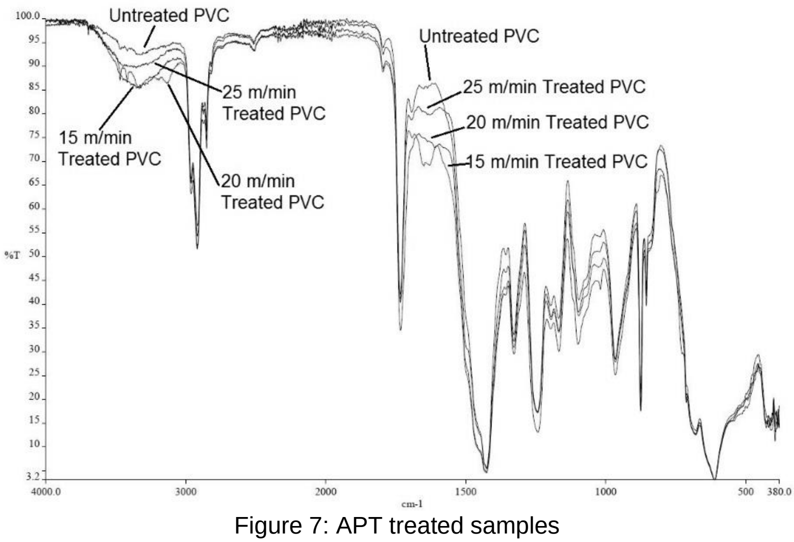

Figure 7: APT treated samples

The APT effects were also evaluated by surface energy measurements. Such values derived by contact angle tests measurements (obtained by water and diiodomethane droplet depositions) and computed using Fowkes theory [3] [4] [5].

Table 1: Surface energy measurements

SAMPLE	*TOTAL ENERGY [mJ/m²]*	*NON POLAR COMPONENT [mJ/m²]*	*POLAR COMPONENT [mJ/m²]*
Untreated	42,9	38,8	4,1
25 m/min	66,6	46,5	20,1
20 m/min	66,1	46,3	19,8
15 m/min	67,0	46,4	20,6

Table shows that all treated samples have similar surface energy values independently from the speed treatment and also that the most incremented value is the polar component which passed from four to twenty.
Such great polar behaviour gained by PVC makes the surface more wettable by polar liquids like water (Fig. 8 and Fig. 9).

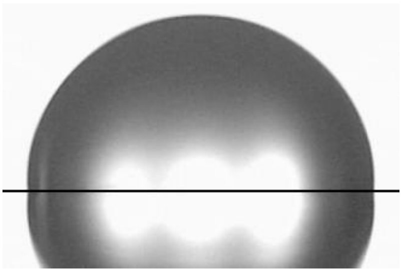

Figure 8: Water droplet on untreated PVC

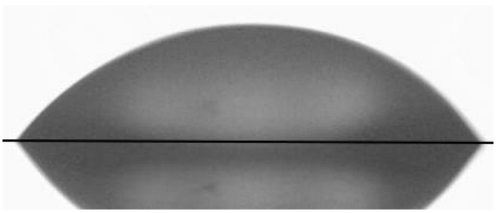

Figure 9: Water droplet on treated PVC

4 ADHESION TESTS ON FINISHED PRODUCTS

Peeling test is a suitable method to evaluate the bonding strength of a PVC foil glued to a PVC substrate. The peeling test was used to compare the performance of a traditional production cycle with the bonding resulting from the new treatments carried out using the APT technique. Peeling test on finished products were done at following conditions:

- Speed: 10 mm/min
- Slope: 90 degrees
- Temperature: 23 °C
- Foil width: 20 mm

Table shows the results: APT treated samples do not reach the minimum value requested by the company acceptability criteria (3,0 mJ/m^2) but there is an appreciable improvement of the joint strength comparing to the untreated samples.

Table 2: Peeling Test

Treatment	*24 hours*	*48 hours*	*72 hours*
Untreated	<1	<1	<1
APT [mJ/m^2]	2,4	2,1	2,6
WPR Primer [mJ/m^2]	3,6	3,3	3,5

5 CONCLUSIONS

The study carried out allowed us to identify a possible new strategy to improve the surface energy of PCV profiles, which is necessary for the subsequent bonding of PVC foils. The use of plasma treatment seems a promising technique capable of substituting the traditional treatments based on solvent-based primers.

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INTELLIGENT DRILLING – DIRECT-DRIVEN, SELF-OPTIMIZING HIGH-SPEED DRILLING SPINDLES FOR FURNITURE INDUSTRY

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Abstract

Time and resources are already an important issue in wooden industry and handicraft that will become more and more important the next years. Components for furniture production, particularly in the industrial sector, are usually manufactured in automated process chains. State-of-the-art for drilling is the usage of systems with bevels, belt drives, angle gears and rigid drilling units. Due to the operating direction and slow working cycles, drilling processes are the bottleneck of production. These rigid drilling gears are currently very intensive in maintenance and inflexible because their spindles are usually mechanically coupled, which leads to unnecessary and excessive energy consumption. Another problem with systems currently in use is the huge amount of setup costs. They are required to adjust drilling units on different components. This leads to an impairment of productivity of the entire manufacturing process. At this point the question arises how quality and efficiency of the drilling process can be increased. It is obvious that the drilling process must be made more intelligent and more flexible. An approach for an optimized drilling process is the use of self-optimizing spindles in future. Therefore a detailed analysis of drilling processes and the development of an eligible feed control are required. According to these requirements a laboratory machine was developed and furthermore the theoretical and practical state-of-the-art of drilling processes were analyzed. To develop a self-optimization for drilling spindles a research project is currently being realized in cooperation between the Laboratory for Woodworking Technologies and Machinery (HS-OWL, Germany)), the Laboratory for Power Electronics and Electrical Drives (HS-OWL, Germany) and the Wittenstein motion control GmbH (Bad Pyrmont, Germany).

Keywords:

Intelligent drilling, drilling processes, direct-driven spindles, self-optimizing spindles, feed control

1 INTRODUCTION

Drilling processes are an indispensable part of woodworking today. Particularly in furniture manufacturing, drilling is essential. This was not always that way. In classic furniture craftsmanship a high variety of alternative techniques such as finger joint compounds, screw and nail joints, gluing and many more techniques are used. Since the beginning of the 50s of last century with the advent of serial furniture manufacturing and the progressive industrialization the importance of drilling processes increased so that they play a central role in the join technology. Drilling holes are not only used in join technology today. Due to the simplified assembling, holes are applied to other functional elements such as fittings, handles or rows. The most important factor here is the precision of the holes due to direct assembly [1]. *Figure 1* shows an overview over typical drilling holes and tools in furniture manufacturing.

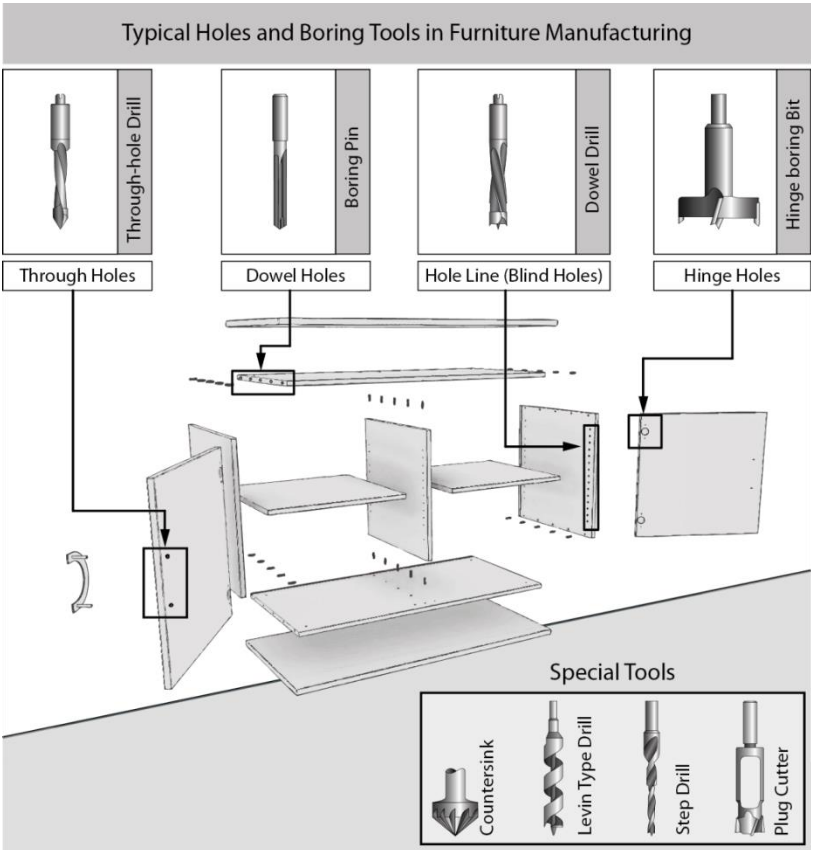


Figure 1: Typical holes and tools in furniture manufacturing.

2 DRILLING IN FURNITURE INDUSTRY – STATE OF THE ART

In furniture industry, automated continuous flow systems or stationary machining centers are used for drilling holes. Particularly in the continuous production of furniture parts, drilling processes are the bottleneck of the production because, different from milling processes, the process operates transversal to the direction of material flow. Often this is one reason for a decentralized positioning of drilling machines in production for instance before the assembling [2]. The drilling machines mentioned above, are usually equipped with rigid drilling units where individual spindles are coupled by bevels, belt drives *(Fig.2)* or angle gears. This leads to a number of disadvantages. For example, all spindles are running, even if only a few spindles are operating in workpiece. This requires a higher engine performance which leads to a tremendous waste of energy. The choice of large, powerful engines and the use of voluminous drilling gears, also leads to very high masses. All that masses must be accelerated and decelerated while operating such a machine. The maintenance and reliability is another significant disadvantage. A single defect requires the replacement of the entire drilling gear. This is associated with large downtimes and financial expenses. A further disadvantage is connected to realization of a working process monitoring. For rigid drilling gears an online process monitoring is only possible for the entire unit. Monitoring of individual spindles and tools is not feasible due to coupled spindles.

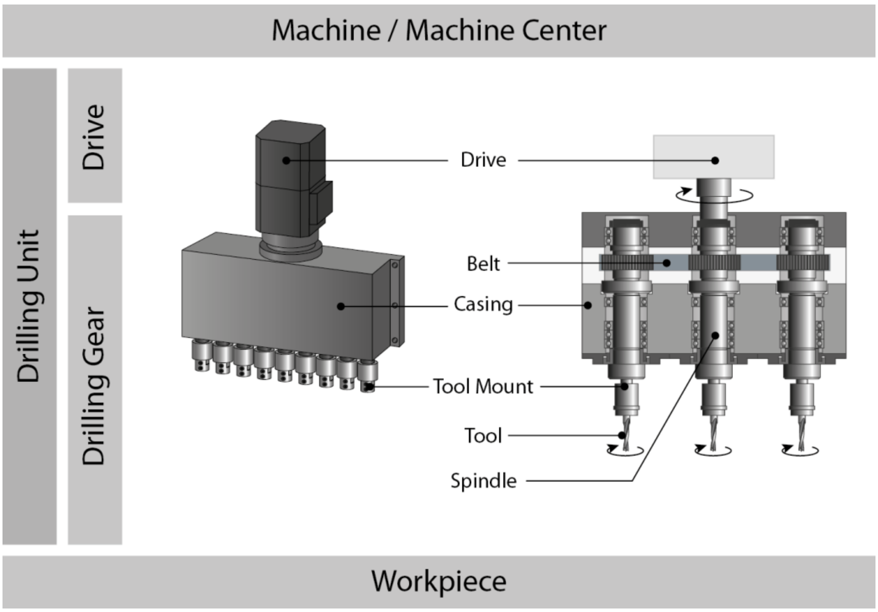


Figure 2: Schematic drilling gear with belt drive.

3 DIRECT-DRIVEN, HIGH-SPEED DRILLING SPINDLES

In contrast to the traditional drilling units, the Wittenstein motion control GmbH has developed direct-driven, high-speed drilling spindles to avoid the aforementioned shortcomings of the traditional drilling units. In contrast to spindles which are coupled by bevels, angle gears or belt drives an attempt is made to achieve a 30% higher efficiency, 70% less power consumption and up to 300% longer life of tools [3]. A better maintenance of the drilling gear can be achieved by the use of a modular system. The Wittenstein motion control system consists of two, not coupled spindles, which are enclosed in a drilling module *(Fig.3)*. Each of these spindles is directly driven by a separate motor. This offers the possibility for monitoring of various process variables such as e.g. the electrical power required during the process. The individual drilling modules can be joined into a frame so that nearly every formation of spindles for a specific drilling pattern with a minimal distance of 32 mm can be achieved. The advantage of this design lies in the significantly higher flexibility and simplified maintenance.

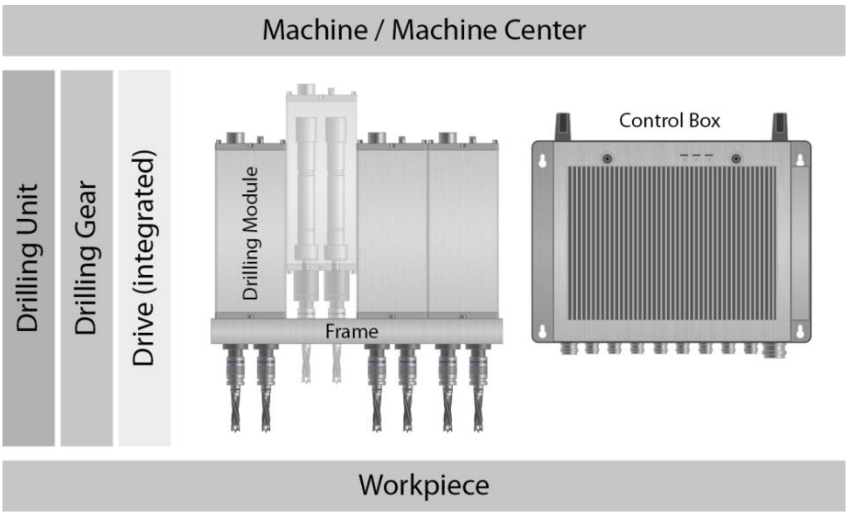


Figure 3: Schematic drilling unit (Wittenstein motion control).

4 PROCESS MONITORING – THE KEY FOR SELF-OPTIMIZATION

The goal of actual researches is to develop a self-optimization for the aforementioned direct-driven, high-speed drilling spindles. To achieve this goal, occurring cutting forces, cutting torque and the kinematics of the drilling process must be monitored and evaluated while the process is running. This is necessary to be able to apply automatic corrections to the process parameters on the fly.

4.1 Measurement - Different Points of View

The use of direct-driven, high-speed drilling spindles enables the recording and automated calculation of different process parameters for each individual spindle. However, it is not yet clear whether the recorded and calculated values correspond to real values. Checking this, the differentiation into tool and workpiece-side of view must be made. Depending on the location, different types of disturbing influences occur. *Figure 4* shows that on one hand side the measured values at workpiece-side are exclusively caused the work of the tool in the material.

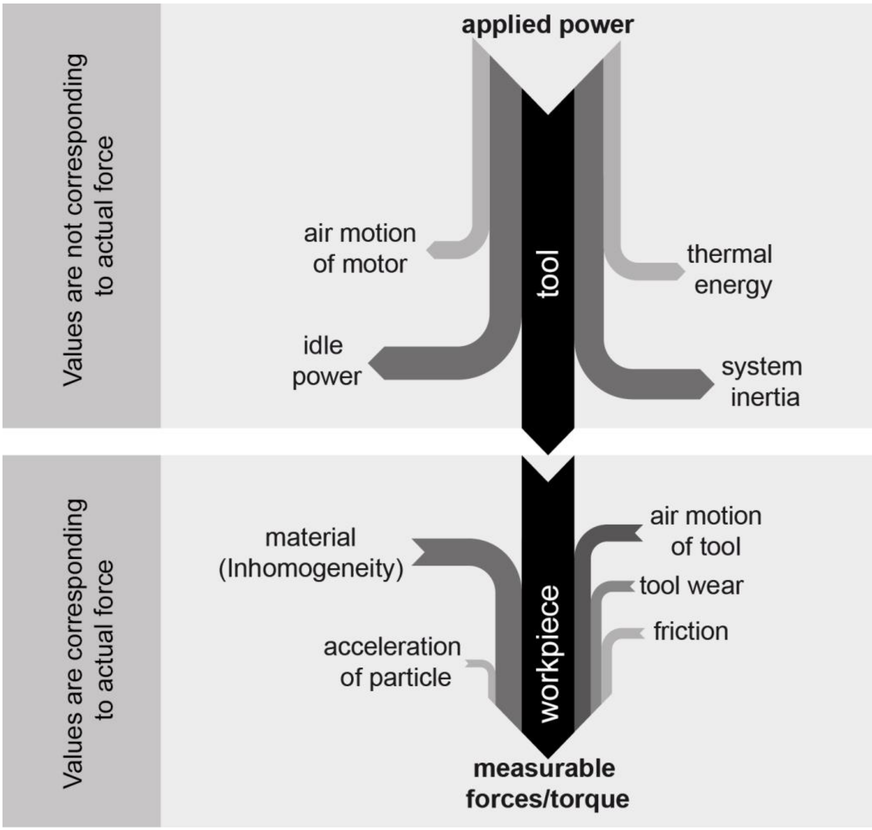


Figure 4: Disturbance values on tool- and workpiece-side.

However on the other hand side the measured values at tool side are further influenced by factors such as air friction, idle power, system inertia and loss of thermal energy. Therefore it is very important to check the way the measured values of tool-side and workpiece-side correlate. Checking this correlation, the use of additional measurement equipment at workpiece-side and the knowledge how drilling processes works are necessary.

4.2 Equipment for Process Analysis

As described above, the spindles of the Wittenstein motion control GmbH allow the recording of the drilling torque and forces. However, the detection of the actual position to workpiece and the actual current speed of the drill at any time of the drilling process are important for implementing self-optimization. Only this way, a meaningful and reproducible evaluation of the drilling process will be possible. To determine the position, it is useful to use a linear measuring system. In order to achieve the required accuracy in the furniture industry of 0.1 mm, the resolution of this measuring system must be about one magnitude below this value. The accuracy of 0.1 mm is typical for furniture production due to deviations (e.g. in thickness) of the inhomogeneous raw materials like particleboards or fiberboards and the movement of solid wood [4]. To obtain unambiguous measurement results it is necessary to control the feed of each Spindle. This is not possible with a machine built according to the state-of-the-art. Here, only the feed of the complete drilling unit can be controlled. For the measurement of unambiguous results it is also necessary to reduce acceleration effects which can influences the measured values. Therefore a long phase with constant feed during the process is essential. Due to high moving masses only low acceleration can be achieved but for a long linear movement with constant feed, high acceleration and deceleration are required. This problem can be solved by using the Wittenstein drilling modules with less than 5 kg instead of drilling units according to the state-of-the-art with approximately 25 kg and more.

As mentioned above, it is necessary using additional measurement equipment and developing a special feed axis to evaluate the correlation between the torque, measured forces and the real acting values. For this purpose, a special powertrain has been developed and a laboratory machine was built up *(Fig.5)*. With this machine, the precision of the measured values are being checked during the actual research project developing a working solution for industry.

To measure torque (M_z) and forces (F_x, F_y, F_z) on workpiece-side a 4-Component Piezo-Dynamometer was installed on the machine table. For recording of positioning information a laser distance instrument was connected directly to the drilling module and to measure forces and torque on tool-side, the rotational speed, strength of electric current and voltage of drilling module and Z-Axis were recorded. Out of these values, forces and torque were calculated.

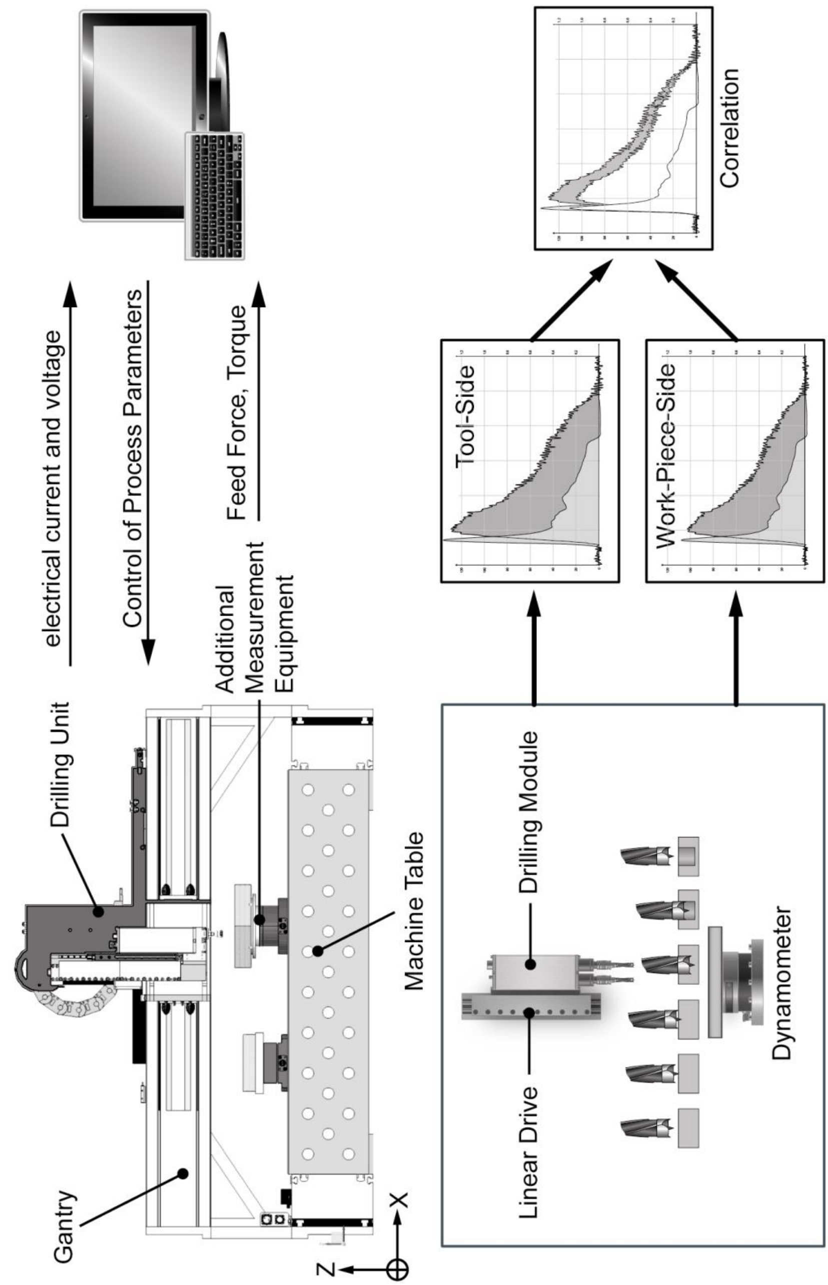
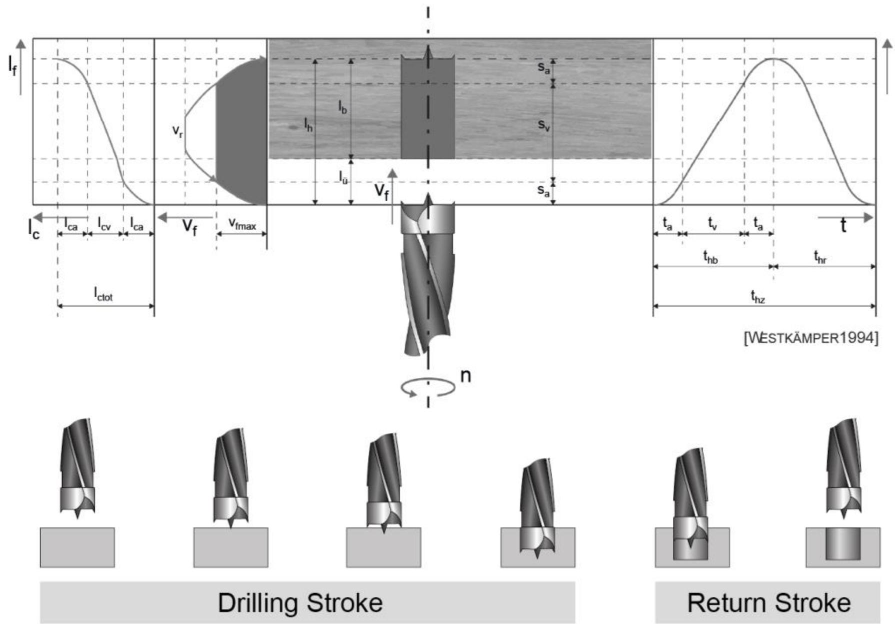


Figure 5: Machine for laboratory measurements and structure of experiments.

4.3 Analysis of Drilling Processes

For developing an operating process monitoring it is rudimentary to understand the drilling process in detail. Generally drilling processes can be divided into two steps, drilling stroke and return stroke. A generic drilling process is shown in *figure 6*.



v_f = Feed Speed
v_{fmax} = Max. Feed Speed
v_r = Feed Speed of Return Stroke
l_f = Advance Increment
$l_ü$ = Distance to Workpiece
l_b = Drilling Depth
l_h = Stroke Lenght
l_c = Cutting Lenght
$l_{c\ tot}$ = Total Cutting Lenght
l_{cv} = Cutting Lenght with a=const
l_{ca} = Cutting Lenght with v_f=const
s_a = Acceleration Distance
s_v = Distance with v_f=const
t_a = Acceleration Time
t_v = Time for s_v
t_{hb} = Time for Drilling Stroke
t_{hr} = Time for Return Stroke
t_{hz} = Cycletime

Figure 6: Generic drilling process according to [1].

The initial step of drilling processes is the idle task. In this position only the no-load current and the no-load voltage of the drilling module can be recorded. As shown in *figure 4* these two values can be affected by air motions of motor, thermal energy and the system inertia. The proper drilling process starts with a so called drilling stroke which can be divided into three steps, acceleration phase, phase with constant velocity and lag phase. It is important to keep the period with constant velocity as long as possible to reduce disturbing acceleration effects. Realization of short acceleration and lag phases submitting the possibility to change process parameters during the short duration of drilling processes and ensures a data acquisition without influences of acceleration effects. To realize a long phase with constant velocity it is necessary to shift the acceleration phase out of the workpiece so that the main drilling process (chip removal with main cutters) can start at the beginning of constant velocity phase.

The first contact of tool and workpiece is a crucial point during the drilling process. The main quality criterion of drill holes is the quality of their edges on surface of workpiece. Due to the commonly very brittle coatings of wood based panels these edges can be easily spoiled by using worn, damaged and wrong tools or wrong process parameters. In this point it is necessary to ensure that spurs of tool scratching the coating of workpiece one complete turn before main cutters starts to work. This can be realized by the use of eligible combination of process parameters (feed speed and rotational speed) and tools. After the phase with constant feed the tool has to be decelerated. This phase is called lag phase. The lag phase occurs during the intervention of main cutters in fact of changing feed direction and leads to an elongation of the cutting length. These elongations in correlation with high feed speeds induces longer acceleration and lag phases [1] and are a reason for wear out of tool. To ensure a longer tool lifetime it is important to reduce the rotational speed during lag phase. The return stroke works in the same way. After the deceleration of the feed, acceleration in opposite direction will be performed followed by a phase with constant velocity and a lag phase until the idle position of the tool. Also during the tool leaves the hole it is important to control the rotational speed. A high rotational speed in this situation signifies waste of energy. If the rotational speed is equal to zero tilting of tool is possible. The edges of the hole can be spoiled if the tool tilts.

Recording of torque, feed force and controlling of feed is necessary during the whole process. Due to changing density an inhomogeneity's in wood based materials, process monitoring and self-optimization of spindle are able to avoid unnecessary waste of energy and wear out of tool. Therefore it is important to analyze the shapes of feed force and torque. In these curves different points of interest can be found. *Figure 7* shows curves of torque and feed force which were recorded on a machine center equipped with the self-developed powertrain and a Wittenstein drilling module. A typical eight millimeter twist drill with center point and spurs was used. The process was performed with a feed speed of 8 [m/min] and a rotational speed of 12.000 [1/min]. The depth of the final hole was 15 millimeters.

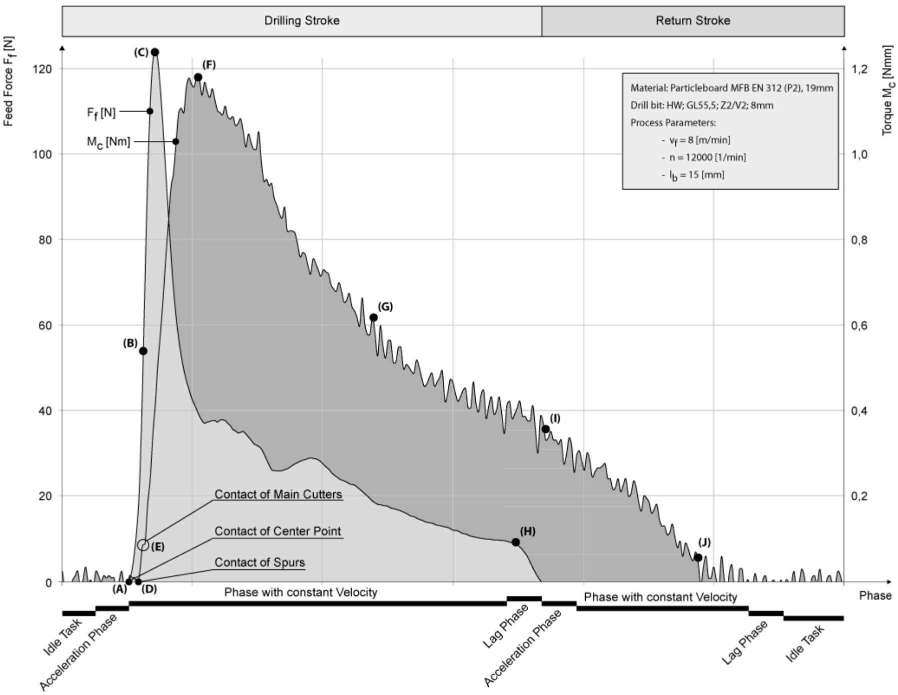


Figure 7: Analysis of feed force and torque curves.

Point **(A)** shows first contact of tool center point on workpiece surface. Result is a strong increasing of feed force **(B)**. This point can be used to identify the start point of drilling process. During the increasing of feed force the contact of spurs **(D)** and main cutters **(E)** can be seen in the curve of torque. Based on contact of main cutters with workpiece and the chip removal, a strong decreasing of feed force can be seen **(C)**. After the contact of main cutters, the torque reaches the maximal value **(F)**. Due to density of the material a decreasing of torque can be measured **(G)**. The material which was used in figure 5 is a standardized particle board with a typical density profile. Density profile means a deviation of density over the thickness of particle- or fiberboards due to their manufacturing. To increase the strength properties of particle- or fiberboards the surface layers get a higher density as the core layer [5]. Due to the deceleration of drilling process a decreasing of feed force in point **(H)** is measureable. This point should be determined before the start of drilling process. After this point process parameters like rotational speed and feed speed shall be reduced to save energy and ensure a longer lifetime of tools. In the end of the lag phase the drilling stroke is finished and the return stroke starts. During the return stroke (point **(I)** until the idle task) only a decreasing torque can be measured. Between the points **(I)** and **(J)** the torque is measureable due to the friction between tool and wall of drilling hole. Outgoing of the deepest point of drilling hole the torque decreases over the drilling depth. In point **(J)** the tool leaves the drilling hole.

The prior shown graph is only an example of a drilling process. The Measured values variegating in dependence of different parameters like density, structure and kind of workpiece etc. and can be influenced by controlling of feed per revolution.

5 ADVANTAGES AND DISADVANTAGES OF NEW KIND OF DRILLING SPINDLES AND SELF-OPTIMIZATION

As shown in the previous chapters of this article, the use of direct-driven, self-optimizing high-speed drilling spindles can offer a lot of advantages for furniture industry. Especially during processing of wood based panels the amount of acceleration phases is very high due to the short ways and the high moving masses [1] which constitutes a problem for process monitoring. By reduced moving masses it is possible to reach longer phases with constant velocity during the drilling process which means a reduction of disturbing acceleration effects during the process monitoring. Also a faster response time of process to react on e.g. deviations of material is possible due to lower acceleration and deceleration phases. This allows a better controlling of the whole process. The energy consumption can be reduced by the lower weight of Wittenstein drilling modules instead of traditional drilling units and by controlling of process parameters to reduce torque and forces. By the use of direct-driven spindles combined with a frame system a higher flexibility is given. The maintenance is easier by changing only defect drilling modules instead of the overall drilling gear. Due to higher speed of the complete system the amount of spindles can be reduced.

But also disadvantages are compound with this new system. The higher technological complexity of the drilling modules places new, higher requirements on staff. Also investment costs of this new system are higher at the moment. To use all advantages and ensure the complete functionality of this system, new types of machines and even new tools have to be developed. To ensure reduction of energy consumption, longer tool wear and a continuous high quality of drilling holes further researches about detailed drilling processes and process monitoring are indispensable.

Despite the disadvantages, this new kind of drilling spindles is able to make a self-optimization possible and usher a new era of drilling processes. The development of a self-optimizing drilling process offers a lot of advantages for furniture manufacturing. Tool wear and energy consumption can be reduced by autonomous adjustment of process parameters. Moreover, the process is able to react on deviations in raw material. This means a better controlling and optimization of process dependent on the material because the process specific knowledge is stored in a database independent of machine operator. Autonomous operating, self-optimizing drilling machines ensure a continuous high quality of manufactured furniture parts due to optimized process conditions. In general self-optimizing systems are able to pursue fixed targets like energy consumption, productivity, time requirement, tool lifetime and so on.

6 CONCLUSION

Realizing operating direct-driven, self-optimizing high-speed drilling spindles require to consider a lot of different factors especially the analysis of drilling processes. During the development of self-optimization, conditions such as rising up productivity of woodworking machinery as well as improving quality and accuracy of drilling processes are created. Energy consumption and adaptation costs for drilling units can be significantly reduced. A final system should be able to optimize a wide range of drilling processes while monitoring only few values without using any additional sensors on workpiece-side. Under best conditions these implementations can be transmitted to other wood working processes such as milling and sawing. The developed process model is therefore basic for a new generation of machine and system concepts for future furniture production.

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THE 8TH AND 9TH WASTE - THE MOTIVATION AS A KEY ELEMENT FOR THE SUCCESS OF THE LEAN TRANSFORMATION

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Abstract
The Lean Manufacturing is not just a collection of techniques and tools to produce with fewer resources, but is primarily a philosophy of company management that requires a radical change in the employees' mentality and way of working. By their ideas and actions, the employees allow a sustainable transformation only if they are highly motivated. This goal is achievable because of actions that need to be planned carefully and that, starting from information and training, through the correct communication process, come to objectives sharing, involvement and motivation.

Keywords:
Lean Manufacturing, Motivation, Involvement, Communication, Change

1 INTRODUCTION

In the technical literature concerning company organization, it is already codified the eighth waste, that happens when the firms use only the hands and the arms of their persons, losing the precious contribution of ideas coming from their mind. I would propose to add to this eighth even the ninth waste that is the lack of passion doing things, passion coming from a strong motivation (the "holy fire" as I use to say) that pervades people and allows them to reach a sort of self-actualization doing well their own job. Are not perhaps evident the engagement and the passion put by people working on their preferred hobby? And what can be said about the attention to details shown by a craftsman? These should be the objectives of the companies applying the Lean Production. The matter of a fact is that, in recent years, a growing number of companies have adopted (or claims to have adopted) the Lean philosophy, but studies done by the best global consulting firms, show that less than a quarter of companies gets sustainable results over the time while most of them miserably fail after a certain time (Figure 1).
Why does this happen?

- Is it a problem of poor commitment of the management?
- Is it a problem of lack of knowledge of the techniques?
- Is it a problem of incorrect application of the tools?
- Is it a problem of "sabotage" done by some members of the organization?

There may be a bit of everything, but mostly it is a problem linked to the **corporate culture change and motivation of the personnel**.
Lean is not based on directives imposed from the top but on the willingness of individuals to think in a new way and to act accordingly, facing with the problems by applying tools and techniques that have internalized because intimately convinced of the goodness of the new philosophy for the company and for themselves.

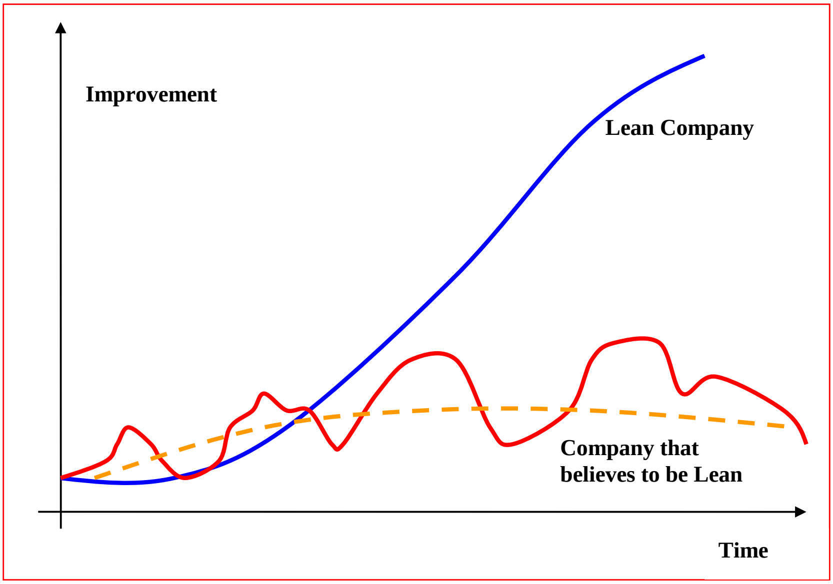

Figure 1: Improvement along the time

2 THE CORPORATE CULTURE

The corporate culture is a set of powerful forces, hidden and often unconscious, that determine individual and collective behavior, perceptions,

pattern of thinking and values. It is determined by the history over the years of the company that has identified objectives, adopted policies and strategies, achieved results, cultivated traditions. The ownership and top management and their personal goals, their cultural background and their experiences also influence the corporate culture. Finally, important factors are also the available financial resources, the expertise of the company, the human resources with their culture, experience, age, company age, origin, history and struggles and relationships.
Often, for an easier understanding, the concept of corporate culture is simplified by reducing it to slogans such as:

- "The way we do things around here"
- "The rituals of our company"
- "The organizational climate of the enterprise"
- "The current climate within the company"
- "The whole of our core values

Some of these phrases can give an idea of the climate but it is always risky to rely too much on such simplifications, especially when the company's human resources are involved in.
The best way to read the corporate culture is to realize that several "levels" exist, and it is necessary to understand and manage the deeper ones.

a) **Behavior:** The most visible level when you enter an organization is connected with behavior, i.e. what you see, hear and feel when you go through the production workshops or offices, talking with the people who work there. The differences are often macroscopically evident. We could find a company where people often meet, apply the group work, use an informal dress code, call each other by their first name and gives the impression to work quickly. On the other hand, we could visit an organization where people dress formally, work in individual offices, with limited communication, and feeling of slow motion. From what we see, we cannot perceive clearly how their businesses are going, but we can definitely see the difference between the two corporate cultures (Figure 2).
b) **Declared values:** The lower level is more difficult to perceive. It is necessary to dig deeper and ask questions about what is valuable in that organization. Why do you act in a certain way? Why do you create open spaces in offices or why do you prefer to work in individual rooms? These in-depth questions will be placed especially when the behavior does not seem consistent with the values reported by the company. These inconsistencies highlight the existence of a third deeper level of thoughts and perceptions that are driving the visible behavior.

c) **Shared unspoken assumptions**: At the lowest level, the essence of culture consists of values, beliefs and assumptions learned together, become common and taken for granted, while the company continues to be successful. It is important to remember that they are the result of a joint learning process. Originally, they were only in the mind of the founder and the management. They become common and obvious only when the new members of the organization understand that those beliefs, values and assumptions made them successful, and therefore they must be "right", All those ones become "paradigms", ways of doing things, unchangeable, "because they have worked so far". This is the feeling of people, especially those who are responsible, because, acting in this way, they were successful and develop their career.

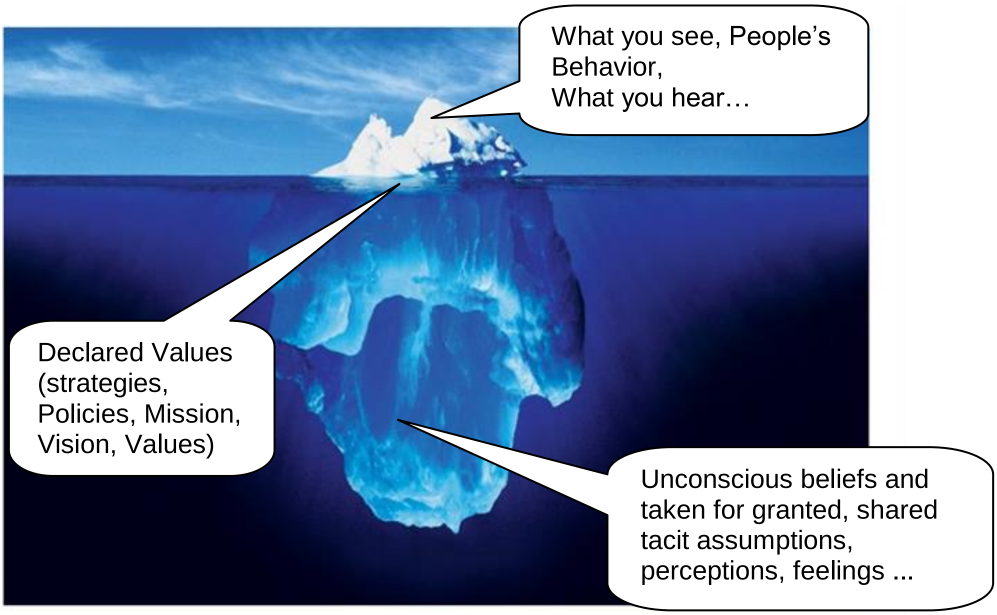

Figure 2: "Iceberg" of the levels of corporate culture

3 THE CHANGE OF THE CORPORATE MENTALITY

The company must therefore break these paradigms, free from proceeding constraints, and make the change if it does not want to have the same poor results. If there is the perception of weak signals indicating dangers or difficulties, the company needs to change something in the organization. The Lean Manufacturing shows that the performance improvement is provided by process improvement and its continuous adaptation to

changing market conditions. There are significant changes of the performances if there is a continuous improvement of the processes that generate it. This way to operate becomes the main strategy for a successful business and the way of daily work of all employees of the Company.
Process improvement is the result of many small adjustments done constantly by all staff. The different phases of each process are connected to each other as in a chain: the output of one is the input of the other one introducing the supplier-customer relationship inside the company.
Process improvement is not the result of the directive of an authority, nor the result of a single company function activity. It is a collective awareness that results in the full involvement of employees in the achievement of corporate objectives. The secret is the motivation of the individual person who, better than anyone else, knows what he is doing, knows the problems and then is able to solve them. Therefore, giving the staff the opportunity to develop a new way of thinking constitutes a substantial change of the current paradigms.
Three phases characterize the change process:

First Phase: Defrosting. Change implies not only learning something new, but also unlearning something that people already know and that is "frozen" in their mind. This is the phase of "thawing", considering that, in order to start a new learning, it is not enough to have a sufficiently clear view of a positive future.

Second phase: Acquisition of new concepts and new meanings for old concepts. If people have been trained to think in a certain way and are part of a group that has the same feelings, is it possible to easily change and think in a different way? This can be done by increasing the sense of psychological security of the learners, for example showing an irresistible positive outlook, structuring a deep education, involving the learners, providing feedback and support.
If we consider the difficulties of these steps, the energies and the resources that have to be spent to put them into practice, there is no wonder if the changes are often not sustainable long term.

Third Phase: Internalization of the new concepts. The final step in any transformation process is the internalization of the new concepts that leads to a new behavior. If the behavior matches with the personality of individuals and is consistent with their expectations, then it becomes a permanent characteristic of the person and, at the end, of the group. Otherwise, the organization will slowly return to old concepts and behaviors.

4 RESISTANCE TO CHANGE

Of course it easier to say than to do because, during the change phases, conflicts and resistances within the organization frequently happen and their main causes are shown in Figure 3, where their chaotic representation well expresses the level of fear and anxiety that the topic generates in people.
These conflicts occur first inside the people’s mind because the change determines the necessity to unlearn beliefs, attitudes, values and assumptions and learn new ones. People resist to changes because the process of unlearning causes discomfort and anxiety.

5 THE LEAN TRANSFORMATION SUCCESS

The operational field practice shows that the success of lean transformation depends on a number of steps.

Statement of Company Direction: The entrepreneur and the top management must be the first ones to be convinced of the need to address the business with a client-centered point of view, just as the consequence of a deep conviction and not only to comply with a fashion. Management should know that this is not an easy and short process and therefore should apply the highest level of determination and patience, conjoined to the ability to lead by example.

Figure 3: Resistance to change

Belief and involvement of the top and middle-management. The immediately following step is to explain the new philosophy to the top and middle-management which is directly in contact with the main actors of change (blue and with collars); These are the levels of organization that more than others resist to the change because they are the ones who risk more for the new philosophy. The traditional system of power is questioned because the quantity of information moved to the base of the organizational structure is much higher than before, and, at lower levels, a large intake of responsibility, and a significant increase of autonomy are required. People is asked to make decisions, develop standards and then the leaders feel belittled in their responsibilities and sometimes bypassed. The most difficult task is to let the middle management understand its new role and new responsibilities, finding the positive feedback to all the fears and anxieties. The middle managers will get in touch with the new culture through both formal and field training. Most likely the new philosophy will also cause some change in the organizational structure that will require a great care choosing the key role managers. Finally, the reaction to possible conflicts must be very quick before they widen to other members of the group. The management at least will measure the effectiveness of its behavior considering the consistency level used to achieve the decided targets and the ability to take care of its employees. The task is to help them overcoming the doubts and problems and bringing them to a level of performance never achieved before.

Employees' motivation. What it said for the middle management can be repeated for the base of the organization. The implementation of a correct and constant action of employees' information, involvement and motivation is necessary to ensure the Lean Transformation. The suggestion is to organize soon enough activities in the shop floor or in the offices because nothing is better than practice to explain the new philosophy. Of course, these practical activities should be prepared very carefully. It is better to choose a close-knit team and an accepted leader to make sure that the first attempt is successful. This will encourage and incentive other groups to start improvement activities. If the first test fails, the motivation of the people will drop immediately and this can undermine the success of the whole project. It is relatively easy to change a machine or plant, but it is much more difficult to change the behavior of people. Likewise, it is not so difficult to apply the techniques and tools of Lean Manufacturing, but it is much more difficult to convince people that they can think and act in another way, maintaining a high level of motivation to achieve goals.

The long-term sustainability is certainly a function of the goodness of the starting phase, but is also a function of the commitment provided by the Direction and the management to the initiative along the time. Their pressure on the organizational structure must be constant as long as the techniques do not become company's procedures and their application becomes automatic because internalized by people. In any case, signals such as the indifference of the Board and the top management to the achievements of the improvement groups or the lack of participation in events celebrating the successes are deleterious, because they ease the emotional strain on the subject and slowly the company slides backwards.

6 THE MOTIVATION OF THE EMPLOYEES

The most important factor for the success of a lean transformation is the motivation of the employees that can be seen as a personal inner tension that determines the will to achieve the defined goals, through actions that make the individual behavior. To better explain this concept, consider the following situation. Suppose that a person is hungry and is focalized on the way to get the food. He then begins taking actions to research the food, to obtain it (purchase, theft, cultivation etc..) to cook it etc.. The last action, eating the food, is the achievement of the objective and the satisfaction of the initial need. The behavior is the set of actions taken to achieve the objective, noting that the evaluation is not only on "what" is done, but also on "how" it is done. One thing is, in fact, to achieve the objectives keeping good interpersonal relations and harmony with the other functions inside the company, other thing is to achieve the same goals by acting as a steamroller which paves the way to all obstacles, without considering the negative consequences on the rest of the organization.

In conclusion, the goals achievement is determined by the existence of a need and a so-called "inner tension", an energy inside the individual, determining his/her behavior. This tension or " inner spring" is defined as "motivation."

How can an industrial organization maintain along the time a full motivation of its people? My belief is that it is the conclusion of a virtuous and standardized path, shown in figure n.4 and characterized by the fact that each level can be reached if the activities of the previous level are fully carried out, with exactly the same logic as the "Pyramid of A. Maslow".

People are motivated if they are heavily involved in the determination and selection of actions necessary to achieve the defined objectives. Involvement is possible only if there is the possibility to share targets and projects, which follows to the comprehension phase where people understand the needs of the company and the problems to be solved.

The understanding depends on the content of information, the level of training and the type of communication that have to be appropriate to the recipients. The interesting thing is that the virtuous path shown in Figure 4 is standardized and their content as well.

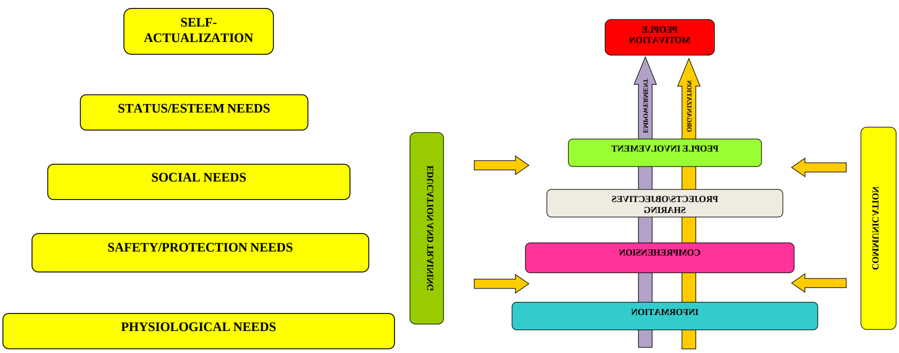

Figure 4: Pyramid of A. Maslow (left) and Pyramid of Motivation (right)

7 THE EMPLOYEES' INVOLVEMENT

In the preceding paragraphs it was underlined the need to motivate and involve people as necessary factor (although not sufficient) to implement the Lean Transformation. The involvement can be defined as the action intended to affect people and let them feel strongly engaged in a project, where they contribute actively to its preparation and implementation. In this way, people increase responsibilities and achieve challenging goals as well.

Leading scholars of behavioral sciences and applied psychology agree to regard it as one of the most important motivating factors at work. People involvement in the company is encouraged by certain conditions, such as the opportunity to improve their skills and abilities, the appreciation of the good job done, the appropriate level of autonomy, the opportunity for professional growth and career advancement in the company, etc.

8 PROJECTS AND OBJECTIVES SHARING

The managers have to acquire the ability to motivate employees because the Lean Transformation is moved by the participation of people of all levels. If participation is voluntary and complete, the results achieved by the company will be significant, because the creative energy of people is huge and is waiting to be released. It is also evident that, among many factors, people's involvement in small or large-scale projects, in things to do, goals to be achieved. is certainly the most powerful mean to develop motivation. Nevertheless, in order to be involved in projects and targets, first they have to be to shared. The sharing of the project and the objectives requires, first of all, the knowledge of the topic and of the context around the company. From here, the conclusion is that the sharing of objectives and projects is related to the understanding of the information that people have on the subject. This will be high if their training on those issues and the communication level will be appropriate.

9 THE INFORMATION

Information and training are the basic conditions to ensure involvement and motivation of employees. In fact, while announcing the Lean project to all employees, it is necessary to enable them to understand it and share it, acquiring the necessary knowledge of the different methods and techniques. Information and training are thus closely interconnected. In particular, the information phase must be constantly applied to all levels of the company, top down and bottom up in order to ensure a homogeneous knowledge of the company's problems. This step is accomplished by:

- constant contact of the managers and the leaders of the workgroups with their colleagues;
- the implementation of a simple but effective visual communication system (Visual Management), based on patterns, boards or signals, which, continually, update on production performances (see figures 5, and 6);
- the adoption of daily informal meetings, standing, where, at the beginning of the morning the groups gather, for 10-15 minutes, with the

pertinent responsible to highlight the issues raised at the start of the activities or still present since the day before. At the end of this quick meeting, the teams leaders meet with each other and the head of manufacturing for example, for 20-30 minutes, and immediately after, the production manager sees the other colleagues at the same level and the plant manager. In this way, in about an hour, the whole chain of command of the production unit is aware of what is happening and what kind of solutions are intended to take. Note that in this way, every manufacturing organization can "standardize" the information to be shared with their own people.

10 TRAINING

The information provided to the workers cannot be fully understood if people are not properly trained. This activity must be calibrated in relation to the concerned persons, leading to different types of training for:

- the understanding of business issues (quality, production planning, technologies, etc.).
- the acquisition of know-how about the methods and specific techniques of Lean Manufacturing.

Figure 5: Boards of graphs, targets and metrics

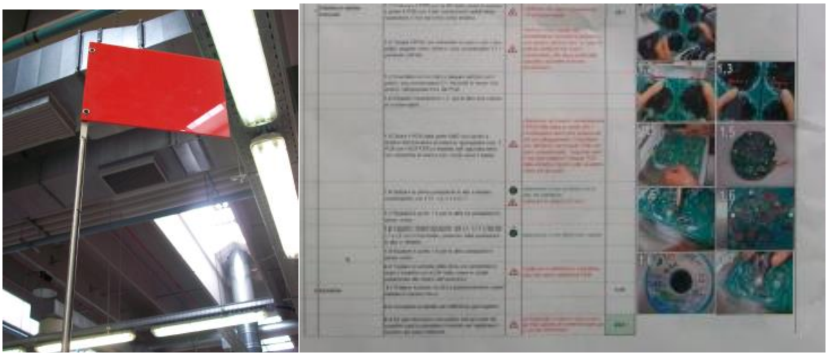

Figure 6: Andon and working instructions

- the acquisition of skills to increase flexibility against changes in volumes, mix and number of workers. In this case it is appropriate to build the so-called matrix of competencies, (figure 7) where are depicted skill levels currently achieved by the operators in the pertinent work stations.

In order to allow workers to understand, learn and remember easily the concepts, experience suggests that the best way to present these arguments is to use interactive and highly instructive games. The games concern different topics (5S, Standard, JIT, Kanban, One piece flow, etc.) and have to be standardized, in order to ensure cultural homogeneity within the workshop. The aim of the game is to break the traditional roles and ways of seeing and doing things and to allow people to change their point of view. After discussing and sharing what happened during the game, it is easier to explain the theory and the principles upon which Lean is based.

ID	TURNO	Cognome	Nome	Postazione di lavoro	TABELLA DELLE COMPETENZE PER REPARTO CILINDRI										
					Tornitura	Fresatura	Fresatura CN	Aggiustaggio	Rettifica	Lucidatura lavaggio	Controllo tecnologico	Piantaggio boccoa	Tornitura boccola	Equilibratura	Equilibratura automatica
1	2	A	X	Equilibratura						2		2		3	3
3	1	B	Y	Controllo Tecn.	4	3	3	4	4	3	4	4	4		
6	2	C	W	Fresatura		4	2							2	
7	2	D	Z	Aggiustaggio		3		4	2	3	4	3		4	3
8	1	E	X	Tornitura	4	4		4	3		4	3	4	3	
9	1	F	Y	Lucidatura						3					
10	1	G	W	Equilibratura						3				4	4
11	1	H	Z	Aggiustaggio		4	3	3	2	3	3	3	3		
12	2	I	X	Controllo Tecn.				4	4	4	4	4	4	4	
13	2	L	Y	Tornitura		2			3	3		4	4		3
14	1	M	W	Tornitura		2			2				2	2	
15	1	N	Z	Controllo Tecn.		3		4	3	3	4	4	3	3	2
16	1	O	X	Aggiustaggio		3		4	2	3	4	4		4	2
17	1	P	Y	Fresatura		4	4								
18	1	Q	W	Rettifica	3	3	3		4	3		3	4	4	4
19	2	R	Z	Controllo Tecn.		4	4	4		3	4	4		2	2
20	2	S	X	Rettifica		2			3	3			2		
21	2	T	Y	Equilibratura	4	3	3	3	3	4	3	4	4	4	3
22	G	U	W	Piant.boccola		2				3		4			
23	2	V	Z	Tornitura	4	4	4		2	2		2	2		
				Totale operatori autonomi per postazione	5	12	7	9	8	14	9	12	8	9	6

Figure 7: Competencies board

For this purpose, very used are for example games like:

- image recognition inside videos or photographs, showing the power of the paradigm that makes you see things only in a certain way and not in others;
- the use of Lego bricks to demonstrate the effectiveness of techniques such as the 5S and standardization;
- the simulation of a mini-production department manufacturing simple products (i.e. ballpoint pens, plagues, sockets, sort of origami, etc.), in order to show the power of pull vs. push systems.

11 THE COMMUNICATION

In each of the phases analyzed above, it is essential that the work leaders, the engineers, the managers own proper listening and communication skills. They must show to the workers that their listening is full and active, giving great importance to the non-verbal signals, as looking straight at the speaker, nodding with the head, keeping the right facial expressions and posture toward the person. Equally important is the ability to communicate, where clarity and synthesis must excel together with the use of simple words, linear concepts, and examples. Particularly critical is the communication of a negative response to a proposal done by a worker. You have to explain the reasons why the proposal cannot be developed, whilst avoiding the psychological block that can lead the person to a non-participation in the future improvement process.

12 THE ORGANIZATION

One of the best ways to involve and motivate is the working group where people with different skills, come and work together to address and solve problems affecting their job. A leader, who works as the others, has the overall responsibility for the results and the coordination of the entire group. This is the place of the allegations of company values, autonomy and participation, where the hierarchical structure is substitute by informal relationships and there is space for free expressions and ideas exchange. What are the elements that characterize a team? Some friends who discuss together certainly do not form a team, while a football team that has signs of recognition, a spirit of cohesion and where each member has a specific role is identifiable as a team. The difference between a group of friends and a football team is that the latter has common and shared goals, plays to achieve the best result where individual members have clear responsibility and awareness of the things to do.
Among the various features of a team are important individual potential, motivation, roles, effectiveness, method and the climate. The latter is particularly important and, if positive, makes easy to communicate and to exchange ideas, to increase the likelihood of achieving the objectives and motivate the team members. Work as a team today is necessary because it allows to share the goals and to have a global vision of the processes. All this facilitates the application of Lean Manufacturing and helps to create a favourable climate for each member, moving from the logic of "'I" to that of "WE ".The work team expresses its full potential during the members' meetings. It is therefore necessary that the team leader prepares and leads effectively these so important moment.. Each stage of the meeting must be carefully managed, taking care of its preparation, discussion and conclusion. In this last phase, it is important to summarize the topics discussed, highlight the decisions taken, develop an action plan for the next meeting, establish date, and finally close the meeting at the specified time. Every company should establish and standardize the groups' operating rules, in order to get consistent results.

13 CONCLUSIONS

Every time we touch the sphere of human resources we enter a delicate mechanism and we should be extremely cautious. However, company's direction and managers need to focus on motivation of their employees because only they can do the changes making them sustainable along the

time and avoiding the eighth and ninth waste. The Lean Manufacturing is not a collection of techniques and tools to produce with fewer resources, but it is a philosophy of company management that requires a radical change in the mentality and the way of working. A path to the full motivation of the human resources is outlined in the preceding pages and that is summarized in Figure 5. The motivation of the people is the consequence of actions that need to be planned with great care, starting from the top-down information and from the training that let the people to understand the information sent through the proper communication process. This fact enables individuals to understand and share projects and objectives, the basic condition for being involved in achieving them. The involvement in the definition and implementation of shared projects usually generate a high level of motivation and satisfaction, freeing the best creative energies of the people.
The other important factor is standardization that makes these mechanisms known to everybody and easily repeatable. Practically every phase is standardizable: it can be the information packages at the level of company, factory, workshop and workgroup, the key indicators to measure and show the performances, and the subjects and the ways to deliver the training as well. Finally, we can standardize operating procedures, involvement methods and organizational structure necessary to operate the lean transformation.

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AUTOMATIC PATH-PLANNING ALGORITHM FOR REALISTIC DECORATIVE ROBOTIC PAINTING

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Abstract

The industrial spray-painting process is currently split into two main branches: the uniform covering of surfaces (e.g. automotive), and decorative painting (e.g. furniture, porcelain). While the former makes extensive use of robotics, the latter does not, relying instead on the manual skills of expert painters.
In this paper we propose an innovative algorithm to reproduce non-uniform, photorealistic, grey-scale images on surfaces, using an ordinary industrial spray-painting robot.
The algorithm splits the process into a set of iterative steps with the spray gun located at decreasing distance from the canvas or generic surface. Since the spray morphology is cone-shaped, at higher distances the stroke will be bigger than at closer distances. Taking advantage of this characteristic, the algorithm can efficiently build up the image starting with a big stroke to paint large details of the image. Then, with increasingly smaller strokes, it can paint the rest of the smaller details. The core is based on a constrained ordinary least squares (OLS) method. The image is segmented and a path is defined using an approach normally used in CAM: offset generation via Voronoi diagram. A set of critical points in the image are then chosen to avoid oversaturation and used to build a system which is then solved using OLS.
Depending on the image to reproduce, this methodology promises to be far more efficient than printer or plotter-like painting processes, where the image is built one point at a time. Applications of this innovative methodology are range in the field of decorative or functional painting, from furniture to houses and buildings, to automotive, to naval architecture.

Keywords:

Spray painting, robot, path-planning, Voronoi.

1 INTRODUCTION

Robotic painting is presently a very common task in the industry; it spans from automotive to furniture, even to art. In the vast majority of applications the spray painting technique is used rather than others, i.e. brush painting. Indeed this technique couples very well with automated systems, and can be very efficient. Normally the painting process is targeted towards having a surface (of arbitrary shape) covered uniformly by paint. It is apparent that, in the light of this fact, some aspects of robotic painting were left behind, in particular those concerning non-uniform painting. An ordinary example of this kind of painting is a photo, or a drawing. At present no automated methodology or algorithm exist to replicate an accurate copy of a digitized image (be it a photograph or something less realistic) on a large surface by means of an industrial spray-painting robot. The purpose of this work is thus to present an innovative methodology and an algorithm to tackle this challenge.

Several branches in the industry could be positively affected by this methodology, especially where decorative and/or functional painting is required. Automotive and furniture industries, particularly in the high-end segments, can present the need for this type of operations, and up to now this was generally met with the aid of highly skilled artisans or with complex masking systems (which, in turn, needs other professionals as well). It goes without saying that these procedures often impose great cost and time. Another promising branch is the one involved in construction; some companies (Cité-Création, in Lyon, France, http://cite-creation.com) use classic techniques like *fresco* and *trompe-l'oeil* to decorate buildings and homes, this mainly in an attempt to increase quality of life in crowded and dull city environments. Along the same line, in a less artistic way perhaps, industry buildings often need signs, text or warnings on walls or machinery, and while on small surfaces decals can be used, with larger surfaces this becomes impractical. The history of painted furniture is as old as society in itself, dating back to at least ancient Egypt; in modern times the interest in this kind of art has somewhat subsided due to high costs, but examples are still present. If, though, the process were to be completely automated and robotized, cost would lower substantially.

At present, the mechanics of the spray painting are well understood, for example Balkan et al. [1] Conner et al. [2], and Chen et al. [3] present models for the flow rate flux of a paint gun and for the paint deposition in spray painting. Chen et al. [3] experimentally analyze the paint coating characteristics for uniform velocity with overlapping paths. Atkar et al. [4] published a work on robotic uniform spray-painting in automotive. *Robotic* spray painting is also widely acknowledged; in normal industrial practice the manual teaching methods (see Baldwin [5]) are widely used. Chen et al. [6] propose a review of the current state of the art in the automatic path planning for industrial robotic spray-painting. Artistic, non-uniform painting by means of autonomous or automatic systems has been a subject of research

in the last two decades, mainly since the work by Haeberli [7] on the virtual representation of images using pictorial, abstract styles. A crucial reference for our paper is the concept highlighted by Hertzmann [8], in which the painting is carried out (virtually) with progressive decreasing-size strokes, following the footsteps of Haeberli. A series of different artistic painting robots are presented in literature, a few examples of which are in [9][10][11]. All these are not adequate since they tend to produce artistic-looking, and non-photorealistic paintings.
Perhaps the unique example of system built and used to reproduce photo-realistic images on a surface is the printer, in its various forms. The problem of these systems is that they operate essentially dot by dot, regardless of the detail sizes in the image. This translates in very long times if the surface tends to be large. Moreover, the resolution is ultimately established by the hardware in the print head, which is a big limitation in flexibility.
For these reasons, in this paper we propose an innovative methodology to reproduce photo-realistic images on surfaces by means of a fully automatic robotic spray-painting process. The method is centered on the concept that with a spray-painting robot we can achieve a wide range of stroke sizes; this can be taken advantage of by using the larger strokes to paint the large details, and the smaller strokes for the smaller details. Efficiently calibrating this process leads to virtually any outcome, from low-detail and hi-speed to slow-speed but high-detail executions. The core of the methodology is an adaptive, smart algorithm that uses techniques like Voronoi diagrams, convolution and ordinary least squares (OLS) to define a path and feed-rate to control a general robot. In this article we use only grey-scale images, but extension to full color is straightforward.
In section 2 we outline the methodology in its most general form. In section 3 we present the findings of a preliminary experimental campaign on the morphology of a paint spray cone in an airbrush. In section 4 we present the actual core algorithm of the methodology and in section 5 we display and discuss the results with a test image. Finally in the Conclusion we discuss the overall efficiency and accuracy of our methodology.

2 PROPOSED METHODOLOGY

As already mentioned, the key concept in our approach is that, in the spray-painting process, the distance of the nozzle of the gun from the surface determines the size of the stroke. Since the distance can be varied easily by moving the end-effector of the robot, we can precisely establish this size. In Fig. 1 one can qualitatively appreciate the morphology of the spray-paint cone originating from the nozzle. The Gaussian-like structures shown at distances d_1, d_2 and d_3 are the cross-sectional speed-profiles of the jet. Note that these represent equally well the paint collected in a unit of time on a surface if said surface were placed at that distance.

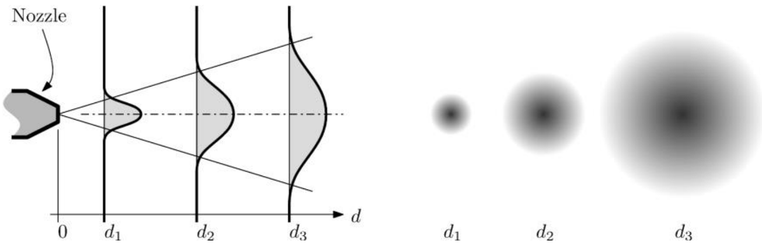


Figure 1: Spray-paint cone morphology. The cone originates from the Nozzle, and at various distances (for example d_1, d_2 and d_3) an indication of the cross-sectional speed distribution is visible in grey, along with the resulting stroke on the canvas (on the right).

The central challenge in our approach is to split the painting task into a series of progressive sub-tasks with increasing detail demands. It is apparent that as detail increases, the time required to perform the sub-task increases greatly; for this reason it is crucial to perform as much work as possible in the first steps, where the larger strokes are employed. The diagram in Fig. 2 helps to clarify the overall process.

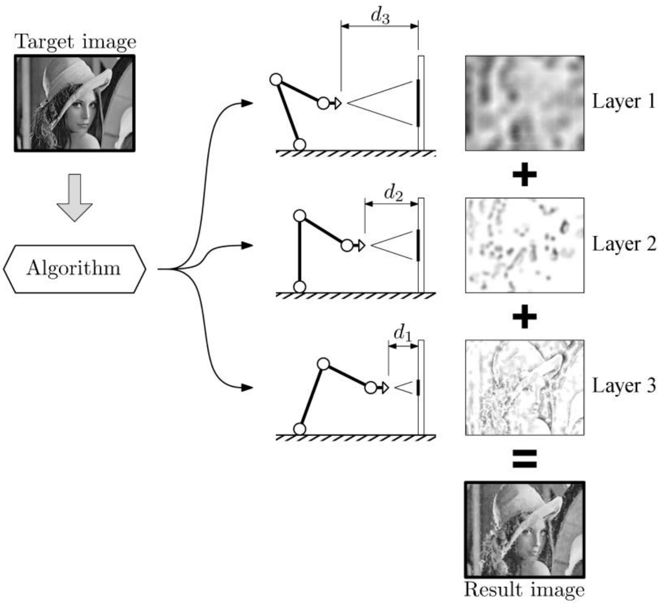


Figure 2: The general methodology. The image (upper-left) is fed into the algorithm, which, according to the spray morphology and mechanics, splits the work in a series of consecutive tasks, each of which takes advantage of a different stroke size, and operates mostly on details of matching size. The progressive execution of these steps generates the resulting image.

It is easy to understand that, in order to obtain a good result, the stroke size at each step must be chosen wisely. Furthermore, the number of steps and the size of the stroke at the last step are very important for the overall quality of the finished piece. Many methods are available to calibrate precisely these parameters (empirical, semi-empirical, numerical optimization), but are not of our immediate concern for the purpose of this paper.

3 EXPERIMENTAL INVESTIGATION OF THE SPRAY MORPHOLOGY

In order to explore the physical characteristics of the painting process we performed a preliminary experimental campaign; this comprised two separate tests. The former was to identify the paint density profile (or thickness) shape at different distances of the nozzle from the surface, the latter to determine how the deposition of paint on the canvas varies with time. The paint density profile is crucial to precisely define how the paint will be distributed on the actual surface: it is the main parameter for the algorithm, as will be shown ahead in the paper. The deposition rate is less important, as long as the law is approximable as linear.
The main objective of this campaign was to provide a framework, and to define a procedure to evaluate the main physical properties involved in the system. The experimental accuracy and setup was therefore not aimed to be up to standard, but just to convey a general idea of the process of measurement.

3.1 Paint density profile

This test was done by performing a quick burst with the airbrush at fixed distances from the canvas. This approach is similar to many found in literature [1]. The paint used in the experiment was black acrylic at a 2:5 paint to water ratio. Note that the airbrush nozzle was placed orthogonal to the canvas. The resulting strokes were then digitized with a *Canon PIXMA MP280* scanner; the image was then analyzed to provide a paint density profile.

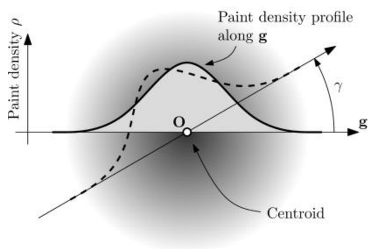
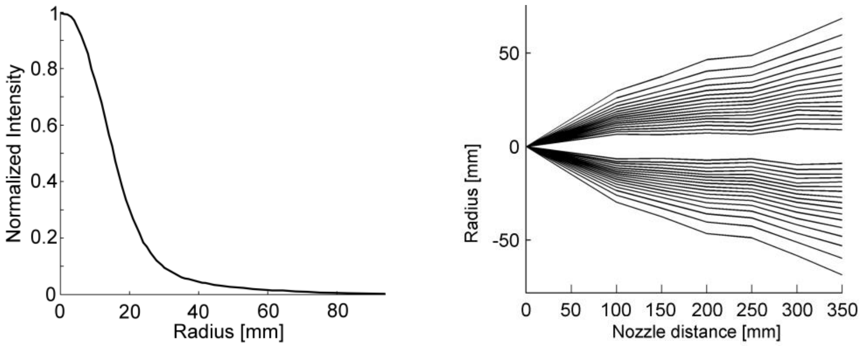


Figure 3: Analysis of the paint density profile ρ of the paint stroke. The centroid O, the axis g (coincident with O) and the angle γ are visible. The paint density profile is also appreciable for two different orientations of $g(\gamma)$

Taking Fig. 3 as a reference, the axis $\boldsymbol{g}$, centered in $\boldsymbol{O}$, is progressively rotated by $\gamma \in [0, \pi]$ and the paint density along $\boldsymbol{g}(\gamma)$ is stored as $\rho(r, \gamma)$, where r is the radius. In the end we can calculate the averaged density profile by averaging the values of $\rho(\gamma)$ for each radius r value. A typical result is given in Fig. 4. The profile can be well approximated with a Gaussian curve. We generally find sufficient to truncate the curve at 2 or 3σ.



a) b)

Figure 4: Experimental results for the paint density profile at various distances. In a) a general density profile is visible: the nozzle-canvas distance was $100\ \mathrm{mm}$. In b) one can appreciate the qualitative paint density distribution along a longitudinal section of the spray-paint jet.

3.2 Paint deposition rate law

If we consider a small fixed region inside the boundaries of the spray-gun stroke and analyze the density of paint deposited over time, we can come up with the law for the paint deposition ratio. This was performed for a series of different points along the generic radius, and for several different distances. This experiment was performed using a video-camera (*Nikon D90*) to record the spraying process on a common paper substrate. In Fig. 5 one can appreciate a typical result of this last experiment. It is apparent how the first part of all the experimental curves is very close to linearity.

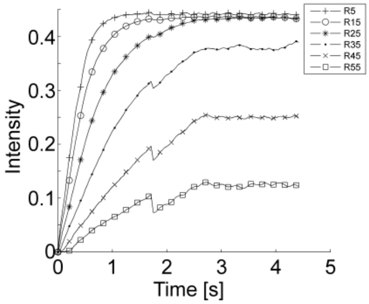


Figure 5: Paint deposition ratio over time. The different lines represent different points along the general radius, from 5 to $55\ \mathrm{mm}$ (starting from the center), as shown in the legend. Note that an intensity of approximately 0.45 is equivalent to saturation due to the video-camera setup. The nozzle-canvas distance was $100\ \mathrm{mm}$. Note the presence of a step in the R25 through R55 lines; this is due to the appearance of spots on the painted surface, which are in turn caused by non-adhesion of the paint to the substrate.

This parameter is important because it determines how two different layers of non-saturated paint interact with each other. If the deposition ratio is linear (or approximable as such) the resulting density of two overlaying strokes of paint will be equal to the sum of their densities in each point.

4 ALGORITHM

The methodology we present in this paper mainly relies on three step algorithm. As mentioned in Section 2, the idea is to work on multiple levels (layers) on the canvas, each determined by a different stroke size (given by the distance), and thus by a different detail size. It is important to stress the concept of *overpainting*: by this term we mean essentially oversaturation, i.e. when the coating of paint is already in its maximum density, and we continue to apply paint; this usually translates in droplets forming on the canvas, which leads to failure. Another kind of overpainting exists: *grey-overpainting*. This is meant in the sense that if we pick a region of the grey-scale target image which has an prescribed black-intensity level of $I_{black} < saturation$, every intensity I that causes $I > I_{black}$ causes grey overpainting: this obviously causes non-realistic output images.
Since the painting process is split into different layers, at each stage we must account for the areas which are already saturated or have reached the prescribed intensity, in order to produce respectively neither overpainting nor grey-overpainting. In order to comply with this, critical points are determined at each step, and are used to limit the paint coating so as not to cause them to suffer overpainting.

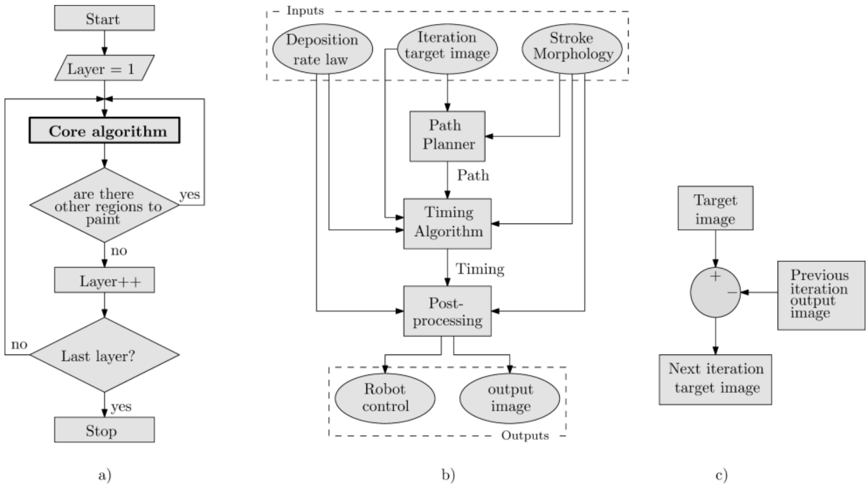


Figure 6: The algorithm used to perform automatic path-planning for a photorealistic painting robot. In a) the general methodology is visible, the Core algorithm block is visible in b), with highlighted inputs and outputs; lastly, in c) the generation of the iteration target image (see b)) is visible.

In Fig. 6 a view of the methodology is presented. In Fig 6a we can see the general layout: we start with the first layer at the maximum distance, we feed the target image to the *core algorithm* and from the output image we investigate if there are any other regions still to be painted at this detail level, and we eventually sub-iterate the process. If no regions are left we can proceed to the next layer (at a closer distance) and repeat everything until the last layer is reached. The *core algorithm* is visible in Fig. 6b; it requires three main inputs: the deposition rate law, the stroke morphology (the size and shape of the stroke) and the *iteration target image*. This image is obviously coincident to the target image in the first sub-iteration of the first layer, but at the following steps it is found following the diagram in Fig. 6c. This concept can be perhaps more clear by examining Fig. 7.

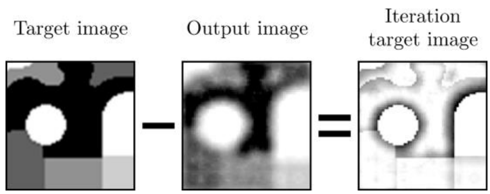


Figure 7: Generation of the iteration target image. During a general step of the algorithm the iteration target image is found by subtracting the output image (resulting from the preceding step) from the target image. Black areas are to be painted.

In Fig. 6b we can see that three operational blocks exist; we will now consider the *Path planner* block. This block is based on an algorithm which uses offsets computation via Voronoi diagrams [12][13]. The boundaries for the calculation are chosen by a simple thresholding technique applied to the *Iteration target image*. The output of this process is a hierarchical collection of offsets, which is ultimately the *tool-path*. The successive block is the most important: the *Timing algorithm*. This calculates the time the spray-gun must “rest” over each point of the image; this easily translates into a *speed profile* along the tool-path. The algorithm relies on the Bresenham algorithm to define the pixels of the image which are crossed by the tool-path. It then follows some heuristical considerations to select specific critical points. The speed values in these points, along with the speed values in the points selected by the Bresenham algorithm, are then considered as variables for an ordinary least squares method (OLS), which provides the solution as a speed profile. A constraint is applied to the computation, in order to limit the maximum speed. The complete process in the elaboration of a generic layer is summarized in Fig. 8.

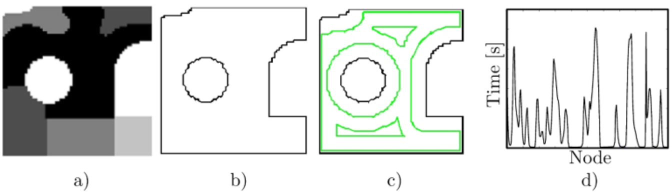


Figure 8: Generation of the tool-path and speed profile for the robotic system. In a) a simple target image is visible, in b) the contours of the paintable area are detected; the computed offsets which form the actual tool-path are presented in c). Finally in d) one can see the speed profile along a partition of the tool-path.

The *post-processing* generates the projected output image at the current layer, following the timing profile along the tool-path. This provides the next iteration image, as is clear from Fig. 6b and c.

5 A PRACTICAL APPLICATION, RESULTS AND DISCUSSION

In this section we propose a practical case based on the famous 1973 "Lena" standard test image. In Fig. 9a we can see the see the actual 800×800 pixels image at a resolution of 1 pixel/mm. For the test we used 3 progressively decreasing distances, which translated into the following stroke diameters and relative layers: layer 1, 81 pixels; layer 2, 27 pixels;

layer 3, 9 pixels. The shape of the stroke profile was approximated as a 2σ-truncated Gaussian curve. The "intensity" of the paint flow was assumed as $0.3\ \mathrm{I/s}$, where $I \in [0,1]$ is the intensity of the image. For the intensity, a global tolerance of $I_{tol} = 1/255$ was used in the algorithm. A speed limit of $1\ \mathrm{m/s}$ was imposed to the *timing algorithm*.

Figure 9: Results summary images. In a) the target image is visible, whereas in b) we can see the resulting image after 3 Layers and 6 total sub-iterations.

In Fig. 10 we show the results of the *path planner* block for each iteration and sub-iteration. It immediately appears that the smaller the size of the stroke gets, the smaller the distance between the offsets, and the higher the number. This translates into quite long computation and execution times.
Furthermore, one can see that the plots in Fig. 10*a*, *c* and *e* are, in general, more packed. This is due to the fact that these are sub-iteration steps, and do not need to carry out much work in order to complete the corresponding layer.

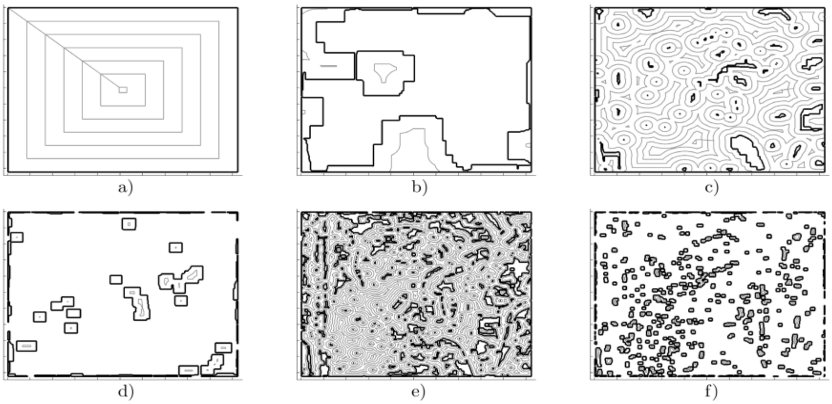


Figure 10: Tool-paths generated via Voronoi diagram computation by the path planner algorithm; the area to be painted is shown with a solid black contour, whereas the tool-paths are in grey. Since the general algorithm performs some sub-iterations, some of the steps presented in this figure belong to the same layer. In fact, a) and b) are relative to Layer 1, c) and d) to Layer 2, and e), f) to Layer 3.

The OLS method (*timing algorithm*) highlighted in Fig. 6 computes the time the nozzle should rest over each point of the generated tool-path. This easily translates into a speed profile, as shown in Fig. 11. Note that the speed remains always under $1\ \mathrm{m/s}$, as prescribed.

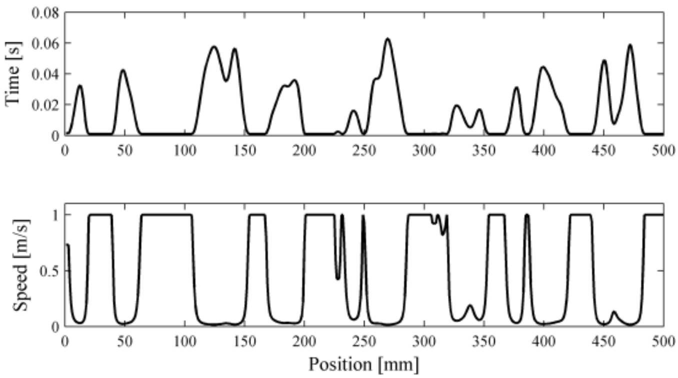


Figure 11: Timing and Speed profile of the tool-path generated by the timing algorithm. This is a partial result from the tool-path in Fig. 10a limited to the first $500\ \mathrm{mm}$.

Finally, in Fig. 12 we present the progressive cumulative result after each of the tool-paths shown in the corresponding letter in Fig. 10 was fed into the *post-processing* block, along with the stroke parameters, the tool-path and the speed profile.

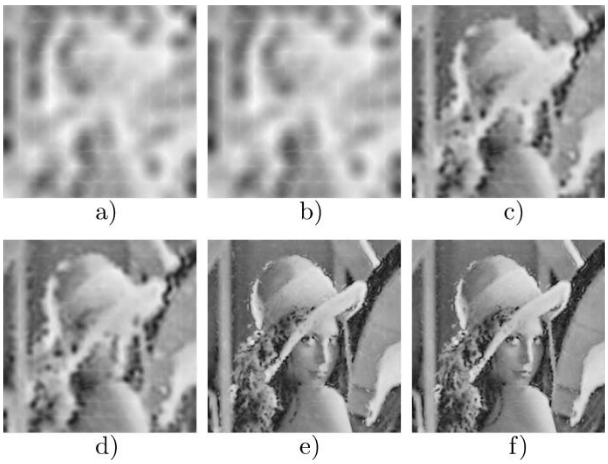


Figure 12: Progress of the output image at completion of the various layers. a) and b) are relative to the 1st and 2nd sub-iterations of Layer 1, c) and d) belong to Layer 2 and e),f) to Layer 3.

From the same figure one can immediately appreciate that the difference between the pairs *a*-*b*, *c*-*d* and *e*-*f* is not very significant; this is due to the sparseness of the sub-iterations tool-paths (which *b*, *d* and *f* are indeed). Aside from this, it is clear upon examination of Fig. 12f that the final output image resembles the target image rather well, while sensibly limiting the number of offsets, which are visible in Fig. 10.
The time required for the robot to complete the painting was calculated using the speed-profile and resulted in 2692 s. We computed a gross estimate of the time that a Cartesian printer-like methodology would require to complete the same painting with a similar resolution. The idea is assuming that this Cartesian printer performs as our robot does when at the nearest distance from the canvas (smallest stroke size). The resulting execution time is 15251 s, more than 5 times the one needed by our approach.

CONCLUSION

The proposed methodology provides an efficient means to perform photographically realistic paintings of digital images on large surfaces by means of a robotic system like an industrial spray-painting robot. The method we developed promises to outperform normal printer-based methods where the result does not require a very high degree of detail, both in terms of costs and of execution time.
We outlined a general framework for the characterization of the spray-gun's spray morphology, which consisted in the measurement of the paint density profile shape and the paint deposition ratio. Both these are critical to correctly operate with the algorithm we presented.
All in all, this innovative approach promises several applications in the field of industrial and artistic spray-painting, allowing the complete automation of tasks previously limited to the world of craftsmanship or assisted robotics.
Important steps should be made in the future to further refine the methodology, especially in the field of optimization (tool-path, timing, etc.) and in the actual control of the robotic system (i.e. maximum acceleration control).

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IMPROVEMENT OF PRODUCTS' ENVIRONMENTAL SUSTAINABILITY THROUGH USAGE OF LIFE CYCLE MODELLING

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Abstract
The attention of regulators to environmental sustainability has deeply changed industrial strategies in product development and manufacturing. At the same time, customer awareness towards environmental performances is becoming even more important. In this context, ecodesign has to be considered as the most effective approach to optimize product development activities preserving at the same time companies' bottom line. On these considerations, the research focuses on the integration of product's life-cycle simulation within product development strategies, with the aim of optimizing the life span of a product, tailoring its use phase, including maintenance and refurbishing/reconditioning operations, on the needs of users. In this ambit, a framework of a general nature, which could be used for the assessment and the improvement of maintenance activities from an environmental perspective, was developed and tested through its application to a gardening machine. Results show an improvement in the efficiency of the product in terms of technical and environmental performances, as well as an optimization of end-of-life strategies.

Keywords:
Ecodesign, environmental sustainability, maintenance strategy, life-cycle modelling, life cycle assessment

1 INTRODUCTION

Attention paid to environmental sustainability in recent years has been deeply changing industrial strategies in product development and manufacturing. At the same time, also customer awareness of environmental performances of products is becoming ever more important: green attributes of products are becoming competitive weapons on the market [1-3].
On these considerations, the research work carried out is focused on the integration of product's life-cycle simulation (through the use of the Life

Cycle Modelling method, LCM [4]) within product development strategies, with the aim of optimizing the life span of a product, tailoring the use phase (including maintenance and refurbishing/reconditioning operations) on the needs of users. Such an approach was used to develop a general framework for product development, which was applied to a gardening machine, utilized by both professional and non professional users. Results obtained following such an approach show an improvement of the efficiency of the product both in terms of technical and environmental performances, as well as an optimization of end-of-life strategies.
The paper is structured as follows: in section 2 the general background and research motivations are presented; the research approach is described in section 3, while its application to a real case study is presented in section 4. In the end, discussion and conclusions are provided in section 5.

2 BACKGROUND AND MOTIVATIONS

As underlined by many authors [5-8] the focus on the development of environmentally friendly products has pushed engineers to take into account their "green" attributes and processes in concurrency with other aspects, such as technical and economic requisites. In this context, ecodesign has to be considered as the most effective approach, able to optimize product development activities preserving at the same time companies' bottom line. The recent standard ISO 14006:2011 [9] probably summarizes in the best way this holistic approach, defining ecodesign as the activity aimed at the "integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle". It is clear then the key role played by design and development of a product, intended as a good or a service, or a combination of them: the effectiveness of managing these activities influences all the phases of product's life cycle. As a matter of facts, it is important to take into considerations the behaviour of the product during its whole life cycle: the more detailed such an analysis, the better results can be achieved in improving its environmental sustainability.
In such a context, a large number of tools have been proposed in literature, e.g. in [10-12], and the selection of a proper product development approach can be carried out following international guidelines, as the ISO/TR 14062:2002 technical report [13], which provides a general framework that can be adapted well to the development of most common industrial products. This approach is continuous and flexible, and focuses on the early identification and planning of environmental aspects of a product, promoting the use of tools and techniques for the assessment of different factors which influence the environmental attributes of a product. In this way, also the traditional properties of a product, such as Safety, Ergonomics, Reliability, etc. can be analyzed to provide a product which satisfies the expectations of customers.

Nevertheless, to better understand the manner in which a product will fit the task it is designed for, as well as its environmental burdens before putting it on the market, the characteristics of the use phase of the product have to be identified, considering both the users' needs and maintenance operations, which will be carried out during the product's usage. In fact, the environmental impact of the product is strictly related to its behaviour in this phase: apart from energy consumption when the product functions, other important aspects depend on the choices made for its maintenance and for the length of its life span. In particular, the relationship between maintenance and environmental sustainability of a product has not been sufficiently investigated: in literature, most of research works on these topics are aimed at the assessment of assembling/disassembling processes [14-16], of the opportunity to extend product's life span [14], and at improving equipment and process efficiency [17-18]. A correct design of the product management, instead, can improve the whole product's life cycle, as demonstrated by the so called "6Rs" approach [19].
As schematized in Figure 1, this approach underlines the role that maintenance activities play in each phase of system's life-cycle, including design and development activities.

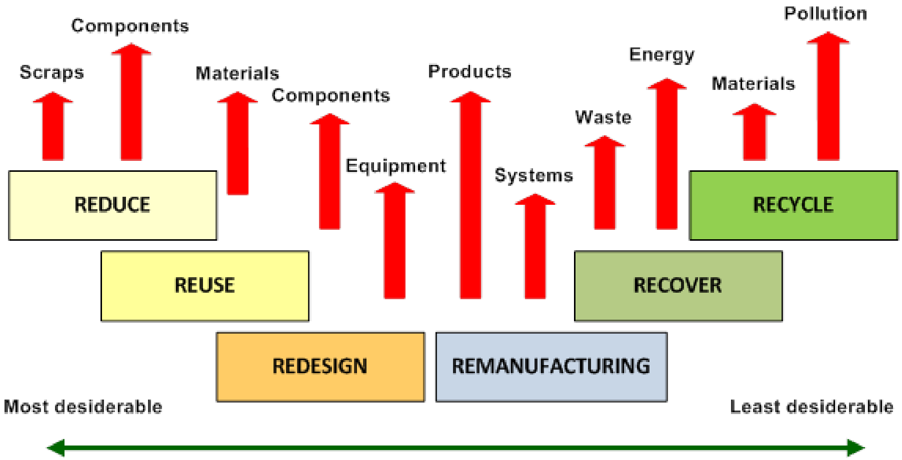

Figure 1: 6Rs approach: influences of maintenance on environmental issues.

As a matter of facts, a proper maintenance can reduce material and energy consumption, as well as waste and pollution by preventing breakdowns and keeping the equipment's efficiency at a high level. Adequate maintenance can also increase the quantity of material which can be recovered or recycled, given that components are replaced before failures. While reuse of old equipment and components is increased by maintenance activities,

the redesign and remanufacturing of new items can be decreased by augmenting assets' life-span [20].
Moreover, it is deemed that the combination of products and services, such as maintenance, play a significant role in the improvement of environmental sustainability. An example is given by the ever increasing attention paid to the industrial Product-service system (PSS) approach [21], realized in an extended value creation network.
PSS puts in evidence the importance of investigating customer life cycle-oriented combinations of products and services. In this ambit, maintenance management issues can allow engineers to better closed loop manufacturing. Nevertheless, modifying the product's or components' life span, e.g. making it longer or shorter, can have both positive and negative effects on the environment, depending on the specific usage of the product. For these reasons, the integration of Life Cycle Design [22] tools into the traditional product design framework is needed in order to augment the performances of the product in its use phase, improving the product's life cycle management issues. In order to investigate this relationship, the research work was focused on the synergic use of Ecodesign tools together with maintenance management issues.

3 RESEARCH APPROACH

Research work was based on the analysis of real case studies such as the analysis of a cogeneration system [20], and in the sector of agricultural machinery. After a preliminary study carried out on grass trimmers [23], a more detailed analysis was performed taking into account the development of a wheeled push petrol lawn-mower for gardening activities. In particular, its use by both professional and non professional users was investigated, focusing the attention on the different requisites needed in these two contexts during the use phase, and how this can influence the other phases of the product life cycle from the environmental point of view.
With this aim in mind a framework of a general nature, which could be used for the assessment and the improvement of maintenance activities from an environmental perspective, i.e. from what we called "eco-maintenance", the use of ecodesign tools was foreseen in synergy with other methods which do not directly concern environmental performances of a system, but analyze other properties which might affect its environmental sustainability. Some examples can be provided considering system reliability, which affects: life-span of a product; resources used in repairing, cleaning, refurbishing; losses caused by unexpected failures and downtime periods; etc. All these aspects play a significant role in the life cycle of the system in terms of both environmental and financial loads. At the same time, a proper management of the system life-cycle can allow the achievement of beneficial effects on the environment, especially by optimizing those life

cycle phases during which the system is managed by the customer (i.e. use phase, end of life phase).
The proposed approach was based on the study carried out for the analysis of a cogeneration system [20], applying the Eco-Maintenance to the development of the lawn mower for different types of users. In practice, as shown in Figure 2, the scheme provided by the ISO/TR 14062 guidelines was augmented by means of the use of the following design tools:

- Environmental Effects Analysis (EEA).
- Quality and Environment Function Deployment (QEFD).
- Life Cycle Assessment (LCA).
- Ecodesign PILOT.
- Screening Life Cycle Modelling (SLCM).
- Quality Function Deployment for Environment (QFDE).

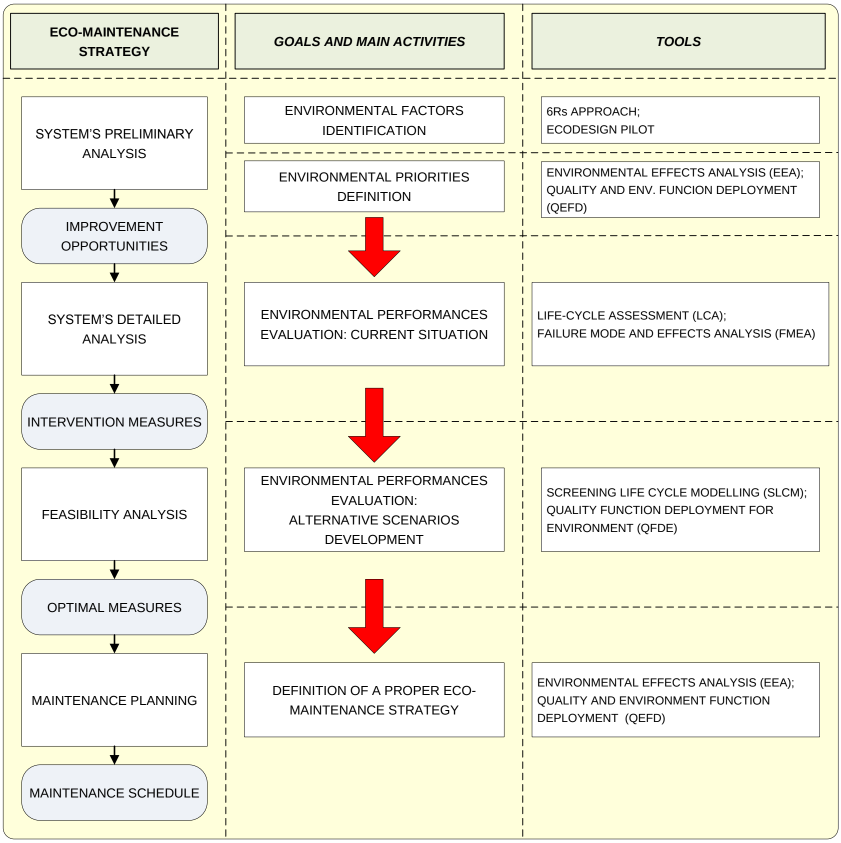

Figure 2: General framework of proposed methodology.

4 CASE STUDY

The proposed methodology is described more in details in the case study, carried out in collaboration with both a lawn mower manufacturer and the national association of retailers of agricultural and gardening machinery (UNACMA), which provided us information about the users of this type of product and data concerning maintenance interventions and services.
The main characteristics of the lawn mower analyzed are summarized in Table 1.

Table 1: Main features of the lawn mower analyzed.

Engine	
Size	190 cm^3
Power	2,4 kW
Fuel capacity	1 l
Engine oil capacity	0,5 l
Drive system	
Traction system	Self-Propelled, mono shift transmission
Driving wheels	rear-wheel drive
Maximum speed	4 km/h
Cutting system	
Deck material	Aluminium
Cutting type	Trio Clip
Cutting width	53 cm
Mowing height range	30 - 87 mm
Mowing height adjustments	6 adjustable positions
Other specifications	
Deck levelling gauge	Central
Grass clippings collection	Grass bag + mulch plug
Grass bag capacity	60 l
Handling	Handle bar +flywheel brake lever
Bearings	Double ball bearings
Wheels, front/forward	190 mm/210 mm
Dry weight	43,5 kg
Life span	
Life span for non professional use	12 years

4.1 Preliminary analysis

The first step of the methodology consisted in the definition of environmental factors and priorities related to the product’s life cycle, both analyzing the users’ needs by means of the use of the Quality and Environment Function Deployment (QEFD) method [24-25], as well as environmental concerns emerged trough the application of the Ecodesign PILOT method [26]. Both these analyses were performed by using a selected focus group, in which technicians, users and retailers were involved in.

4.2 Detailed analysis

Results obtained by the preliminary analysis allowed us to define the life cycle scenario of the product, including the occurrence of most common failures, and repairing operations.

The following step consisted in a more detailed assessment of the product’s environmental performances by means of the application of the LCA analysis [27] (using the Eco-indicator 99 method [28]. In Figure 3 LCA results are shown.

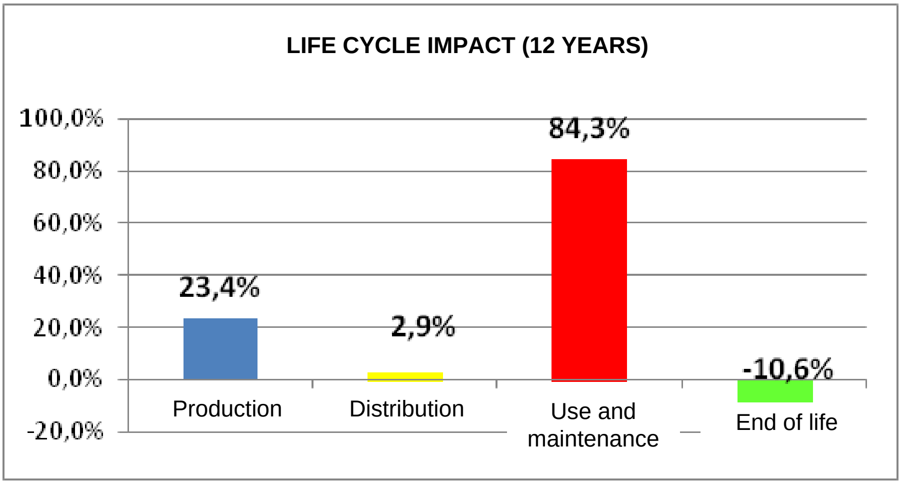

Figure 3: Results of life cycle assessment.

The most critical phase is the usage phase, taking into account the fact that the average users estimated by the company is the non professional one.

4.3 Feasibility analysis

In order to define optimal improvement measures, the Life Cycle Design approach was applied to the use stage, taking into account all different maintenance operations needed along with the life span of the mower.
In accordance with the SLCM procedure [4], a base scenario reflecting this situation was developed, comparing it with the use of the same mower by a professional user. In this case two different scenarios were developed:

- The mower is used by the professional user for 5 years, then disposed and replaced by a new product.
- The mower is used by the professional user for 5 years, then the engine is replaced and the product is used for other 5 years before disposal (in this case the engine is oversized by 20%).

Main characteristics of these all three scenarios are summarized in Table 2.

Table 2: Maintenance interventions' intervals for each scenario.

	Duration	**Working hours per year**	**Engine duration**	**Engine replacement**	**Additional Maintenance operations**
H - Base scenario (non professional)	10 years	50	10 years	-	--
S.1 - Scenario 1 (professional)	5 years	1000 (5h x 200 days)	5 years	-	--
S. 2 - Scenario 2 (professional)	10 years	1000 (5h x 200 days)	5 years	1	+25%

Modeling analysis brought to light that, in accordance to results provided by LCA, Scenario 2 is the most environmentally friendly, without sensibly reducing system efficiency. At the same time, considering the comparison of environmental burdens in the case of non professional and professional users, it has to be noted the use phase influences less the overall impact of the product. While, in scenario 2 the disposal stage (assuming that the product is properly dismissed) the percentage of recycled materials/reused parts can be higher.
From maintenance operations point of view, the increase of interventions in the case of scenario 2 is compensated by the higher efficiency in fuel consumption, and in the higher performances in the disposal stage.
In Figure 4 the comparison of the behavior of the two scenarios is shown.

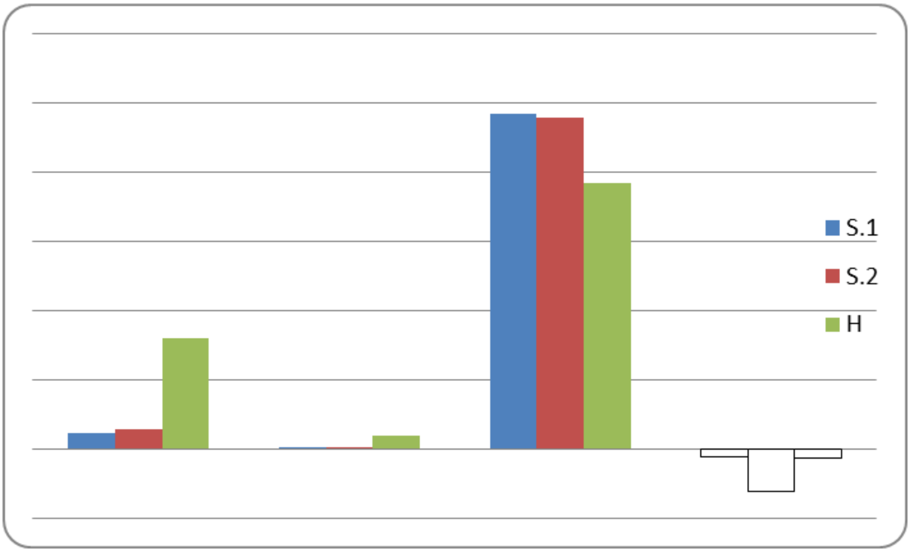

Figure 4: Results of life cycle modelling.

5 CONCLUSIONS

The study was based on the definition of a proper methodology (i.e. the coordinated combination of different product design and management tools) aimed at the improvement of environmental sustainability of a product-system focusing on its maintenance. Effectiveness and applicability of this methodology (Figure 2) were tested through an industrial case study. Results from the analysis shows that maintenance activities sensibly influence (positively or negatively in case of excessive maintenance) environmental sustainability of a system during its whole life cycle. By adopting proposed methodology, weak points of the maintenance plan were identified (by means of the product-system life cycle analysis) and proper corrective measures were suggested thanks to the simulation analysis. Even though a further research work has been already planned in order to perform both a life cycle costing analysis (LCCA) method, results obtained using the eco-maintenance framework were considered reliable by the company, which has modified maintenance schedule according to the optimized model.

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APPLICATION OF ABC METHOD AND VSM ANALYSIS AT A FURNITURE COMPANY

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Abstract
The article describes a model to assess the product cost through the definition of direct and indirect costs. Indirect costs were determined according to the Activity Based Costing approach and compared with those obtained by the traditional method of Direct Costing, applied directly to the corporate budget items. Subsequently, the value created by production processes was analysed by means of the Value Stream Mapping: some solutions to production improvement and increase of profitability are finally presented.

Keywords:
Activity-Based Costing (ABC), Value Stream Mapping (VSM), Furniture Manufacturing

1 INTRODUCTION

The introduction of new production methods and technologies is associated to the rise in indirect production costs and a corresponding fall in the costs of direct labour. The man-hours devoted to supporting activities, such as supervision and maintenance, have surpassed those employed for direct transformation of the product, and the increasing complexity of the manufacturing process have required the increase of indirect activities [1].
In the traditional accounting (direct costing, cost centres) the basis for the allocation of costs to products is related to the volume of output produced in a given period of time. Yet, taking into consideration the above mentioned aspects, the indirect costs are not related to production volumes, but to the number of transactions needed for the realization of the product: therefore, the determination of product costs using volumetric bases of imputation can lead to distortions in the results. Consequently, a typical phenomenon is the cross-subsidization between products, namely the underestimation of the unit cost of products with low volume but high complexity, with greater allocation of indirect costs on standardized products characterized by high volumes [2].
In fact, overhead costs are mainly caused by the volume of activity due to complex products with low volume. Accordingly, the Activity Based Costing (ABC) determines the cost of a product through the assessment of the cost of indirect activities that generated it [3]. The activities provide the services

for the realization of products and consume the inputs. In sum, the unit cost of the product is the sum of the costs of performing the activities demanded by the product and the cost of direct materials and labour as reported in its work sheet. The calculation of the cost of activities and the measurement of the output obtained allows the calculation of the cost per unit of activity, which is a specialized allocation of indirect costs.
In order to measure the cost of a resource's capacity, the activity cost rate is calculated on the basis of its maximum production capacity (practical capacity), excluding the possible disruption of activities [4]. This coefficient allows to assess the cost of an activity to a product regardless of the actual demanded volume of activity:

$$Activity\ cost\ rate = \frac{cost\ of\ activity\ in\ the\ analysed\ period}{practical\ capacity} \qquad (1)$$

Measuring the actual output, it is possible to quantify the residual unused capacity and its cost. Given the volume of the cost drivers and the practical capacity of the activities, the costs related to the unused available resources and to the resources actually employed to perform an activity, are determined by means of the equation (2):

$$\text{cost of available resources} = \text{cost of used resources} + \text{cost of unused capacity} \qquad (2)$$

Using the activity driver with the practical capacity, the cost of resources required to perform the activity in a specific time is determined [5]. The difference between this value and the cost of the available resources provides the cost of unused capacity.

2 VALUE STREAM MAPPING

The value stream is the set of activities that lead to an output through a coordinated series of transformations that progressively increase its value. An activity is included in the value stream if it has three characteristics:

- it belongs to any of the three families of activity: design, management of information for order fulfilment, realization of the output;
- it changes the characteristics of an input transforming it into an output;
- it is not a waste.

An activity that does not produce an output which can be effectively used by the subsequent activity in the flow, does not increase the value. The activities that correspond to one of the seven forms of waste (stocks, waiting, handling, excess production, defect, over-activity, transport) are defined as non-value-adding activities; some of these activities are acceptable (Muda of type 1) as they cannot be eliminated in the short term due to a company's technical or organizational constraints.
The value stream is made up of two streams:

- the production flow, from the raw material to the customer;

- the design flow, from the idea to product launch.

The flow can be read going upstream in the production cycle, from the finished product/service paid by the customer to the raw material. The technique used to structure and analyse the flow of value is the Value Stream Mapping (VSM). VSM includes several tools which support the design of an ideal future stream (represented on a future state map – FSM) starting from the present stream (current state map – CSM). While the CSM defines the present situation of the flows of material, people and information and represents the starting point of the analysis, the FSM defines the objective to be reached by means of a continuous series of improvements.
The FSM is achieved by defining how an upstream activity can produce only the output which is necessary for the downstream activity, when it is required. The first step is to identify the value for the customer. The activities of the production flow are mapped in the CSM and classified as: value-adding activities, necessary activities and activities that do not create value. FSM design is mainly focused on the value-adding activities, while the other kinds of activity are subjected to simplification and waste removal actions (kaizen) [6]. In summary, the main objectives of such efforts are productivity maximisation, lead time minimisation and stock reduction.

3 THE CASE STUDY

The ABC and the VSM methods were applied at a company which manufactures furniture products. The company's industrial processes are not much flexible to changes in production volumes. The plant covers an area of 26,000 m^2 and it is arranged in two levels. The workforce consists of 56 people: 18 employees and 38 operators. The principal market is Italy (90%) while other customers are based in Germany, France and Russia. The company targets the upper-medium segment of the furniture market with several product lines for indoor furnishings; they offer both standard products and customised solutions. The main raw materials are solid pine-wood and fir.
The company's main production environment is make-to-order (MTO), while make-to-stock (MTS) is reserved for items with high rotation. The production lead time is 4 weeks and the delivery to the client is made at the fifth week after order confirmation. The master production schedule (MPS) is planned on a weekly basis with a time lag of four weeks. The planning of purchase orders is made according to the reorder point method based on historical data. Emission of purchase orders is performed on a monthly schedule.
The change process which was carried out at the company included two stages. Firstly, the costs of some selected products obtained by the direct costing method were compared with those obtained through the ABC method. Subsequently, the VSM analysis was applied to a set of products in order to determine possible improvements to the existing process; in this

respect, the main goal of the company was to reduce the process throughput time.
In order to identify the target products, a Pareto analysis was performed on the results of the sales revenue of the previous year; two collections of products were identified the products of which were divided into the three classes (A, B and C) according to their revenues (Table 1).
In addition to the revenue, a second criterion was used to select the target products: the opportunity to maintain or not an article in the catalogue. The criteria allowed to identify 28 items, including item T1138, a cabinet with two doors which is the first article in the Class A of Pareto chart. For each of these 28 items,a production sheet was set out highlighting the industrial direct costs (see Table 2, which concerns article T1138, as an example).

Table 1: Results of Pareto analysis.

Classes	Number of articles	% on total quantities	Total net amounts	% on total amounts
A	109	13%	€ 1,499,331.00	80%
B	174	20%	€ 282,786-00	15%
C	578	67%	€ 93,675.00	5%
Total	861	100%	€ 1,875,792.00	100%

Table 2: Direct costs of article T1138 from production cycles.

Article number	Finishing of product	TWC [min]	C_{Mdo} [€/h]	C_{Mdo} art. [€/h]	C_m [€]	C_{dT} [€]
T1138	Tinted Brusche	112,0	33,0	61,7	192,6	254,3
T1138	Lacquered brushed	115,7	33,0	63,7	192,6	256,3
T1138	Talc generic	126,8	33,0	69,8	192,6	262,4
T1138	Fieno talc	120,9	33,0	66,6	192,6	259,2
T1138	Creta talc	134,7	33,0	66,6	192,6	259,2

Table 2 shows the total work content (TWC), namely the time assigned to to carry out all the activities to complete the product, which is the sum of the time used by all operators involved in the production cycle. The total direct cost to article C_{dT} is given by:

$$C_{dT} = \left(TWC \cdot C_{Mdo}\right) + C_m = C_{Mdo-art} + C_m \tag{3}$$

where: C_{Mdo} = labour cost per hour, $C_{Mdo\text{-}art}$ = labour cost per article and C_m = cost of raw material.

These data are obtained from the work sheet; the fixed cost is added to the result taking into account the inefficiencies, which are defined by the index of operational efficiency:

$$Index\ of\ \ operational\ efficiency = \frac{Turnover}{Total\ activity} \tag{4}$$

The analysed company has a turnover of € 5,636,222.00 and total assets of € 7,608,420.00: the value of the index is then 0.741, this defines the efficiency of the use of resources in relation to sales. To determine the fixed costs two methods were used and compared:

a) the traditional method for calculating indirect costs of product;
b) the Activity Based Costing method.

In the first case, the income statement was reclassified to the contribution margin. The values of the incidence of direct and indirect costs on the total cost incurred during the year under review were obtained:

1. percentage of total costs to sales revenues: 111.42% and 11.42% of the loss for the year before taxes;
2. percentage of the direct costs to the total cost incurred during the year: 63.12%;
3. percentage of indirect costs to the total costs incurred during the year: 36.88%.

Using the third value, the final results of the production cost are obtained. Table 3 shows the result for the article T1138.

Table 3: Total cost of the article T1138 with the traditional method.

Code of article	C_{Mdo} [€]	C_m [€]	C_{dir} [€]	i_e	C_{indCL} [%]	C_{totCL}[€]
T1138	61,70	192,60	254,30	0,741	36,88	437,05

The total cost with the traditional method C_{totCL} is given by:

$$C_{totCL} = \frac{\left(\dfrac{C_{Mdo-art}}{i_e} + C_m\right)}{\left(1 - C_{indCL}\right)} \tag{5}$$

where: $C_{Mdo\text{-}art}$ = labour cost per article, C_m = cost of raw material, i_e = efficiency index and C_{indCL} = indirect cost with the traditional method.

The same calculations were used for to all selected items. The final results are shown in Table 4 (the table shows 10 of the 28 items), where the following parameters are reported: the direct cost (C_{dir}), the production costs (C_{prodCL}, $C_{prodABC}$), the two percentage markups of 50% (M. 1) and 5% (M. 2) and the resulting costs (C_{calCL}, C_{calABC}) with either method compared to the list price (C_{list}); the percentage differences between resulting costs and list price are also reported (Δ_{CL}%, Δ_{ABC}%).

Table 4: Comparison of results with the two methods.

Articles	C_{dir} [€]	C_{prodCL} [€]	$C_{prodABC}$ [€]	M. 1 [%]	M. 2 [%]	C_{calCL} [€]	C_{calABC} [€]	C_{list} [€]	Δ_{CL}%	Δ_{ABC}%
T0058	136	238,99	248,20	50	5	503,14	522,52	438,78	-15%	-19%
T1138	254	437,09	411,83	50	5	920,19	867,02	989,83	7%	12%
T0602	82	144,85	196,90	50	5	304,95	414,53	288,40	-6%	-44%
E0121	80	136,70	188,57	50	5	287,79	397,00	364,62	21%	-9%
E0148	33	58,47	121,03	50	5	123,09	254,79	172,01	28%	-48%
E0467	105	166,35	242,58	50	5	350,21	510,69	570,62	39%	11%
T0814	108	171,10	217,20	50	5	360,22	457,26	649,93	45%	30%
R0210	223	386,09	357,66	50	5	812,81	752,96	768,38	-6%	2%
T1150	346	596,94	554,13	50	5	1256,71	1166,58	1205,10	-4%	3%
T0696	173	301,61	323,99	50	5	634,97	682,09	616,97	-3%	-11%

In order to apply the ABC method, the indirect (overhead) cost items are identified from the balance sheet and the supporting activities in the whole production process are determined. Overhead costs are allocated among activities by means of resource cost drivers so as to obtain their cost. The last step of the method is the definition of the activity cost drivers for the allocation of the costs of the activities among products [7] [8]. The activity cost drivers express the quantity of activity demanded by products: they measure the frequency, duration or intensity of use of an activity by a particular product. They are linked to the analysed object making the allocation of the activity cost proportional to the actual “consumption” of the activity by the product. This allows to allocate costs more accurately than by the traditional methods, which allocate indirect costs proportionally to the direct costs of a product. In conclusion, the part of overhead which is allocated to a product consists of the sum of the costs of every activity which is used by the product. Table 5 shows a sample of the overhead items and Table 6 presents some of the considered activities.

Table 5: Example of overhead cost items.

COST ITEM	COST [€]	DESCRIPTION RESOURCE COST DRIVER
Electric energy	114.637	Cost per department
Heating	42.212	Cost per volume of department
Depreciation machinery and equipment	189.764	Cost per department
Transport	201.510	Percentage estimate per activity
Commercial	338.189	Percentage estimate per activity
Staff	582.724	Cost per person-hour
Legal fees/insurance/banks and current accounts	162.566	Percentage estimate per activity
Depreciation software/office machines	40.228	Cost per hour of use of activity
Administrative services	23.977	Percentage estimate per activity
Advice	85.313	Cost per hour of use of activity
Depreciation R&D	290.048	Percentage estimate per activity
Manufacturing overhead	411.013	Percentage estimate per activity
Lease	236.124	Cost per area of department surface

Table 6: Example of activities.

ACTIVITY	COST [€]	DESCRIPTION ACTIVITY COST DRIVER
Order management in centres of work	45.172	Cost per number of components of the finished product
Emission DDT / Invoice	27.946	Cost per number of lines of code components
Handling	330.826	Cost per average time detected
Procurement	141.770	Cost per number of purchase items
Setup	51.425	Cost per execution time
Shipping	340.450	Cost per volume of finished products

The cost of production with the ABC method ($C_{prodABC}$) is given by:

$$C_{prodABC} = \frac{C_{Mdo-art}}{i_e} + C_m + C_{indABC} \tag{6}$$

where: $C_{Mdo\text{-}art}$ = cost of the labour for the article, C_m = cost of raw material, i_e = efficiency index, C_{indABC} = indirect cost with ABC method.

Table 7 shows the result for article T1138. The list costs calculated using the ABC method (C_{calABC}) and the percentage difference between these and the costs included in the price list (Δ_{ABC}%) were computed.

Table 7: Production cost of item T1138 with ABC method.

Article code	$C_{Mdo\text{-}art}$ [€]	C_m [€]	C_{dir} [€]	i_e	C_{indABC} [€]	$C_{prodABC}$ [€]
T1138	61,70	192,60	254,30	0,741	135,97	411,83

It is worth noting that overhead allocation, in the traditional costing method, is based on a fixed percentage of the product direct cost. This means that products with similar direct costs absorb comparable quantities of overhead without taking into account possible differences in the production processes. For example, article E0467 (a kitchen base) and T0814 (a table) have similar direct costs but different production processes: this is made apparent by the resulting costs obtained by the ABC. By focusing on every activity and the respective quantity used by a product, this method makes a specialized imputation of overhead possible.
The traditional costing method is simple and quick to apply. Conversely, the ABC method needs time to collect the data required by the analysis, in particular to obtain the cost drivers which better represent the distribution of the activities among products. Nonetheless, the calculation of the amount of a driver used by the activities using the practical capacity, allows to determine the value of the used in respect of the available resources, and, therefore, the cost of unused capacity. A critical analysis of the whole order processing cycle, which was investigated by means of the VSM, is then possible; indeed, the ABC gives the opportunity to analyse the validity and efficiency of each activity performed in the company.
The method of the VSM was applied to the production cycle of item T1138. The realization of the VSM was developed through the analysis of the information and material flows in the company and by measuring the cycle, waiting and handling times. The cycle time (T/C) and the flow rates ($IF_{element}$) calculated for the CSM (Figure 1) are shown in Table 8. The goal is to reach a value of the overall cycle time as close as possible to the takt time, which represents the average time between two consecutive units of product as required by demand assuming a one-piece-flow production:

$$takt\ time = \frac{available\ time\ per\ shift}{quantity\ requested\ by\ customer} \qquad (7)$$

From the analysis of the flow of materials in the production cycle, it was decided the repositioning of two machines of the paint shop to reduce the space and time needed to handle the components. These changes allowed a saving of 126 m and of 4.2 minutes in the production cycle of cabinet T1138. Table 9 shows the differences of path length and time obtained from the implementation of the changes foreseen in the FSM (Figure 2). Nonetheless, the FSM is not seen as a finished result, but as a work in progress.

Table 8: Values obtained from the analysis of the flow of article T1138.

		CSM			FSM		
Article	Element	T/C [min]	LT att. [min]	$IF_{element}$	T/C [min]	LT att. [min]	$IF_{element}$
T1138	Side	538,7992	9600	17,82	538,1232	7200	13,3798
	Top	29,8418	9600	321,70	29,8418	7200	241,2723
	Bottom	29,8418	9600	321,70	29,8418	7200	241,2723
	Shelf	30,5048	9600	314,70	30,5048	7200	236,0284
	Back	17,0368	9600	563,49	8,7768	7200	820,3445
	Base	775,2364	9600	12,38	774,7964	7200	9,2928
	Door	1040,1526	9600	9,23	1040,1526	7200	6,9221

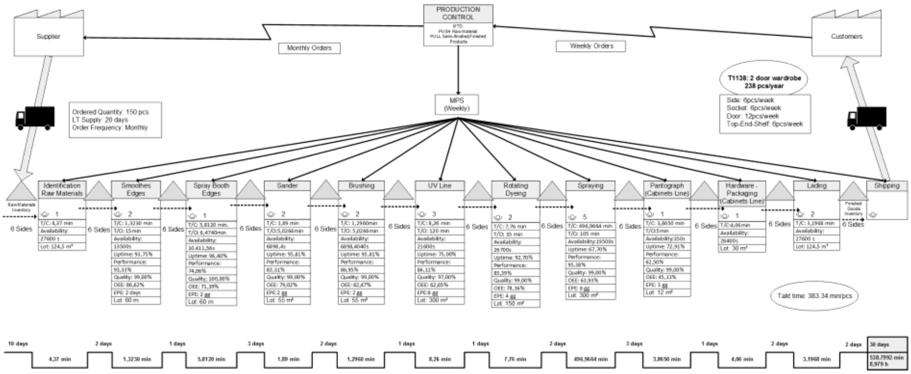

Figure 1: CSM side cabinet T1138

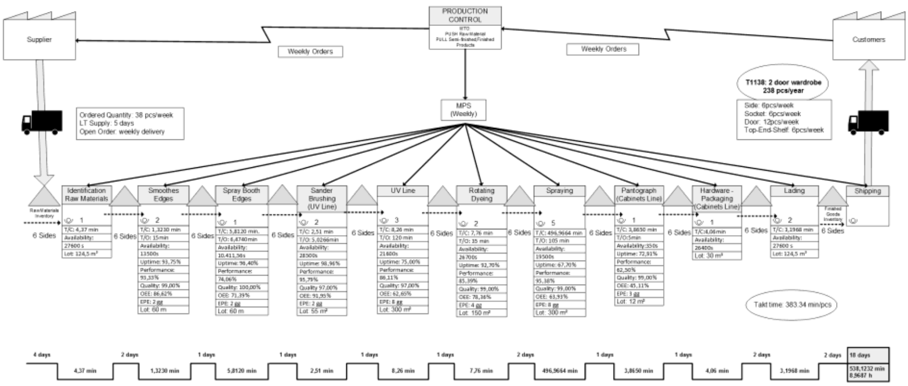

Figure 2: FSM side cabinet T1138

Table 9: Differences between CSM and FSM in the flow diagram for T1138.

Element	CSM		FSM			
	Distance [m]	Travel time [min]	Distance [m]	Travel time [min]	Δ [m]	Δ [min]
Side	647	21,6	521	17,4	126	4,2
Doors	572	19,1	556	18,5	16	0,5
Bottom/Top/Shelf	497	16,6	479	16,0	18	0,6
Back	464	15,5	87	2,9	377	12,6
Base	869	29,0	853	28,4	16	0,5

The pre-existing mobile roller conveyors were substituted by forklifts for handling semi-finished items (SL) in the vertical position and this made it possible to eliminate several sorting operations that were needed with the rollers, which resulted in a saving of 597 man-hour per year.
Material Requirement Planning (MRP) was introduced to plan raw material stocks with weekly instead of monthly: this allowed to reduce the single order quantity. As for the sides of the cabinet the average days of inventory changed from 10 to 4 days. The changes foreseen in the FSM result in a production lead time reduction of 5 days for T1138 product (from 20 to 15 days) with respect to the CSM. The average throughput time is reduced from 30 days to 18 days.
A performance parameter of interest is the flow rate (IF), defined as [12]:

$$IF = \frac{\left(t_{op} + t_{cont} + t_{tras} + t_{att} + t_{imm}\right)}{t_{op}} \tag{10}$$

where: t_{op} time of operational activity, t_{cont} = time of control activities, t_{tras} = time of transport activity, t_{att} = waiting time and t_{imm} = time of storage activities.
In the present case, the overall flow rate was reduced because of the throughput time reduction from 9,600 min (20 days) to 7,200 min (15 days). Only for the cabinet back component the IF did not improve as it was decided to purchase it. It is worth noting that such item has a high IF because it is subjected to several non-value-adding activities (such as picking, transportation, waiting and handling in the paint shop and in the packing line).

4 CONCLUSION

The ABC analysis shows the presence of 15 items which are sold at a fraction of the cost of production, instead of the 7 identified by the traditional method, out of the 28 analysed articles. This indicates the increased accuracy of the activity-based costing method in the allocation of indirect costs to the products.

The VSM proved to be a valuable tool for the analysis of the activities performed in production from raw material to finished products: it was capable to spot the areas of improvement according to the lean principles. The FSM should be applied iteratively, in a continuous improvement logic, with the ideal goal of a production flow only consisting of value-adding activities. In the specific case, the FSM implementation was limited by the financial resources available for investment in new equipment.

What is not in dispute, though, is that these analyses require the collaboration of all the people involved at all levels of the organization, a fast growing awareness of the need for change and the commitment to the change process.

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STRATEGIC MANAGEMENT AT HORA GMBH & CO. KG

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Abstract
Small and medium-sized enterprises (SME) perform strategic management only rarely. One reason for this, amongst others, is the lack of targeted scientific and empirical evidence models and processes, which the executive board and managers of SMEs can apply and implement.
This paper presents a strategic management phase model and tools, which have been implemented in Holter Regelarmaturen (HORA), an SME that has been able to proactively and successfully establish itself in a turbulent market.
In the summary it will be shown that this model is transferable to other SMEs.

Keywords
Strategic Management, Phase Model, Balanced Scorecard, Methods and Tools for Corporate Management

1 STRATEGIC MANAGEMENT NECESSITY IN SMEs

Studies show that strategic management is mainly used in large corporations [1], [2]. In SMEs systematic, long-term corporate development is often neglected [3], [4]. SMEs are, therefore, not maximizing their potential for success [4].
This ascertainment is alarming in that, in Europe, 90% of all corporations can be categorized as SME and these employ one third of all employees [5]. Moreover, the OECD regards SMEs as an important source of innovation and technical progress, most importantly of all the economic prosperity and technical competitiveness of European economies are secured by it [1], [6].
The necessity of strategic management is increasingly important because SMEs in particular are subject to grave challenges, such as internationalization, skills shortages, increase in complexity, keener competition coupled with pressure to innovate and rationalize.
In this paper, strategic management is defined as a comprehensive management concept with which the corporation can be prepared for the

future and with which the long-term success of the corporation can be secured through an analysis of the current situation and anticipation of possible future developments [7]. Future-proof, preventative corporate decisions can be made on this basis. A phase model, with the relevant tools will be described in more detail later.

The question is, why such a systematic approach to future-proofing is rarely applied in SMEs, although empirical studies prove that strategic planning has a positive impact on SME corporate success [4]. A study by Clausthal University of Technology and Haufe Academy (228 respondents) shows that corporate strategy is viewed by medium sized businesses as being highly relevant to corporate success, but often exists only in the minds of the management [2]. The results of this and other research can be summarized to identify the constraints illustrated in figure 1, which may differ from SME to SME.

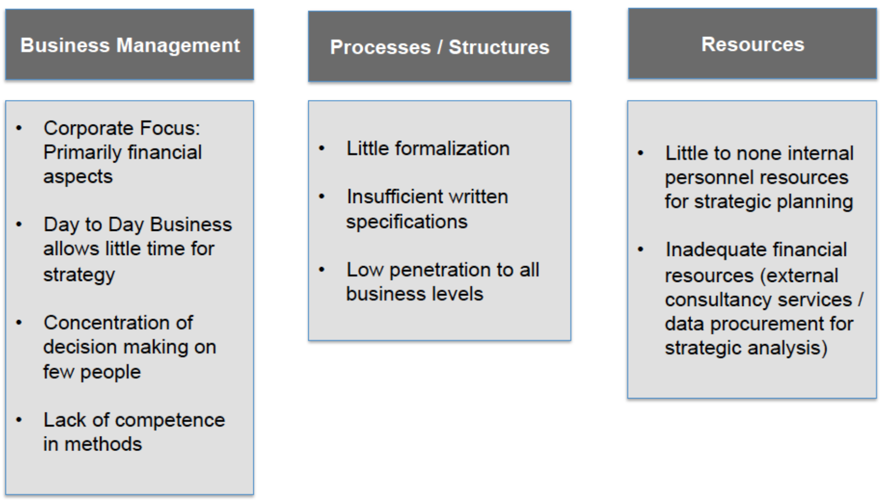

Figure 1: Strategic Planning Characteristics in SMEs taking [2], [4] into account

As an example the column “Business Management” in figure 1 is explained shortly. Mostly, strategic planning in SMEs is concentrated on the entrepreneur, with financial perspectives being a high priority. Managers are also fully occupied with day-to-day business and hardly have time for further activities. To further complicate matters, strategic decisions are usually made by only very few executives. Even if basic strategy tools, such as product lifecycle analysis or value chain analysis are known, they are often unused [2], [4].

If one examines the relevant strategic management literature, it is noticeable that, whilst there is a great amount of textbooks; practice based

SME oriented publications are very rare. This may also be a reason why the incidence of strategic corporate management is so low in SMEs.

On the basis of this general situation, in the following the initial situation at SME Holter Regelarmaturen (HORA) is described, fifteen years ago. A phase model formed the basis of this SME oriented, incrementally implemented strategic management. SME oriented meaning that essential tools were selected in order to implement them gradually. Examples will be given of how such tools were used at HORA and what has changed through the use of this system. In summary it will be shown how it is possible to transfer this process to other SMEs.

2 INITIAL SITUATION AT HORA GMBH & CO. KG

2.1 HORA Corporation

HORA – Holter Regelarmaturen GmbH & Co. KG is an SME with 300 employees and a turnover of 50 million Euros, which was founded in 1967. It is a family owned enterprise, currently being run by the second generation. HORA develops, produces and sells control valves and actuators exclusively from the Schloss Holte-Stukenbrock (Germany) headquarters. Sales and distribution are supported by a worldwide network of partners, with the export ratio being over 65%.

HORA concentrates on two of the very segmented valve markets. In order to serve the unique requirements of the two market segments *Flow Control* and *Power Technology*, the company is divided into two Business Units:
In the Flow Control (FC) Business Unit, variants of control valves and actuators for building automation are custom-built to order. These control valves can have lead times of a few hours.
The Power Technology (PT) Business Unit designs, develops and manufactures valves as tailor made solutions for fossil-fired power plants and may have lead times of one year.

2.2 Challenges Facing the BU Power Technology (HORA PT)

Since the end of the boom in power technology for the former East Germany in the mid 1990s there has been a new challenge due, in particular, to the internationalization of the power business outside of Europe.
In the last fifteen years, the construction of fossil-fired power stations has increased greatly in “emerging markets”, particularly in China, India and Russia.
Critical control valves are usually imported from Europe or the USA.
The strategic shift of turnover to markets outside of Europe brings new challenges with it, such as a rise in order handling complexity, country specific product solutions and approvals, as well as the prompt and local

availability of after sales capacities. The dependence upon international sales partners is also growing.

In China and India, which have meanwhile become the most important export countries for HORA PT, technical competence is growing locally to such an extent that control valve imports from Europe for low and mid-tech applications are, for cost and delivery timescale reasons, barely competitive.
For domestic business it is essential today, in the middle of Germany's changing energy policy, to find answers to the decline in power production by fossil-fired stations.
Internationalization is, however, a strategic challenge not only in sales, but also in procurement of important raw materials such as steel castings. HORA has also used the past few years for a strategic readjustment to worldwide sourcing.
Alongside these challenges on the customer and procurement side, for the past few years competitor's power technology business structure has also been changing. Important competitors, after many mergers and acquisitions are no longer small, independent units but part of large, internationally operating multi national listed concerns. These concerns often have more than one valve producer in their portfolio in order to effectively use synergies and economy of scale.

This short outline makes clear that the HORA PT business unit, since approximately 2000 has and is still facing enormous challenges, which have increased in intensity. A professional strategic management was and is, therefore indispensible.

3 STRATEGIC MANAGEMENT IMPLEMENTATION APPROACH AT HORA GMBH & CO. KG

3.1 Phase Model

It is often suggested in the pertinent literature, that strategic management should follow a sequence of defined phases [7]. Figure 2 shows the five relevant phases, with the breakdown of the phases to the second detailed level. For reasons of legibility, breakdown into the fourth detail level will be omitted. Figure 3 shows further detail. The authors collected the subdivisions after a comprehensive review of the relevant literature, from consultancy projects in various SMEs and from practical experience. In essence, the detailed levels contain practice-oriented tools, which is described in further detail in [8].

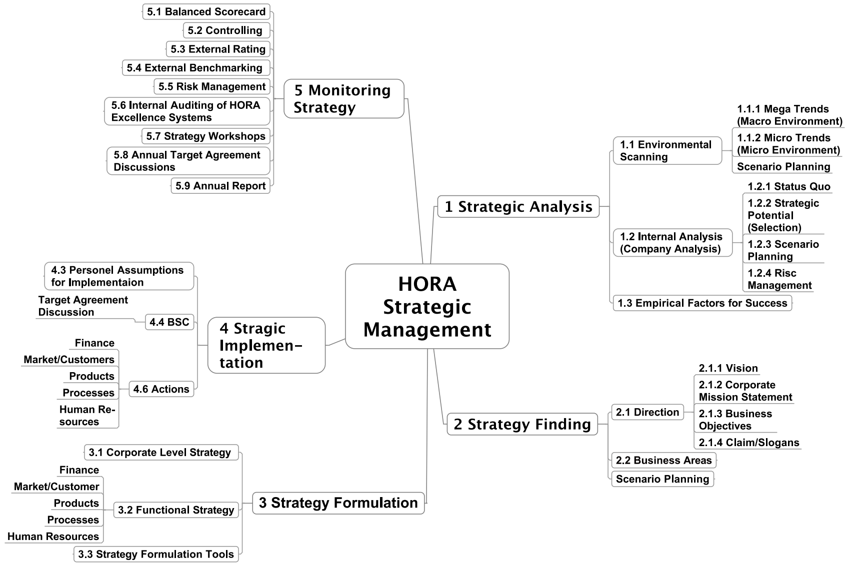

Figure. 2: Strategic Management Phase Model (simplified).

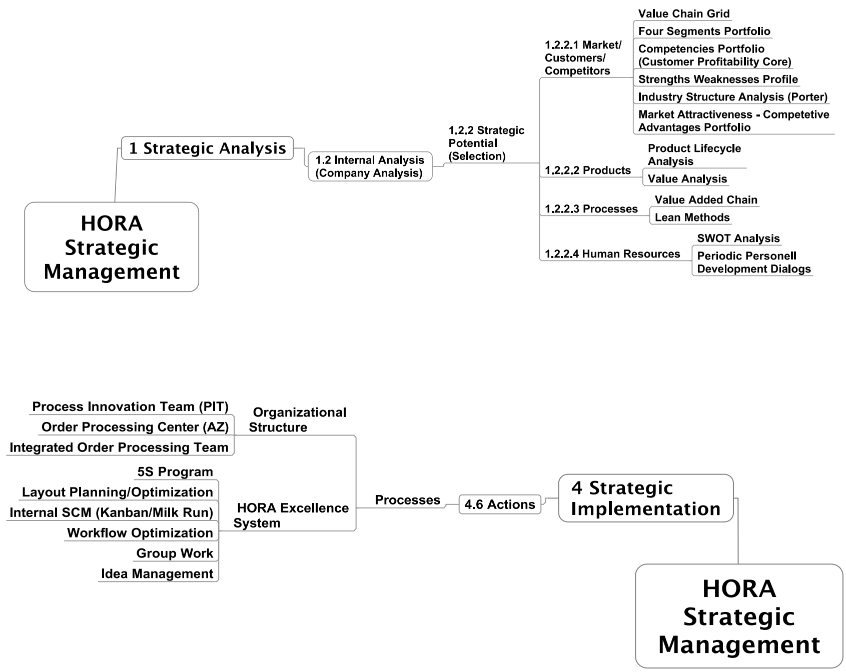

Figure 3: Phase Model (Examples in Detail).

Phases 1-3 contain primarily general tools, phase 4 (figure 3) is much more corporation specific because the strategy implementation has to be tailored to the SMEs particular operational requirements. The single phases will often not take place in the theoretical correct chronology, but with phases being performed in advance or at a later stage. After completion of the process, it may be re-started due, for instance, to a change in market needs, or new competitors having entered the market [9]. Strategic management therefore means a continual cycle of all phases.

3.2 First Steps of the Strategy Process Implementation at HORA PT (2000-2005)

In 2000, before HORA began the strategy process, the company had been experiencing growth, from a manually structured company in the early 1990s, with fewer than 100 employees, to an industrial enterprise. Strategy processes had not previously seemed necessary, but the boom between 1990 and 1995, after the fall of the wall in Germany, led both business units to believe that success was practically inevitable. Strategy processes appeared until then to be unnecessary.

Figure 4 shows the complete strategic management phase model. Due to this paper's printing format, it is not possible for this to be legible, but the point is to demonstrate HORA's strategy implementation status in 2000 and the progress achieved since.

Until 2000, the business was primarily driven by financial considerations (financial figures, budget planning, liquidity planning etc.), it was therefore more reactive (relatively few spots, see figure 4).

As described in paragraph 2.2, for HORA PT the market environment changed significantly for the worse in the mid 1990s. Given this, it was important to introduce the strategy process appropriately and to keep the employees on board. The following steps were begun in 2000:

The analysis of the internal and the external environment (see internal analysis in figure 2) was at first performed with a rudimentary SWOT analysis, the results of which were not only not complex enough, but also only partially complete. However, the results were nevertheless the ideal tool to raise awareness of the coming strategic process.

The company philosophy was formulated into a Vision, Corporate Mission Statement and Claim (see direction 2.1 in figure 2).

Working on and with key figures was introduced across the company, an essential tool for this process was the implementation of Balanced Scorecard (BSC) Concept, which lasted approximately two years [10]. The degree of realization of the committed department and company objectives has since been measured locally, with the use of scorecards updated on a monthly basis. Commercial controlling was improved. A management information system (MIS) provides key figures in the intranet.

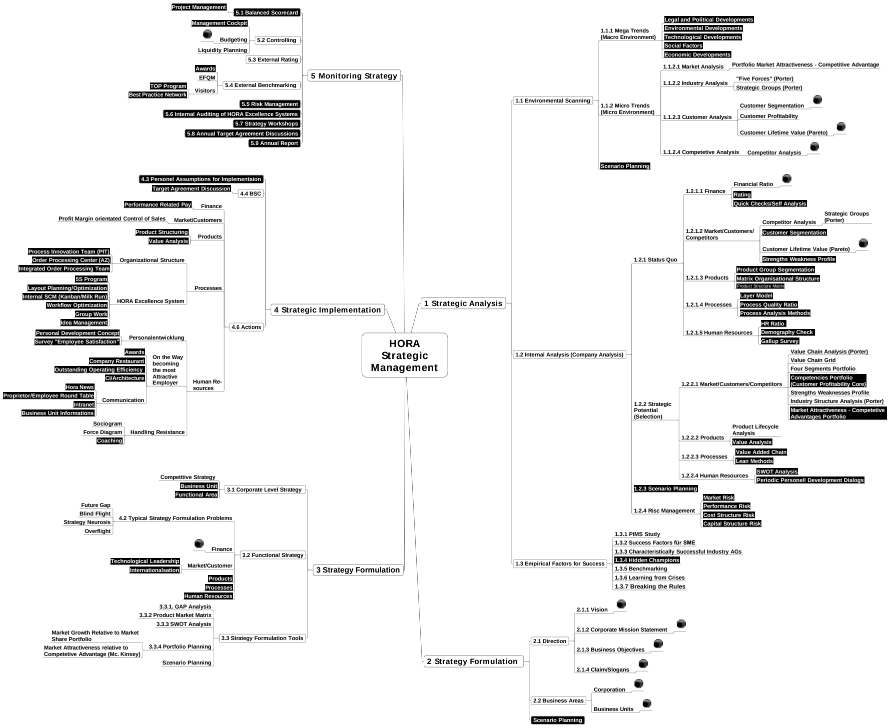

Figure. 4: Phase Model of Strategy Implementation.
Before 2000: Marked with a Spot
Between 2000 and 2013: Marked in Black

With the introduction of theses steps, the company has had the following experience: in the mean time all departments work with agreements, action plans and projects. This system did not previously exist.

It is not easy for every department to develop meaningful, easy to understand scorecards. Management quality quickly becomes clear, with the help of three questions:

- Does the manager set ambitious objectives?
- Is the manager able to define and implement the necessary measures (actions, projects, …)?
- Is every member of a department able to explain the scorecards on the information boards, to for example an external person?

3.3 Strategic Management at HORA PT from 2000-2013

As figure 4 shows, the developed phase model has, over the past nearly fifteen years, covered almost every important sphere of activity. Step by step and tailored to the company, HORA has successively amended every procedure and tool, improving the strategy process and making it more effective.

At the start of the process activities were concentrated on strategy monitoring and implementation, these have since become firmly established, as shown in figure 5.

Perspective	Tool
Finance	• **Risk Management** • **Multi-annual Planning** • **Budgeting** • **Controlling**
Processes	• **HORA Excellence System (div. Lean Tools)** • **Organizational Structure and Business Processes Adjustment (PT Order Processing Center, PT Outer/Inner Sales, Cell Structure for PT Production, Product Management)** • **External and Internal Auditing** • **Benchmarking through Awards** • **Annual Target Agreement Dialogue**
Market and Customers / Products	• **Product Development Planning** • **Product Structuring**
Employees and Management	• **Periodic Communication Procedures and Quarterly Half-Day Target Agreement / Achievement** • **Personnel Development Programs SXP, JXP** • **Knowledge Management** • **Performance Based Compensation**

Figure 5: Established Tools at HORA PT.

In the mean time, due to the acute changes in the market described in paragraph 2.2, the focus has shifted more towards strategic analysis and strategy formulation. For some years now, detailed internal and external analysis has been performed using typical strategic management tools, resulting in new or improved strategies. Integrated into all phases, is the BSC model structure of the five perspectives Finance, Market/Customer, Product, internal Business Processes and Human Resources.

After significant progress in the BSC-perspectives “finance” (value-based management) and “processes” (operational excellence) the HORA Business Unit PT now strengthens the perspective “market, customer and product” too, as shown in figure 6:

- Market/Customer and Product Perspective: Strategic market approach
- With which products, in which markets and with which competitive advantages can HORA be successful in the future?
- Process Perspective: Operational excellence
- How will HORA attain general and industry specific benchmarks in business operations?
- Finance Perspective: Value-based management
- Success will be measured by the short, mid and long-term increase of the corporate value.

Approach	**Strategic market approach**	**Operational excellence**	**Value based management**
Objectives	▪ Country specific products ▪ proactive after sales ▪ growth in emerging markets ▪ (product-) USP ‘s ▪ new key accounts and/or countries ▪ new applications ▪ extension of engineering-competence (calculation incl. tools like product configurator, CFD, FEM, Test Facilities)	▪ State-of-the art production facilities (welding, machining, CAD-CAM) ▪ stability of the order-handling-processes for production and administrative activities ▪ response-time and -quality for inquiries ▪ professional project management ▪ standardising of product structures for tailor-made products (incl. software tools like PDM)	▪ inventories management ▪ cash management ▪ risk management
Typical KPI ‘s	▪ Sales ▪ USP ‘s	▪ leadtime ▪ in-time-delivery ▪ cost coverage ▪ quality cost	▪ Capital Employed ▪ EBIT

Figure 6: Present Strategic Approach at HORA PT.

3.4 Success of Strategic Management at HORA PT

Since HORA PT set out to pursue strategic management methodically and consistently, the Business Unit PT has achieved measurable success, examples of which are:

- HORA PT turnover doubled between 2005 und 2011.
- PT has been successful in evolving from a medium-tech to a high-tech producer of valves for power stations.
- In 2000, this business area achieved less than 10% of the turnover in this field. Today the high-tech share of PT’s turnover is almost 50%.
- The percentage of PT sales to China, India and Russia ((B)RIC) in 2000 were less than 10%, in 2011 these were already over 50%.

- Products in the BU PT were hardly standardized. The “product structure management” project, together with product data management (PDM) and product configurator tools will enable individual, tailor made product solutions to be made from standardized components (along the lines of the platform concept in the automobile industry).
- Internal order processing was unsuitable for punctual delivery of non-standard control valves: The percentage of products delivered on time improved from 30% in 2003, to over 90% today.
- The management team has long since accepted the process-orientation of strategic management. The specific phase model used by HORA is a central theme of the business, providing orientation, quickly highlighting areas needing attention and, most importantly showing gaps. Working with the most important tools has helped enormously in professionalizing company management.

4 SCENARIO PROJECT “THE FUTURE BUSINESS ENVIRONMENT FOR HORA PT SERVICE”

The following summarizes how a very modern tool, Scenario Management^{TM,} has been used at HORA for the second time (see also [11]). The systematic and participatory process has been successfully used in various practical projects since 1998.

The question arose as to whether it made sense to further develop the After-Sales-Service in PT as a strategic business area. Due to the extremely complex environment and the scope of this decision the management board decided to employ an external consultant, in the form of Scenario Management AG (ScMI AG) in Paderborn. During the “Strategic Management” course within the Masters Double Degree “Production Engineering and Management” approximately 25 students with technical training from the University of Trieste and Ostwestfalen-Lippe University of Applied Sciences worked on this topic. Technical experts from ScMI AG moderated and HORA employees provided the input required. Over one semester, the students worked through the scenario development phases shown in figure 7.

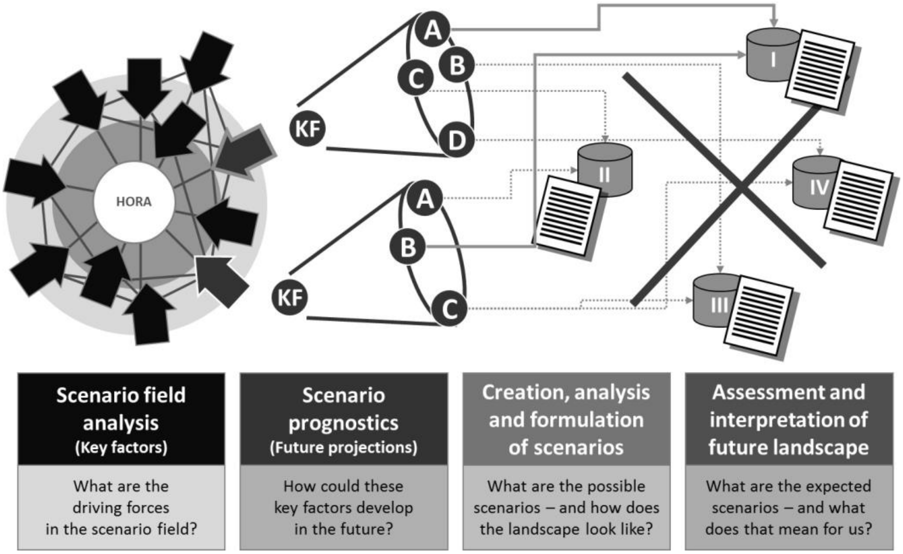

Figure 7: Four Steps of Scenario Development. (ScMI-internalchart)

The result was seven alternatives, but consistent scenarios developed and visualized in a map (figure 8).

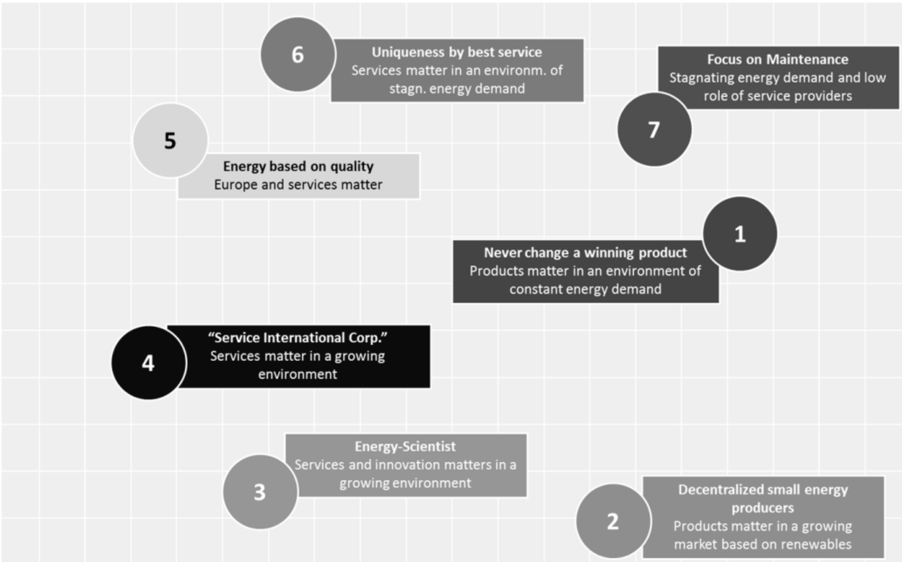

Figure 8: Map of the Future. (ScMI-internal chart)

Discussing the different future visions enabled creation of innovative ideas and the development of various courses of action.
The evaluation of the various scenarios with regard to the desired and expected forecasts stimulated further discussion, the HORA management team preferring the scenarios which were forecast in points three and four of figure 8.
HORA PT derived strategic priorities from these forecasts:
the offer of innovative Retrofit Solutions for optimizing existing plants
as well as growing local services (also in cooperation with partners), particularly in non-European countries.

5 SUMMARY

Starting from the assumption that strategic management is very rarely applied by SMEs, an approach for medium sized businesses, including the practically oriented modification of suitable tools, has been developed and successfully implemented, based on the professional experience of HORA.
This process has proven that the phase model provides management with a comprehensible orientation and that it is possible to begin the process with any phase of the model. HORA began with strategy implementation and monitoring, but if the phase model is illustrated using a mindmap and the implementation status is color coded, it will then be clear which area has not been covered (company specific tools and priorities are essential here). Each phase must be continuously refined as the external and internal corporate environment is in a permanent state of change.
As shown in this paper, adherence to a standard process delivers measurable success and greater strategic development stability.

In the meantime this concept has been taken up and applied by the owner of another medium sized enterprise. Together with his managers, he adapted the HORA mindmap to fit his corporation and management has been working successfully with this model for three years.
This paper shows that there is considerable demand for implementation-oriented analysis of the scientific and empirical knowledge of strategic management, this applies particularly to medium sized businesses.

The authors have applied this to make a contribution and gained the first benefits from it.

Any endeavor to implement a systematic approach, supported by tools such as BSC and provide incentives such as performance-based compensation, to strategic management is dependent in the last instance upon the management team. The process outlined can be implemented only with competent and ambitious managers (figure 9).

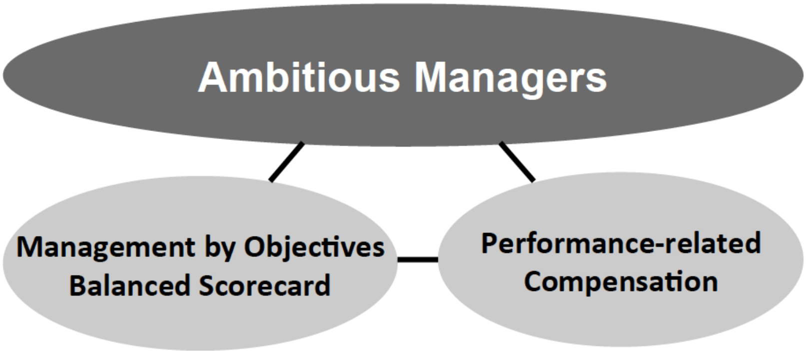

Figure 9: Effectivity of Incentive schemes and Management systems.

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INNOVATION BENCHMARKING: ANALYZING AND OPTIMIZING EFFICIENCY AND EFFECTIVENESS OF R&D

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Abstract
A low focus on innovation output management generally can be observed in many companies. The first reason for this situation is that innovation output measurement has many facets, and many attempts to measure the innovation output have failed due to this complexity. Therefore, the expectations of an innovation output measurement system should, in practice, be based more on the 80/20 rule. The easiest way to make an output measurement system a failure, is to address all potential exceptions. The second reason is that output measurement differs between industries and innovation types, for example, the innovation output measurement approach will vary between the electronics industry, with very short product lifecycles and the chemical industry, where the majority of products are older than 10 years. The output measurement will also be different in the respective innovation types, for example, pure research activities will not directly focus on financial output, whereas new product development activities, which target the selling of a new product, typically consider profitability aspects. Therefore, an output measurement approach needs to be pragmatic and at the same time has to be customized and tailored to a specific situation.
A three-step approach is proposed in this paper, to direct innovation management towards a stronger focus upon output. First of all, companies need to ensure that they have innovation input transparency, the process itself and the output must also be transparent, so that they are able to measure improvements. Then they need to have transparency of any shortcomings and constraints, in order to correctly place the focus of optimization activities. Lastly, in order to define the required improvement actions, they need to have an overview of the relevant difference to best practice.

Keywords:
R&D performance evaluation, output-based innovation, innovation output measurement, return on innovation, gap analysis, best practice, Key Performance Indicator (KPI)

1 INTRODUCTION AND GENERAL DEFINITION

"If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle," Sun Tzu, the great Chinese strategist around 500 BC [1].

One of the old management wisdoms states, further that "you can't manage what you don't measure." The authors would like to apply this to the field of innovation management.

Few business processes are more critical to a company's continued performance than innovation, but because of its broad reach, unpredictable nature and dispersed ownership, many executives struggle to manage innovation as they would other business processes. Failure to develop and implement a practical way of measuring innovation effectiveness and efficiency is often at the heart of the problem. Executives have difficulty in finding practical indicators that clearly measure what is important. Then they find it hard to turn such measurements into actions that effectively fix what is broken. Finally, they stumble when trying to implement innovation measurement as a self-sustaining continuous improvement process.

About 20 years ago, a study by A. H. Schainblatt [2] revealed that only 20 percent of the R&D managers in major companies even measure the productivity of their R&D operations. Of the 20 percent that do measure productivity, only a few measure any kind of return on investment or amortization in R&D.

The overall context of R&D has changed: Lifecycles in many industries have shortened significantly and require 'faster' R&D processes. Many companies have attempted to increase their R&D efficiency for example, by implementing stage-gate processes, by directing the focus of their R&D organizations towards stronger project orientation or by leveraging internal resources with 'open innovation' elements. However, in terms of innovation output measurement, the situation remains largely unchanged. Very few companies have, in order to manage their innovation topics, established a systematic innovation output or effectiveness evaluation process. The impact of efficiency measures on innovation output is, therefore, most often not proven.

According to the management wisdom mentioned above, more than 600 billion $ are invested annually in R&D without being properly managed towards output.

1.1 Innovation and its discrimination in the context of product development

Innovation can be distinguished by different differentiation criteria, as the scope here is to investigate what the innovation refers to. Another aspect is what causes or initiates innovation. The degree of novelty is designed to give information about the ‘newness’ of the innovation. Continue to the degree of change to determine what changes the innovation requires within the enterprise (see [3]). It is always assumed that the focus is laid on product innovation and the processes of product development.

Product innovations are of most eminent importance for companies and are the most common subject of innovation in enterprises. Product innovation aims to secure competitive positions by the launch of new products and to expand the market share.

Product innovations can be divided into the creation of completely new products and the modification of existing products. The alteration of existing products can, on the other hand, be classified according to their influences on their environment: product variation, product differentiation and product standardization.

Process innovations are carried out to secure flexibility and time to reach the market (time to market) and therefore the profitability of the company. They are essential for continuous improvement of processes and the development of new systems.

The term ‘process’ can be defined as the purposeful creation of a performance and a result, whose activities happen in a logically linked sequence, processes are operations of completed contents, which are activated by an event and have a defined input and output. They are sectioned into core processes, support processes, business network and the management processes of a company. The main benefit of innovation activity in the process context is an increase in productivity through new procedures and process quality improvement. This increase in productivity allows for cost savings. The quality of business processes affects both the product quality and time to market.

Social innovations serve the fulfillment of social objectives of the people in a company (e.g. increased job satisfaction, job security, etc.). They will not be further considered here.

To understand R&D, it might be helpful to characterize distinguished types of product innovations:

1. **Research, advanced development and technology development**
   Output of this innovation type is normally know-how and intellectual property rather than new products. The output typically serves as a precondition and an input for new product development (NPD). This innovation type does not directly lead to financial impact, with the exception of selling intellectual property or technologies. Research and technology and advanced development departments therefore need a different steering logic compared to new product development.
2. **New product development (NPD) for new products**
   Output of this innovation type is basically profit generated by new products. The term ‘new product’ needs to be aligned to the product lifecycle of the industry, e. g. a two year old mobile phone is

recognized as really old while a two year old chemical is virtually perceived as brand new.

3. **New product development (NPD) for new applications** Existing products, or minimally altered or adapted ones, are used for new applications and purposes. The output of this innovation type can basically be described as profits from new applications, which might have the same product code.
4. **Facelifts**
Facelifts are normally understood to be smaller changes and alterations to existing products. These changes can include functionality or purely aesthetic design. From the innovation management perspective, facelifts entail the risk of pretending that there are a large proportion of 'young' products in the product portfolio.
5. **Process improvements**
The output of this innovation type can normally be described as lower cost or higher quality. The product code does not necessarily change. A different steering approach is needed compared to new product development.

Another distinction is whether the innovation is characterized as sustaining innovation, as efficiency innovation, or as disruptive innovation [4]. Generally, established companies tend to direct their product development towards established markets and are accustomed to change their products more or less incrementally, or they compose their product from modules and parts of established technologies. This procedure is normally included in the field of sustaining innovation, where existing products are improved to get ahead of the competition. Efficiency innovations are directed towards making products cheaper and more efficient to produce or to market, for instance by modularization. Sustaining and efficiency innovations can be benchmarked comparatively easily. It turns out to be much more difficult to benchmark innovation processes in disruptive innovations which generally match the needs of small new markets which again results in smaller revenues and sometimes need more time to get any return on investment. On the other hand, disruptive innovations, which are also called empowering innovations, are an attribute of most those companies which are recognized as being 'innovative' [4].

1.2 Benchmarking as an analyzing and optimization method

Robert C. Camp, the inventor of the benchmarking method, said "Benchmarking is the continuous seeking process of a company to improve its performance and to gain competitive advantage by focusing on the respective bests… " [5]
The following definition was provided by Mertins and Kohl [6]: "Benchmarking is the search for solutions based on the best methods and procedures of the industry, called Best Practices, and lead a company to

excellence.” By benchmarking a continuous search for and exploitation of success potentials become essential. "Benchmarking supports target-oriented search for new ideas for methods, procedures and processes outside one’s own corporate and organizational world or outside one’s own branch in addition to classic corporate comparison.” [6]

Table 1: General outcomes and benefits of benchmarking

Position reckoning for one’s own company	Often the most important objective is to get an overview of one’s own company compared to other enterprises. Shifts/changes in comparison to other companies can be analyzed and documented by repeated benchmarks.
Identification or confirmation of company’s optimization potentials	Often improvement potentials can be derived directly from the comparison. In addition, by correlation between single performance indicators and success (if the success is measurable) the influence of a performance indicator on the overall performance of the process can be quantified.
Identification of “Best Practice”	Using the described correlations which details are decisively responsible for success is determined.
• Learning from success and failures of other enterprises • Motivation gain by comparability • Recognition of need for action and generation of need for action • Attain certainty of doing the right things right	

According to Sabisch and Tintelnot [7], benchmarking has the following functions:

1. Measurement and scale function

Where the company stands compared with its competitors, other companies and even other industries must be evaluated and the best of their solutions are to be used. In addition, options and potentials are analyzed as to which will be the best solutions to problems in the future.

2. Recognition function

What other companies do better or worse than one’s own and the causes of this should also be identified. What can the company adopt from other companies (proven total solution, partial solutions and methods)? The question also arises how best practice can be used as a basis for generating one’s own problem solving.

3. Objective function

The fundamental questions are: what types of changes are necessary within the company to improve competitive position? What objectives are to be achieved and what market position to be pursued as a strategic factor? Which conditions must be created to make the competition process successful must be highlighted.

4. Implementation function

What measures are necessary to realize the planned changes should be exhibited.

Benchmarking generally shows direct and indirect benefits [6]:

Among the direct benefits of benchmarking are that a company analyzes, the company or organizational unit will be compared, best performances are defined, performance deficits are identified and alternative solutions are appraised (see table 1).

Among the indirect benefits of benchmarking are that an understanding for the company's own business processes is generated, corporate objectives and company strategies are scrutinized, competitiveness is strengthened and a continuous improvement process is initiated.

Because innovation means more than improving individual processes, productive practice groups play a particularly important role in this field. Only with a direct exchange of experience, can a better understanding of processes, product characteristics and innovation potentials be achieved. Purely quantitative comparisons are not easy to accomplish, but possible and certainly useful, however they are not usually sufficient for becoming better in terms of innovation.

2 THE RELEVANCE OF EFFICIENCY AND EFFECTIVENESS IN R&D

Quantitative performance management is established in many business areas. Performance management in general management means the measurement of Earnings before Interest, Taxes, Depreciation, and Amortization (EBITDA) and cash flow measurement. Performance management in sales means to measure sales and CM (Contribution Margin). Performance management in production means to measure Overall Equipment Effectiveness (OEE) or parts per day and performance management in Accounting means the measurement of accounting expenses per revenue.

However, in almost all industries carrying out quantitative performance management of R&D is rare. Few companies have established a process of systematical evaluation of their innovation output or effectiveness in order to manage their innovation topics. The impact of the efficiency measures on innovation output is, therefore, most often not proven.

Anonymous examples of today's situation, for example, how development managers and other managers and executives are encouraged towards innovation, show the entire dilemma. According to “you can't manage what you don't measure“, there is substantial room for improvement in innovation management activities.

3 THREE STEP APPROACH TO INCREASING EFFICIENCY AND EFFECTIVENESS IN R&D

Most of the initiatives to improve the R&D process are structured according to the analysis - conception – implementation pattern.
This approach frequently includes some fundamental weaknesses:

- Countless shortcomings are identified in the analysis. As long as no clear output and target parameters are implemented, no systematic optimization in terms of targets can be made, i.e. the prioritization of weaknesses with regard to effectiveness is usually carried out in a very subjective way. A company implements, for example, an idea data bank, although the execution of projects is the real problem.
- Strong ‘internal’ thinking is involved in the elaboration of concepts. In many cases, proven best practice is not systematically incorporated into the process.
- The evaluation of the success of R&D optimization initiatives is very limited due to the lack of output measurement.

A three step approach is thought to overcome these weaknesses and to ensure successful R&D optimization initiatives:

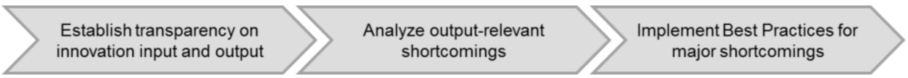

Figure 1: The Three step approach to ensure successful R&D optimization initiatives

3.1 Step 1: Innovation input and output transparency

Innovation input and output transparency is the first step in the described approach. The authors have observed two reasons why many companies have problems in achieving transparency on innovation input and output measuring.
The first reason is that innovation output measurement has many facets, and many attempts to measure the innovation output fail due to this complexity. Therefore, the expectations of an innovation output measurement system should, in practice, be more similar to an 80/20 approach. The easiest way to make an output measurement system a failure is to address all of the potential exceptions.
The second reason is that an output measurement approach will differ between industries and innovation types. The five innovation types have already been described above.

In analogy to strategy development a clear segmentation is a key success factor. As long as they are measured with the same approach, which does not consider the differences, the result will be of limited validity.
This means that input and output for the different innovation types needs to be transparent (see figure 2).

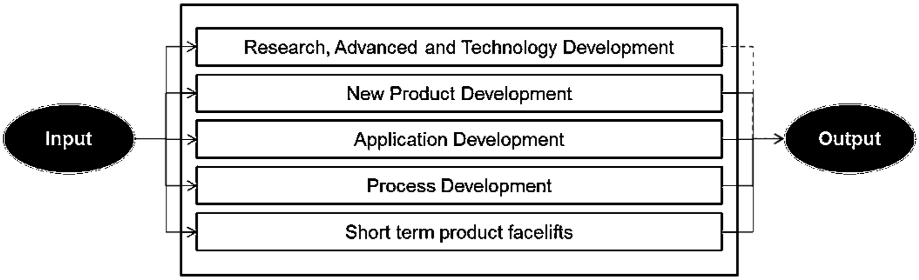

Figure 2: Segmentation of innovation types

Differences also need to be considered from an industry perspective: for instance industries such as automotive, electronics or medical technology can be characterized by frequent model changes which generally lead to smaller proportions of 'old' products. In these industries management pays great attention to new products or at least new models. But the proportion of new products has limited relevance since it highly depends on scheduling of market introduction.
In industries like the chemical industry, in the pharmaceutical or in food and beverage industries one can observe partially very long product lifecycle times. The proportion of new products and models is generally lower, therefore, management attention towards product innovation is, on the whole generally lower. This means that in such industries the proportion of new products is a relevant indicator for innovativeness.
Therefore an input and output measurement approach needs to be pragmatic and at the same time has to be customized and tailored to the specific situation. Input measurement is much easier than output management. However a few things need to be considered:

- Innovation budget contains more than the R&D budget alone. Costs from other functions, e.g. procurement resources supporting project supply, also need to be considered.
- Due to the existence of different innovation types the input needs to be allocated to the above described segments.

To reduce complexity the authors will be focusing only on new products and new applications (NPD) in this paper. For these two innovation types the profit made with new products or new applications is the most important KPI. From a high level perspective it is obvious that new products need to generate profits to cover the development and market introduction efforts and therefore justify an innovation-based business model. In practice some challenges occur in applying this metric.

- The period of time in which a product is considered to be new needs to be aligned with the product lifecycle of the industry. It can be as short as a few months, or several years.
- In order to differentiate between new products and facelifts, customized criteria, depending mainly on the industry, need to be defined to distinguish between these innovation types.
- Strong backward focus - progress within the innovation pipeline is not indicated by measuring profitability.
- Market introduction strategies with the aim of ‘occupying’ a market need to be covered with additional KPIs.
- In order to work with ‘new products’, they need to be ‘flagged’ as new in the ERP system.
- Profitability at a product level needs to be available in the ERP system.
- Disruptive technologies need to fit into an appropriate strategy and they therefore need a different set of metrics.

Due to these challenges other KPIs can complement the innovation output measurement:

- Sales with new products
- Net present value (NPV) of innovation portfolio
- Development of market share
- Competitor benchmarks

However, the profitability of new products is the core KPI for an innovation based business model. If new products do not generate sufficient profit in the mid or long term there will be not enough budget to finance new development projects.

3.2 Step 2: Analysis of output-relevant shortcomings

The second step is generating potential shortcomings transparency. For this purpose multiple approaches have been developed, based on different frameworks and scorecards, as shown in [8], [9] and [10].

However many companies attempt to do this by ‘gut feeling’ and common sense today, by analyzing processes or by comparing the status-quo with best practices. These approaches lead to optimization levers. However they do not support a prioritization towards impact on output.

In order to obtain a stronger focus on effectiveness and therefore on output we propose to apply an approach called de-bottlenecking, which is used to optimize production processes. The overall idea of de-bottlenecking is to identify which step in a multi-step process is the one that most impairs the overall output performance.

Innovations can also be viewed as a sequence of four steps: ideas are the raw materials which are first refined to project proposals, then to projects, then to products/services, and finally they lead to 'sales with new products.' If the 'raw material' is identified as the bottleneck, it does not make much sense to put much energy into the improvement of project management. On the other hand a company should not invest in a new idea database if the launch process is the bottleneck. The last example illustrates the value of this approach. Using the conventional, topic focused, approach the analysis would show that idea management has flaws. It is very likely that a recommendation would follow to implement a new idea database.
The detection of the bottleneck is tricky. When, for example, many launches fail it does not necessarily mean that the launch process is the bottleneck, this is only one potential reason. The other potential reason is a weakness in the project proposal phase: when the specification of the innovation and the customer needs are challenged. Weaknesses in this phase could also lead to the situation that the innovation is properly executed and launched, however, it is based on false assumptions.
In the end an identification of the innovation bottleneck is not possible with 100% accuracy. Nevertheless it is a major advantage for the management team of a company when they agree which of the four steps is the bottleneck. According to the experience of the authors, the following indications support identification of the weak parts of the innovation chain.

1. Not enough high-quality ideas
    - Limited 'competition' between new ideas and running projects: no 'waiting list' for promising project proposals
    - Low new ideas transparency
    - Low ratio (less than 5:1) of ideas to detailed project proposals
2. Weaknesses in project definition and prioritization
    - Low project target achievement
    - Low target achievement in commercialization
    - Low ratio (less than 3:1) of detailed project proposals to started projects
    - Low formal and information quality of project proposals
3. Weaknesses in project execution
    - Low project target achievement
    - Low running projects transparency
    - Many or no project terminations
4. Weaknesses in launch
    - Low target achievement in commercialization
    - Launch planning is not part of project definition
    - Low commercialization process transparency

3.3 Step 3: Implementation of best practices

The third step is to detect and close gaps between the status quo and best practices on the operational level in the areas with the most significant shortcomings, as identified in step 2. A comprehensive overview on best practices and experiences from other companies support the gap analysis and delivers the right choice of improvement actions.

4 ADVANTAGES OF THE METHOD AND OUTLOOK INTO THE FUTURE

The proposed method will not substitute existing innovation management approaches but is intended to give other methods a stronger output-focus frame. Within the method there are three main elements that will contribute to a higher innovation output:

1. Optimized resource allocation
   Innovation output transparency will improve resource allocation decisions in multiple situations. Within one business area the resource allocation between the different innovation types can be optimized, furthermore, innovation resource allocation across different business areas can be aligned, or internal innovation options can be challenged against external options.
2. Optimized innovation target setting and incentive schemes
   The proposed method bases on the calculation of the ‘Return on Innovation’, this KPI can be used as a cornerstone for target setting and incentive schemes. Like most other KPIs it will not be a ‘perfect’ metric for all situations, however, it will give a very clear sign of the overall target to all employees involved in innovation.
3. Higher motivation
   Many large innovations have their origin in a ‘garage’, without sophisticated processes and tools. We observe that many innovations suffer from micromanagement in a stage-gate dominated innovation environment, particularly in larger corporations. The proposed method will not go back to the ‘garage’, however, it will focus mainly on the willingness of people to achieve a defined overall target instead of the formal correct execution of pre-defined activities.

In order to apply the proposed methodology in corporations, further detailing and customizing is required. Additionally, a benchmarking study is being prepared in order to back the hypotheses with empirical data.

5 SUMMARY AND CONCLUSIONS

Since effective product innovation is recognized as the single most deciding success factor for enterprises (as shown in [4] and [11]), it seems to be extremely important to overcome the low output focus of innovation management. Despite the fact that business process benchmarking is generally aimed at measuring process output, product development proves to be totally different to routine processes and is, therefore, much more difficult to evaluate in its output. The first reason for this situation is that innovation output measurement has many facets, and many attempts to measure the innovation output have failed due to the complexity of R&D. Especially since R&D processes are never zero-defect-processes and therefore of high general uncertainty. Furthermore, R & D processes are distinct at the stage of product realization and dependent on different industries.

For all R&D managers and those who are responsible for product innovation, the processes transparency is a major success factor, they need to steadily monitor performance indicators in the field of processes, values and organization as well as resources and budgeting to steer R&D processes properly. The authors show that all R & D efforts must be oriented towards the general goals of the organization in the first place. Therefore, KPIs which are able to monitor the output and outcome side are crucial and they must be adjusted to preconditions, circumstances, status of product realization and industries.

On this foundation, practical benchmarking groups must be implemented to evaluate the findings and to provide the benchmarking partners involved with the information gained.

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SMART FACTORIES – IT IS THE KEY TO THE NEXT INDUSTRIAL REVOLUTION

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Abstract
Modern, smart factories contribute substantially to strengthening Germany as a business location, these factories must, to a large extent, be able to optimize themselves as well as production processes [1].
Within the framework of the Government's High-Tech strategy, the initiative "Industry 4.0" was created. The aim of the initiative is the Smart Factory which, through adaptability, resource efficiency and ergonomics, is characterized by integrating customers and business partners into the value added process.

This paper shows the approach which will be realized within the "Smart Factory Lemgo".

Keywords:
Cyber-Physical Systems (CPS), Smart Factory Lemgo, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES)

1 INTRODUCTION

The technological foundations of Smart Factories are Cyber-Physical Systems (CPS) and the Internet [2]. CPS are distinguished by the integration of information technology into component parts and are characterized by the possession of embedded sensors or actuators for relevant data acquisition.
The transformation process to cyber physical systems assumes increased automation and a transparent, user-centered Production Planning and Control (PPC) in order to control the production networks in real-time. The "intelligent components" communicate independently with people and systems and find the optimal route through Production [3], that is to say de-centralized, autonomous control [4]. This allows improvements to be achieved in order fulfilment, production, material management, supply chain management and life cycle management [5].
However, production planning and control is, regarding methods and techniques used, as well as the commercially available IT Solutions, predominantly designed for mass-production with central planning and control concepts. Material requirements and production planning are systematically based on successive planning of quantities, deadlines and capacities. A computer aided optimizations procedure is lacking and an

improvement of logistics performance, which is a very important unique selling point for medium sized enterprises, is not possible with these systems. In fact, networking of production resources and a transparent, user-centered PPC is required.
Manufacturing execution systems (MES) contribute to improvements in transparency and user-centered design, which enable real-time, central monitoring and control of the production process [3]. These systems are offered as add-ons to ERP systems and connected to process automation modules, for instance to machines, personnel and support services, as well as to all the other processes which have an immediate effect on manufacture and assembly processes. They facilitate fast reaction to malfunction as well as monitoring or control of manufacturing in real time. At present, data collection is generally achieved through terminals or interfaces situated in production.
However, production planning and control is, explicitly, not possible with these systems. Present systems responses are simply too inflexible [6], lack transparency and are not user-centered. The MES should, in fact, be able to provide autonomous CPS with relevant information in order to make communication more effective [3]. Communications should also be kept transparent enough that users are not overwhelmed with information whilst still being able to see the current planning and control status at any time [5].
The result is a paradigm shift away from centrally planned PPC towards an autonomous, decentralized control, with self- organizing production units, to so-called Ad-Hoc value added chain [7], where ERP and MES form the backbone of the manufacturing and information flow within the company.

2 REQUIREMENTS OF CYBER PHYSICAL SYSTEMS

Cyber-Physical Systems (CPS) collaborate with other computational elements, for example MES, and control physical entities [8]. Today, a pre-cursor generation of CPS can be found in different areas such as aerospace, automotive or chemical processes.
The requirement for an autonomous, decentralized control system was determined in an empirical study [9] and shall be applied to the adoption of CPS. The production managers of 12 corporations were asked what they expected of such a control system.
The reduction of handling costs was considered to be very important by all respondents. Further important aims were a reduction in lead times and an increase in schedule reliability.
The capacity of production facilities, personnel and transport should also be taken into consideration, with particular attention being paid to good utilization of production facilities and personnel.
The requirements determined here formed the basis of the following concept for controlling by CPS development.

3 CONCEPTION OF CYBER PHYSICAL SYSTEMS

3.1 Integration with MES

The application of CPS without an MES is hardly conceivable [8]. MES schedules and plans the resources necessary for production orders. On the one hand this produces the manufacturing date of the production order and on the other hand, it is possible to calculate the manufacturing costs using this data. These costs and deadlines determined by MES provide the default value (desired value) for the CPS.

If no manufacturing breakdown occurs, then the processing proceeds exactly according to the MES parameters, should one of the processes temporarily fail, due to resource or personnel shortage, then communication with the CPS becomes necessary. The CPS then attempt to find an alternative route through production autonomously, one that meets the cost and deadline requirements: creating temporary production networks, which utilize alternative resources and personnel (Fig. 1).

If the alternative production network meet the MES parameters, then the CPS are able to begin the alternative route through production autonomously, the MES merely requires a completion note, so that the data it requires is always up to date. Only if one of the desired values (cost or deadline) would not be met by the new route is an alert note sent to the MES, in order for the planner to intervene manually.

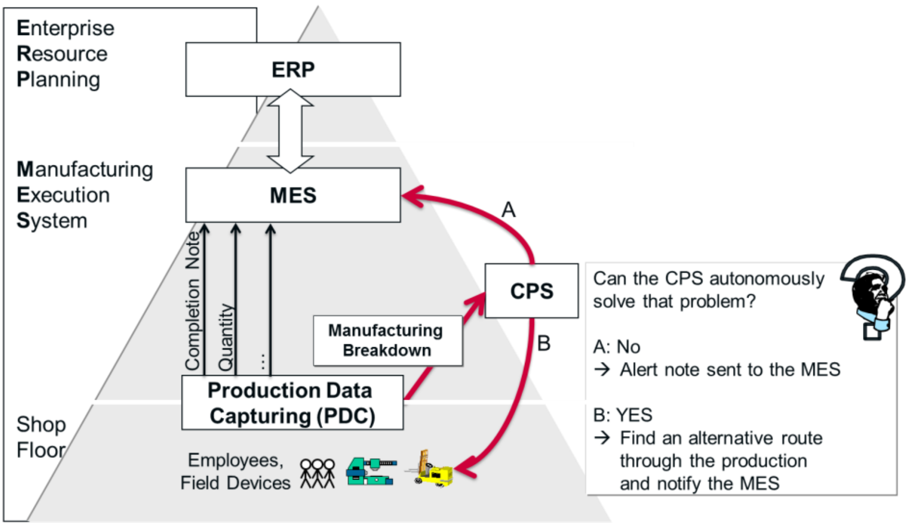

Figure 1: Interaction between CPS and MES.

Manufacturing breakdown can occur suddenly, so the CPS must be permanently informed of important disturbances; this occurs through an interface with the Production Data Capturing (PDC). Continuous control is necessary for this reason, which is carried out by a control circuit model. Control circuits may be deployed to describe processes as well as mathematical output calculation, in this example costs and deadlines shall be calculated.

3.2 Control Circuit Model Design

Costs and deadlines will be determined by MES (desired parameters), when disruption occurs the CPS will calculate the costs and deadlines of alternative routes and check whether they are within the desired parameters.
The control parameter is the output value of the straight line; this is compared with the MES desired parameters and the deviation between the control parameter and the desired parameter is the controller's input value.
The controller can change adjustable parameters, which should minimize the deviation between the control parameter and the desired parameters over the straight line.
Because the straight line can be influenced by external factors, confounding variables must also be taken into account (Fig. 2).

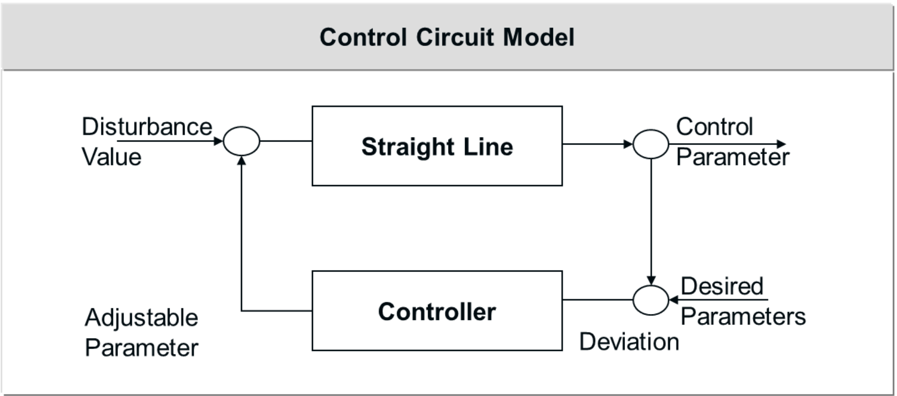

Figure 2: Control Circuit Model.

"Control Parameter, Desired Parameters and Deviations"

CPS have to find routes through production that fulfil the MES desired values, this requires comparison of the alternative routes, which means that the straight line (cost and deadline) must be calculated.

CPS makes use of operational resources raw materials and personnel; the loading rate of both must also be determined and compared with the MES desired values.

"Straight Line"

Temporary production networks are straight lines. If a CPS takes an alternative route through production, the MES determined process time changes. This comprises lead-time, handling, transport and idle time.
The relevant costs are personnel and raw materials, which are calculable through cost per time unit (k), time per unit (t^E) and number of units (n) [10].

- Cost per Resource = $t^E * k * n$ (1)

The information required can be obtained from the master data and the ERP work schedule.
The handling costs (K^B) can be calculated by process time per unit (t^B), processing costs per time unit (k^B) as well as the lot size (n) per material for all resources (s) across all periods (P):

- Handling costs (K^B) = $\sum_{i=1}^{P} \sum_{j=1}^{n} \sum_{m=1}^{s} t^B{}_{i,j,m} * k^B{}_{i,j,m} * x^P{}_{i,j,m}$ (2)

Learning effects can be achieved in production networks if similar products are produced, this results in a reduced cost per time unit, as these are calculated by distributing the total cost of all the resources ($K^F{}_m$) over the operating time [11]:

- $\left(\frac{K^F{}_m}{T_m} * x^P{}_{i,m}\right)$ (3)

Therefore both effects are consequences of temporary production networks that must also be taken into consideration. Taking learning effects (1-β) into consideration results in handling costs as follows [11]:

- Handling costs ($K^B{}_{Lern}$)

$$= \sum_{i=1}^{P} \sum_{j=1}^{n} \sum_{m=1}^{s} t^B{}_{i,j,m} * (1 - \beta_{i,j,m}) * \frac{K^F{}_{i,m}}{T_{i,m}} * x^P{}_{i,j,m} \qquad (4)$$

Preparing materials for processing an order causes Setup costs (K^R). These are calculated by the sum of all materials (s) and all production orders (FA).

- Setup costs (K^R) = $\sum_{i=1}^{P} \sum_{j=1}^{FA} \sum_{m=1}^{s} t^R{}_{i,j,m} * k^R{}_{i,j,m} * x^R{}_{i,j,m}$ (5)

Taking specialization effects into consideration results in (1-ρ) [11]:

- Setup costs (K^R_{Spez})

$$= \sum_{i=1}^{P} \sum_{j=1}^{FA} \sum_{m=1}^{s} t^R{}_{i,j,m} * k^R{}_{i,j,m} * (1-\rho_{i,j,m}) * x^R{}_{i,j,m} \qquad (6)$$

Costs of transportation are dependent upon transport time (t^T) and the means of transportation (k^T).

- Cost of transportation (K^T) = $\sum_{i=1}^{P} \sum_{j=1}^{n} \sum_{m=1}^{s} t^T{}_{i,j,m} * k^T{}_{i,j,m} * x^T{}_{i,j,m}$ (7)

Because the routing plan is set by the MES, idle time is not a relevant factor.

The maximum capacities of operating equipment, means of transport, personnel and warehouse are all constraints, which must also be considered. The following must be applied to all i=(1...P):

- Maximum equipment capacity:

$$\sum_{i=1}^{P} \sum_{j=1}^{n} \sum_{m=1}^{s} x^P{}_{i,j,m} * t^B{}_{i,j,m} + t^R{}_m \le C^{BM}{}_{\max.} \qquad (8)$$

- Maximum personnel capacity:

$$\sum_{i=1}^{P} \sum_{j=1}^{n} \sum_{m=1}^{s} x^P{}_{i,j,m} * t^B{}_{i,j,m} + t^R{}_m \le C^{MA}{}_{\max.} \qquad (9)$$

- Maximum warehouse capacity:

$$\sum_{i=1}^{P} \sum_{j=1}^{n} \sum_{m=1}^{s} x^P{}_{i,j,m} - x^A{}_{i,j,m} \le C^L{}_{i,\max.} UND \ge 0 \qquad (10)$$

- Maximum means of transport capacity:

$$\sum_{i=1}^{P} \sum_{j=1}^{n} \sum_{m=1}^{s} x^P{}_{i,j,m} \le C^L{}_{i,\max.} \qquad (11)$$

The total costs can be fully calculated by means of handling, setup and transport costs, taking the constraints mentioned above into consideration.

"Controller and Adjustable Parameters"

The controller calculates the difference between the control variables and the desired parameters, if the MES input value will not be met then the CPS seeks an alternative route through production.

CPS must be able to find the personnel and machines able to fulfil the order, these must also have capacity to do so. Modelling of this extremely extensive problem is not yet complete; this is a central aim of the research activities in “Smart Factory Lemgo“.

“Disturbance Value”

Disturbance values are, particularly, manufacturing breakdown; in case of this, CPS must spring into action. If the CPS can calculate an alternative route through production, taking the MES parameters into account, they can autonomously take it. In the case that cost and deadline parameters will not be met, an alert note is sent to the MES and an operator must manually intervene.

3.2 Model Incorporation

The calculation of the cost of alternative routes through production is done through straight line. The controller proposes possible courses of action, which lead to temporary networks of combined orders and materials, from which the adjustable parameters result. Disturbance values are identified as manufacturing breakdown of resources that lead to continuous replanning, the instruments of which are shown below.
The following costs are identified as control parameters:

- $K^{Ges} = \Sigma\ (K^B + K^R + K^T)$ (12)

These have been extended to include efficiency and capacity coefficients, which are required when rough planning, into account.

$$\eta^{MA}{}_t = \frac{a^{MA}{}_t}{b^{MA}{}_t}\ [\%] \in \left[\eta^{MA}{}_u \leq \eta^{MA} \leq \eta^{MA}{}_o\right] \tag{13}$$

η^{MA} = Efficiency of employees

$$\eta^{BM} = \frac{a^{BM}}{b^{BM}}\ [\%] \in \left[\eta^{BM}{}_u \leq \eta^{BM} \leq \eta^{BM}{}_o\right] \tag{14}$$

η^{BM} = Capacity coefficients of devices

The factors determined in the survey, are therefore the basis of this model.

4 SUMMARY

The complexity of production planning and controlling has increased in many companies over the past few years. Manufacturing breakdown of resources reinforce this complexity and require manual intervention by a planner, for instance with MES. However, Cyber Physical Systems could autonomously solve many of these breakdowns, so that the planner is relieved of the work and a solution found much faster. The use of CPS causes to increased automation and a user centred Production Planning and Control in order to control the production networks in real-time. The control of this networks using CPS is presented in this paper. This is, in order to facilitate continuous regulation, based on the control circuit model control system of cybernetics.
Control is carried out taking the MES values, in this case costs and deadlines, into consideration. CPS are able to find alternative paths through production. Through the use of CPS, planning time is reduced, costs are reduced and improvement of logistical performance is possible.

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COST PREDICTION MODEL FOR PRODUCT REALIZATION PROJECTS

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Abstract
Early and reliable prediction of product development costs has become increasingly important. On the one hand, this is due to broadening product diversification and a generally increasing product diversity, which lead to an increase in the proportion of development activity. On the other hand, the societal trend towards individualization, and the shortening of product life cycles, causes a reduced number of units sold for each specific product. Product development costs must, therefore, be distributed over an ever-smaller number of sold units, which results in a significant increase in the share of the development cost upon the unit price [1].
In the past, product realization costs could be distributed over a large number of items, manufacturing costs in particular were a principal factor for many companies. This is also reflected by the fact that the majority of “costing” publications are concerned with the calculation of production costs. As a result of the latest developments, a precise and economically defensible prediction of the product realization costs methodology is essential for many businesses.
In this paper, the essential procedures for cost determination are presented and their suitability for the prediction of product development costs will be appraised. Due to the particular relevance of the group of parametric cost determination procedures, parametric cost model building is explained in greater detail.

Keywords:
Cost prediction, project costing, cost planning, parametric cost model

1 THE RELEVANCE OF PRODUCT REALIZATION COSTS

The costs incurred in connection to the product development process include all costs from product conception, to the finished product’s start of production. Product realization costs include labor costs, material costs, capital costs and costs of external service provision [2].

The cost of product development is influenced by many internal and external requirements and conditions including, amongst other elements, the development subject matter, the duration of the project and the preconditions and specifications [3]. Personnel costs represent the defining value of product development costs, because their performance in the development process is mainly of an intangible nature. The average share of personnel costs can be as high as 80% or even more of the total cost as specified in the relevant literature [4], [5].

The planning of product development costs normally takes place at an early stage, before the start of product and production system development. Knowledge of the specific development project costs is an essential prerequisite for numerous subsequent planning and decision-making steps, such as:

- Business planning
- Offer basis for development service providers
- Budgeting of product development projects (target costing)
- Evaluation and analysis of realization alternatives, incl. sensitivity analysis
- Decision making basis for outsourcing of development services
- 'Make or Buy' - decisions
- Basis for the collateral design cost estimate

2 COST PLANNING AND COST SEGMENTATION

In the context of project planning, a structuring of the product development project generally takes place, the objective of which is to divide the project into manageable tasks, in order to achieve better clarity and workability of each individual task, working stage and work package [6].
In cost planning, it is also customary to divide the project into individual work packages and sub components. Beginning with the assumption that the total costs of a project will correspond to the sum of the costs of each project segment, costs for each project segment are initially determined separately [7]. It should then be possible, by aggregation of the individual cost values, to determine the value of the total project costs [8]. In this context, building the total costs upon the costs of smaller project segments describes a 'bottom-up' methodology. Figure 1 shows the theoretical procedure determining cost according to the 'bottom-up'-approach.
A different kind of approach is described as the 'top-down' approach in which, based on a general cost finding, the results of cost calculation lead directly to the total cost of the project [9]. The 'top-down' approach generally leads to lower accuracy of results, when compared to more structured ‘bottom-up’ approaches. This lower accuracy results from the project complexity and the lack of detailed treatment, which goes hand in hand with a lump sum cost estimate.

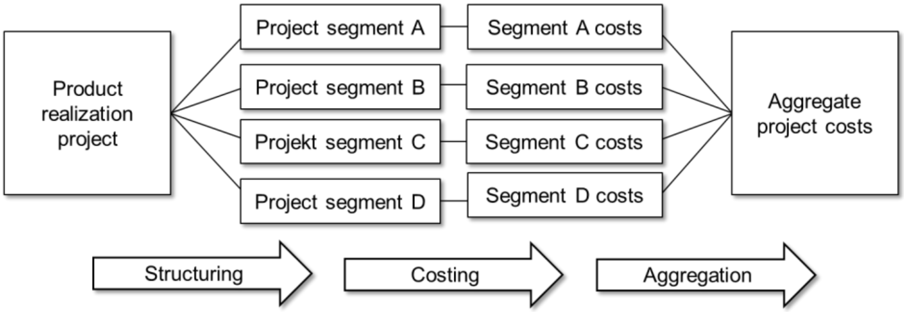

Figure 1: Cost structuring, costing and cost aggregation based on the `bottom-up`-approach: schematic procedure

Segmentation of product development costs can be achieved on the basis of one department's work, or the processing effort required for a specific section of the project, depending upon the level of detail at the basis of a project-specific operation. If possible, the cost segments should be associated with the work of an organizational unit or a person. This simplifies the calculation of costs and takes into account the fact that hourly billing rates for each department and organization unit are generally different [10]. The majority of cost determination procedures which are presented below, are based on the 'bottom-up' approach and therefore represent a combined approach of cost segmentation and calculation of costs.

3 DESCRIPTION AND EVALUATION OF COST PREDICTION APPROACHES

In cost prediction literature, approaches for the determination of product cost (manufacturing cost) are mentioned especially in connection with the calculation of costs. These approaches have their origins in the industrial production of less complex products and thus they are generally without deliberate use of restrictions transferable to other applications [8]. So often, for example, no clear guidelines exist in development at the time of the request [11] on which the cost calculation can be based, in contrast to the article calculation. In addition, there are significant differences in the factors influencing cost. Output quantities and lot sizes are particularly relevant in determining production costs, development costs are influenced to a greater degree by the diversity and complexity of the developed products.
Procedures specially designated for the determination of development costs refer primarily to software products. These methods primarily use software specific factors such as the number of lines of code, or the software architecture, as the basis for the calculation of costs (see [12], [13], [14]).

Depending upon the characteristics of the approach, various input and output parameters can be involved in the cost prediction process. Company specific input comprises of the cost information of completed product realization projects (retrograde cost information) and / or the knowledge of experienced experts. Furthermore, cost prediction may rely on industry specific input such as ratios and empirical values. In each case information is needed with regard to the new project for which the cost prediction is implemented (anterograde cost information). The potential input and output parameters for cost prediction approaches are pointed out in Figure 2.

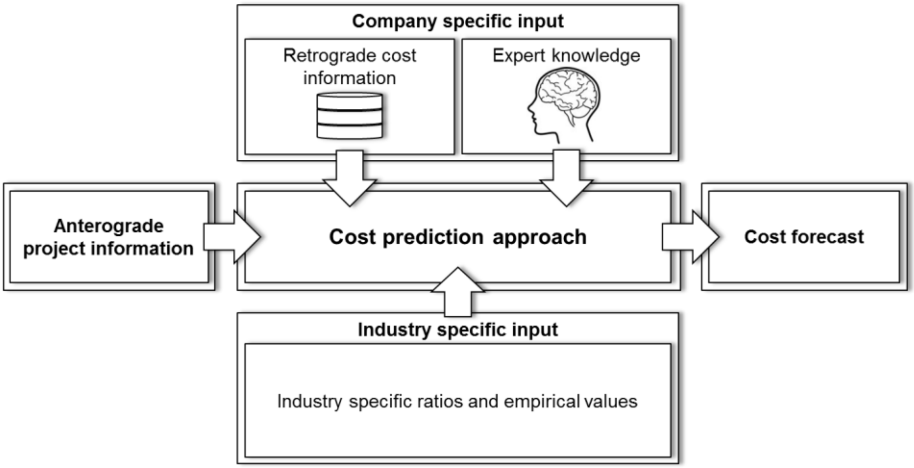

Figure 2: Input and output parameters of cost prediction approaches

The procedural devices presented in the following pages differ in their approach and in the types of source and target data. The spectrum ranges from intuitive predictions up to strictly determinate [15]. The procedures for determining costs in different groups can be categorized according to their methodological approach. The general approach to calculation of cost is always crucial for this purpose, it allows distinguishing between subjective estimation processes, proportion-based processes, comparison-based and parametric processes (see Figure 3).

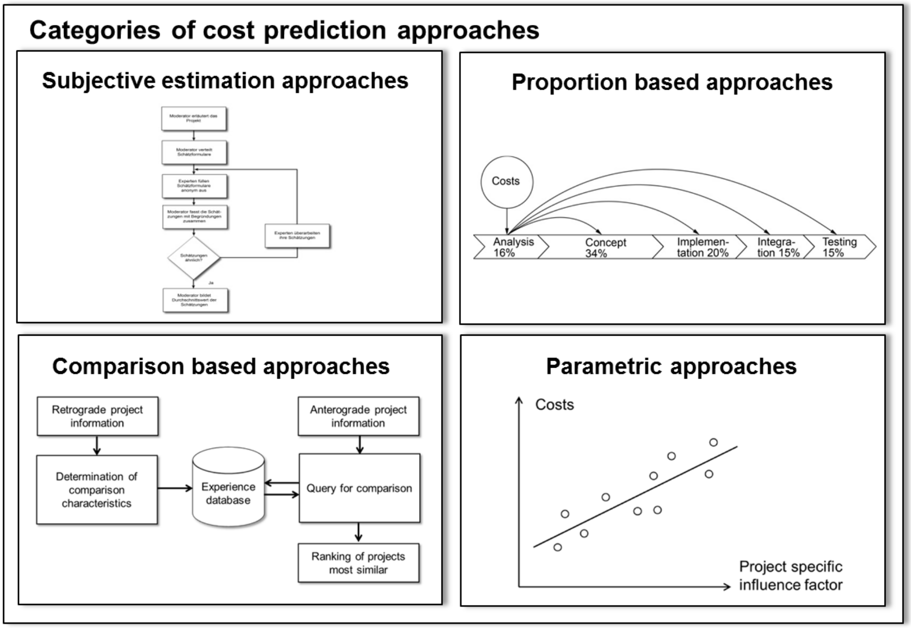

Figure 3: Categories of cost prediction approaches

3.1 Subjective estimation approach

Subjective estimation procedures are amongst the simplest and therefore most widely used methods of determining costs [10]. The potential costs are determined by subjective estimation by one or more persons, the range spreads from an intuitive estimate up to more systematic survey rounds, executed by several experts. It is symptomatic for all forms of this set of procedures that subjective assessment takes place, which is based only on experience, without an explicit consideration of the cost factors [16].

Depending on the type of subjective estimation, individual interviews and group interviews can be distinguished from one another. An estimation of the project costs by only one person, held in a single survey, significantly depends on the knowledge of the respondent. This person should be an expert who has an extensive knowledge of the respective development projects [17]. Depending on how detailed and intricate the development projects have been previously structured, the cost estimate is carried out either as a lump sum for the entire project or with great detail on the basis of individual operations.

Since only one person makes the cost determination and the subjective assessment is not transparent enough for a third party, the result can be checked for accuracy only with some difficulty [10]. Another disadvantage of the face to face survey is expected to be a lack of objectivity from the estimators. Compared to the face to face interviews, several subject matter experts are entrusted with the cost estimate in the group interview. A reduction of the forecast error is almost always achieved by consulting several experts, in contrast to the single expert survey [18]. The estimator group should be composed of the, ideally heterogeneous, departments involved in the development project.

3.2 Proportion based approach

The proportion-based methods are based upon the assumption that similar cost ratios exist between similar projects. In this case, a representative project cost structure is determined on the basis of empirical data from previously completed projects.

This can be used, for example, to set the work and effort of different departments or the expense of different stages in relation to each other. With the help of such cost-cost relations, the remaining project costs can be calculated for a new project, starting from a base size by using relationship building.

Since a base value is always used for the cost calculation, for which costs must already be known, the proportion-based methods are not, strictly speaking, stand-alone methods [4].

In project management literature, especially amongst proportion-based procedures, the ‘percentage based approach’ is mentioned in connection with determining project costs through relationship building. With the percentage-based method, the entire development effort is extrapolated from the effort of one segment of the project [19]. Representative relative costs between the project segments are determined on the basis of information from previously completed projects, i.e. retrograde information. Figure 4 shows, for instance, how the overall project cost is extrapolated, based on a defined cost structure between the various project phases, starting from the phase of 'analysis'.

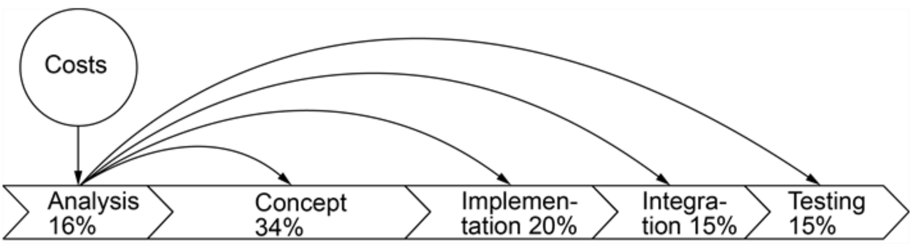

Figure 4: Principle of percentage based approach [10]

One fundamental problem of proportion-based procedures is that errors, which originated in determining the base values, sometimes multiply when extrapolated to the total cost. This can reduce the validity of the method itself [20].

3.3 Comparison-based approach

With comparison-based procedures, expenses are calculated on the basis of retrograde cost values of previously completed development projects. The first step is to search for a completed project for comparison, which should be as similar to the new project as possible. The differences between the comparison project and the new project must then be defined and evaluated. Only those cost elements that differ from the original project are considered here, for this reason the comparison-based procedures are also known as comparison or difference calculation in economic literature [16]. The expense forecast is based on the cost values of the comparison project and the differential expenses as a result of the differences between the old and new project [21] (see equation 1).

$$k_2 = k_1 \pm \Delta k_2 \qquad (1)$$

k_2: Cost of the new project
k_1: Cost of the comparison project
Δk_2: Difference in cost between the old and new project

The assessment of the similarity of two projects and the formation of the differential costs is dependent upon the subjective judgment of the person using the method. If data of several completed projects with an appropriate degree of similarity exist, averages can be identified when determining the reference cost [18]. Experience databases, empirical studies and benchmarks can be determined as sources for reference projects [22]. It is helpful to have these sources systematically stored in databases, especially if there are larger amounts of retrograde information available. A categorization based on previously defined comparison criteria and a brief description of the project in the database should be stored in addition to the cost information. Comparison-based procedures, which rely on a computer-aided project database (which may be part of ERP or PLM systems) in the selection phase of reference projects, are referred to as experience database procedures.

3.4 Parametric approach

The parametric cost determination procedures are based upon the assumption that a functional relationship between the costs and one or more project-specific cost factors exists [7]. Such a relationship must be determined empirically [10] on the basis of retrograde information from completed projects. The significant project sizes and their influence on cost can be determined by using the retrograde data with the help of probing statistical methods. Figure 5 shows a linear dependence between the cost of the project and a project-specific factor using a correlation chart.

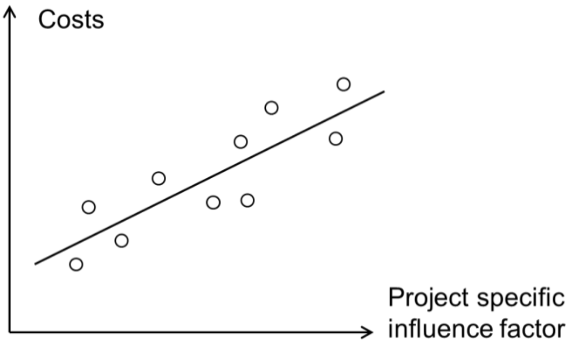

Figure 5: Linear interdependence between project costs and a project specific influence factor

To formally describe the correlation shown in Figure 5, structure probing statistical methods, such as regression analysis, can be used. When the functional correlation is known, the potential cost of a project can be calculated on the basis of that factor. When using cost equations, it is assumed that the costs of two projects are equal in the case that the significant input variables are also equally pronounced.
An important prerequisite is that the expression of the influencing values at the time of the calculation of costs is already known, or is easier to determine than the cost of the project itself. Moreover, the influence value for a large number of projects should be representative and documented in the retrograde cost records of completed projects [4].
In cost determination using parametric techniques, a structuring of previous projects into sub components normally takes place. For each sub component, an individual cost equation can be defined. The total cost is determined by the aggregation of different cost equations. If there are several cost equations, which have to be summarized to enable a full costing for the project, they are called cost models [13].
Depending on the causality related to the development of costs, one or several project-specific values may have an impact on the costs. The inclusion of several factors allows a more accurate assessment of the project-specific terms and conditions. With regard to the statistical calculation of the cost equation, equations with a single effecting value can be created using univariate analysis methods. If a cost equation taking several factors into account is required, multivariate techniques for the statistical analysis must be used.

3.5 Evaluation

Table 1 gives an overview of the specific requirements for a process for the early identification of costs. It also figuratively shows to what extent the procedural devices meet the requirements.

It is evident that the parametric cost determination procedures meet the requirements with regard to quality and information content very well. No other method has a similarly high rating with regard to validity and reliability. This is justified by the fact that the cost calculation is based upon a formalized process and subjective influence factors are of minor impact. In addition, the accuracy of results of parametric cost models can be measured based on statistical indicators. In preparing the assessment matrix a weighting of the criteria has deliberately been omitted. It should be assumed however, that the quality of results is the most important requirement for a procedure.

Table 1: Cost prediction approaches evaluation matrix

How well do the analysed methods (columns) meet the specific requirements (rows)?			**Subjective estimation approaches**		**Proportion based approach**	**Comparison based approaches**		**Parametric approaches**	
			Single interview	Group interviews		Methods without knowledge database	Knowledge database methods	Univariate methods	Multivariate methods
●	Full compliance								
◑	Partial compliance								
○	Non-compliance								
Requirements of the cost prediction method	Result quality and information content	Validity	○	◑	○	◑	◑	◑	●
		Reliability	○	○	●	○	◑	●	●
		Mesurability of prediction quality	○	○	●	○	○	●	●
		Tracebility	○	○	○	◑	●	◑	●
	Effort of implementation	Low personal resources required	●	○	●	●	○	◑	◑
		Minor user qualification required	○	○	◑	○	○	◑	◑
		Limited material resources required	●	●	●	●	○	◑	◑
	Information requirements	Minor retrograde information required	●	●	○	○	○	◑	○
		Minor anterograde information required	○	○	◑	◑	◑	●	◑

In the assessment of the application effort, one must distinguish between the effort for the first and unique creation and the expenses for the pure application in some procedures. So, for example, the creation of a cost model comes along with higher effort and expenses. The eventual application of parametric methods is very fast and easy. High implementation and application costs exist with subjective assessment procedures, since the calculation of costs, as a rule, must be fundamentally carried out anew for every cost determination process and can only rarely be based on standardized tools. Moreover, this assessment must be carried out by subject matter experts, their availability is generally limited.

No clear favorite among the procedures can be determined in relation to the need for information. The need for retrograde information is least pronounced with subjective evaluation procedures. Even if there are no experience values from completed projects, this method can be applied. Many of the other procedures, where the calculation of costs based on experience, have an enhanced need for retrograde information. For this reason, the need for information is more pronounced with multivariate procedures than with univariate methods.

The need for information about the future project (anterograde information) is highly pronounced with subjective assessment procedures, as for a detailed structuring of project processes at an early stage, lots of information about the subject of development and the development environment must be known. The parametric, the relationship and the experience data bank methods are better in this respect, since information is required solely about the cost-relevant influencing variables.

Due to the high accuracy of the results and the fast and economically justifiable applicability, parametric cost determination procedures provide the best conditions for prediction of product development costs.

4 PARAMETRIC COST MODEL DETERMINATION

Due to the particular suitability of parametric cost models for the prediction of product development costs, the model creation is described below. The theoretical modeling attempts to depict real-world issues in a mathematically formalized model, through abstraction and simplification.

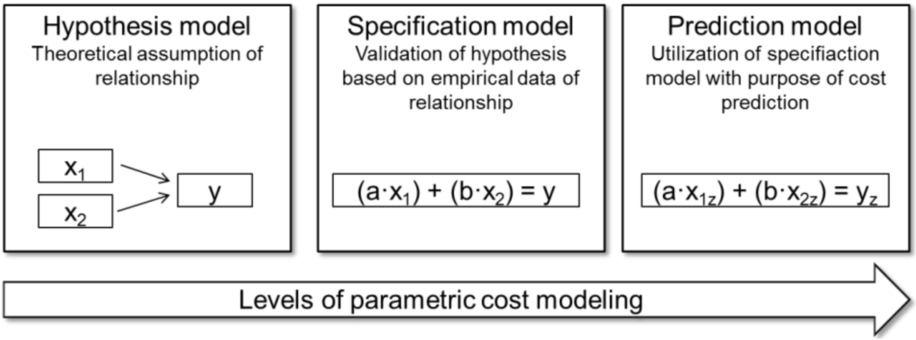

Figure 6: Levels of parametric cost modeling [23]

With regard to the calculation of costs, the model is used to describe the technical and economic context of the emergence of costs and to make them comprehensive. Awareness of the interdependencies within the model allows the forecast of the future. As shown in Figure 6, the process of parametric modeling can be divided into three stages.

4.1 Hypothesis model creation

When creating the hypothetical model for each project segment, the significant influencing factors (independent variables) must be targeted a priori, based on a specified output (dependent variable). The objective is that the model maps the hypothetical interdependencies of the emergence of cost. Since the model should be applied to the prediction of product development costs, costs, or values that are convertible to costs, must be used as output values.

All significant and meaningful factors that have a causally justifiable effect on the product realization cost should be used as influencing factors. Cost-specific factors may result from the product requirements, the requirements of the production system or from the internal project organization. Table 2 shows some examples of independent variables and their causal classification.

Table 2: Examples of cost specific influence factors

Causality	**Influence factors**
Product specific	Number of components
	Number of technologies and principles
	Specification book requirements
Production specific	Degree of automization
	Range of in-house manufacturing
	Number of manufacturing processes
Project specific	Knowledge and experience of team members
	Number of team members
	Use of equipment and tools

4.2 Specification model creation

Within the framework of the hypothesis model, the previously created assumption concerning the interdependencies of the cost model should be proved empirically [23].

For this purpose, the retrograde project data of the respective company are evaluated with structure probing statistical procedures. Depending on the number of independent variables and the expression of the respective links, different analysis methods can be applied:

- Linear regression analysis (univariate / multivariate)
- Non-linear regression analysis (univariate / multivariate)
- Neural networks

The result of the specification model is generally a system of equations that formally represents the mathematical dependencies between the cost model input and output values [24].

4.3 Prediction model creation

The prediction model serves the cost forecast for future product development projects. The anterograde expression values of the independent model variables are used in the formal system of equations of the explanation model. The potential costs for the new development project can be calculated by solving the system of equations. By aggregating the costs for each project segment, the total cost of the product development project can be calculated.

5 SUMMARY AND CONCLUSIONS

Early and accurate prediction of product development costs has become increasingly important. In comparison to other cost determination procedures, parametric procedures have the most advantages, particularly when the accuracy of the results is important. The formal technical and economic connections figure of the emergence of cost is based on a cost model. Cost modeling is based on a systematic approach which is marked by the process steps: hypothesis, specification, and prediction.

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HIGH GLOSS SURFACES: VALID QUALITY EVALUATION

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Including preliminary studies of C. Büttemeyer and M. Ziffling

Abstract
The quality sensation regarding to high gloss surfaces is mainly influenced by the optical impression. For the evaluation of this multifactorial property currently no standard methodical procedure is defined. Present some measurement as well as sensory evaluations are used for the quality assessment of high gloss surfaces. Regarding to Six Sigma, for proper customer satisfaction the voice of the customer needs to be transferred into specific product criteria which are measurable. Associated to the research project “Development of a global quality concept for furniture high gloss surfaces” at the University of Applied Science Ostwestfalen-Lippe possible customers were asked to rank some high gloss samples according to their quality perception. In addition these high gloss surfaces were gauged by common measurements. Building up the basis for a comprehensive quality scale by the analysis of correlations between the measured values and the quality impression of the customers is the subject matter. The waviness of a high gloss surface seems to be an appropriate indicator for perceive quality. For end users brilliance, an even surface and the absence of errors are attributes of an upmarket high gloss surface. Whatever the surface is not the tangible criterion for the purchase decision of furniture in general; design, production quality and price, which are directly affected by surface properties, are more clinches.

Keywords:
High gloss, furniture surface, quality management, quality perception,

1 INTRODUCTION

Former quality concepts were only focused on the detection of factual functionality and they pretended to be objective [1]. Concerning the different surface systems problems are obviously in consequence to the diversity of lacquers and foils. Especially interlinked steps of a procedure like sanding, coating, drying and packing compose the process chain of varnishing. Due to the strict linkage of the processes step all results and set up parameters e.g. of the sanding process have an influence on the following steps of procedure. All process parameters have to be described by evaluation and measuring methods to achieve a constant surface quality. [2] Currently the industry examines the high gloss surfaces visual by many years of experiences, without a few standardized means and methods. The quality assurance has to deal with indistinct evaluations and just a few quantifiable measurement methods with low reproducibility. [3]

However beside the multifunctional needs of measurement different consumer can consider different attributes as important. KAHNEMAN and TVERSKY in [3] describe a procedure of the purchase decision, which is structured in two phases. In the first one the problem of decision is simplified and structured. Therefore the consumers classify the different alternatives into advancement or worsening in relation to a reference point of expired knowledge. Within the decision tree customer's action is based on processing strategy, which is working on comparisons by brand or by attribute. In the second phase these relative results are ranked according to the subjective benefit of the decision-maker [3].

The appearance of surfaces, respectively high gloss influences the purchase decision of end-users in both processing strategies. Based on the Sig Sigma approach, Figure 1 shows that customer's requirements can be identified and transferred into measurable and reproducible product criteria, which need to be in that field of decision attributes to influence the buying decisions.

Initially customer's needs and expectations have to be ascertained. Therefore different methods like interviews or a focus group can be applied [4]. To transfer the voice of the customer into product properties the detection of criteria, which are able to indicate the fulfilment of customer's requirements is needed. These specific customer criteria are called CTQs (Critical to Quality) and should be ascertainable and measurable in an objective way. Following the CTQs are classified and those with an high impact on customer's quality assumption are selected for the evaluation of processes and products [5].

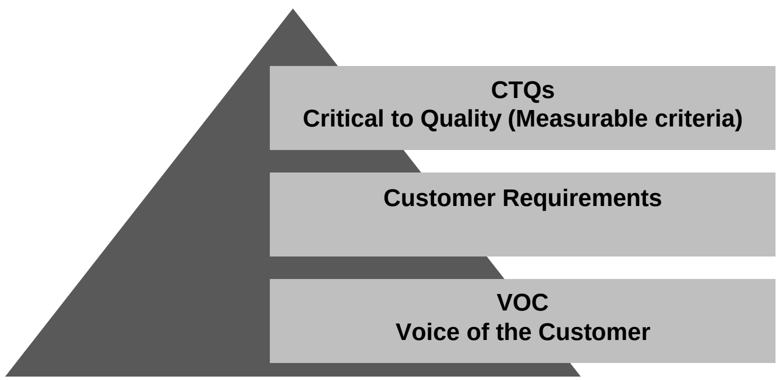

Figure 1: From the VOC to the CTQs [according to 5].

To generate a quality concept with a quality scale that integers customers purchase decision, is the subject matter of the research project “Development of a global quality concept for furniture high gloss surfaces” at the University of Applied Science Ostwestfalen-Lippe. Intended is the detection of potential test criteria which are critical for customer´s quality impression and reproducible measurable. Finally the contribution to the development of a comprehensive quality concept for furniture high gloss surfaces, in relation to the quality assumption of the end user is purposed.

2 STATE OF THE ART

The existing standardised test methods regarding furniture surfaces are generally focused on the mechanical properties. For example scratch resistance, impact resistance and light fastness are tested [6]. Esthetical properties are just represented by the measurement of gloss and colour or the evaluation of colour through the comparison of surfaces following DIN EN ISO 3668 [7].
A perfect high gloss surface needs to have a homogenous image. Furthermore surface properties with over 70 gloss units, gauged by a reflectometer measuring by an angel of 60° are classified as high gloss and should be measured with 20° again [8]. For the final quality, the degree of uniformity is essential. Irregular attributes are caused by interruptions of the production process and affected by the material and the way of processing. For instance scratches, pin-holes and spots can emerge. Products with irregular attributes are often non-marketable. Beside the appearance irregularities are influencing the resistance differently [9]. Process-related regular attributes need to fulfil the requirements and have to be inside of target thresholds. They should be controlled early in process and are on the main focus of the research. RIEGEL and DEKOMIEN structured the essential attributes for high gloss surfaces and show a possibility how to combine e.g. current measurement with sensory quality assessment. Transferring both results into one quality scale will give an objective quality assessment close to the CTQs [10].

2.1 Sensory quality assessment

For a methodical sensory evaluation assessors have to be trained and selected at the beginning. The inspector can be authorized if the ability to identify certain quality attributes is adequate. In general the degree of significance regarding quality ratings rises with the number of involved assessors [11]. Just the visual evaluation of high gloss surfaces is appropriate for the quality assessment. According to experience no haptic differences between materials with high and low brilliance could be detected [12]. The appearance of high gloss surfaces is presented by a number of different attributes, which have to be known by assessors by heart. Mainly different light conditions help the assessors to examine single attributes visually and giving each of them suitable evaluation.

2.2 Measurements

Gloss and Colour

In addition to the visual assessment existing measurement methods are used. For example the colour also can be verified by a spectrometer [13]. The multiple sensor of the spectrometer measures the reflection by means of the wavelength range. By comparison of the gauged values with saved curves of colour mixtures and mathematical integration the stimulus value can be determined. By this method very precise absolute colour data can be generated. The gloss can be measured by the use of a reflectometer. The proportion of direct surface reflection is defined as gloss in accordance to DIN ISO 2813 [8]. The reflectometer has a defined light source with a size of several square centimetres which, is irradiating the gauged surface by a defined entrance angel. The intensity of the reflected light, in the particular reflection angel is measured [8].

Roughness and Waviness

More unusual is the measurement the surface roughness, gauged by contact and noncontact measurement devices. During the measurement with a stylus instrument, which belongs to the contact method a component of the measuring device touches the surface which is evaluated. Thereby damages of the measured material can be engendered [14]. Beyond optical measurement instruments like the wave-scan® instrument are occasionally used for the detection of surface deviations [15].

For the assessment close to customer requirements both technologies above were tested. They were used to execute 50 measurements at the same spot with reference to PFEIFER and SCHMIDT [16]. For the stylus instrument it was of importance to determine if the diamond tip of the device leaves visually noticeable scratches or damages on the surface. Therefore the device was used orthogonal to the measuring direction of the 50 prior analysis measurements. This evaluation showed that both measurements showed a high repeat accuracy. For the comparison of the measured data it was chosen to use a correlation analysis to see whether the measured wave-scan® values of short- and long-wave values have a relation that can be statistically observed to the values derived by the stylus instrument. The values Wx according to DIN EN ISO 12085, the maximum depth of a waviness-motif, were chosen to be correlated in order to represent the vertical values measured by the stylus instrument. The Aw also according to DIN EN ISO 12085, the mean length of the motif, was chosen as a representing horizontal parameter. The two values were both used to correlate them to the long-wave as well as short wave values obtained by the wave-scan measurements. It must be stated that the values for the measurements in x-direction of the specimen were of course correlated with the corresponding x-direction wave-scan values. In a regression analysis using a significance level of 95% the majority of the correlation analysis showed totally different results. None of them showed a strong correlation. The strongest obtained R^2 value was about 0.5. That represents a weak correlation. A correlation or any kind of relation between the values could therefore not be confirmed [17]. Because the laser beam don't reflect just at the surface top and ingredients influence the laser intensity regarding their specific refraction index the stylus instrument were chosen for the following tests.

3 THE DEVELOPMENT OF A CUSTOMER BASED QUALITY CONCEPT

For the development of a customer based quality concept first of all customers were asked for their requirements to combine them with measured values in a second step. The method is described in the following chapters.

3.1 Customer requirements

The voice of the customer, according to furniture high gloss surfaces was gathered with a double-blind survey on the day of the open house at the University of Applied Science Ostwestfalen-Lippe. The survey attempts to identify customer's requests and desires regarding to high gloss surfaces. Further it is intended to build up a link between the quality impression of end users and measurable test criteria. Therefore ninety-four potential customers arranged six different black high gloss samples, of table 1 according to their quality perception. To avoid the assumption of a pre given rank order the surfaces were named by geometric shapes. Test persons, of different age and education levels were interview in the same manner and ranked the high gloss samples at defined light conditions.

Table 1: The black high gloss samples

Sample	***Coating***	***Substrate***	***Main attributes***
Triangle	Priming foil and UV-coated	MDF	Even, bright, brilliant
Square	ABS top on PMMA foil	MDF	Even, bright, brilliant
Arrow	Priming foil and 2K-polyester	HDF	Even, bright, brilliant, pinholes and spot
Cross	Fillered and 2K-Acryl black pigmented	MDF	Waves, sanding-scratches, orange-peel
Star	2K-Polyester	Particle board, veneered with beech	Many spots, sanding scratches, marks of the veneer
Circle	PVC foil	Particle board	Orange-peel

To support the quality decision a light source with a grid was used which leads to the appearance of a mirroring pattern on the sample. To simulate the purchase situation in a furniture shop, where the direct comparison of different cabinet doors, side by side isn't possible the samples were fixed on a rotary drum. As figure 2 shows the positioning of the samples next to each other is avoided by the breadboard.

Figure 2: Breadboard construction on the day of the open house

The subject group mentioned purchasing criteria for furniture and their affinity to high gloss surfaces in general. Furthermore they were asked about their professional experience in the quality assessment of any kind of surfaces. In addition the test persons characterised the attributes of an optically aesthetic high gloss surfaces and provide socio-demographic information. Regarding the questionnaire it has to be considered that the age distribution of the subject group is focused on the range from 17 to 31 years and about 50 % of the probands are students or pupils.

3.2 Measuring

The quantitative assessment of the black high gloss samples of table 1 was carried out by gloss level, colour and the surface waviness were ascertained, which are described in chapter 2. The gloss has been determined by a reflectometer with angels of incidence of 20° and 60°. For the determination of the colour a daylight light source (D65) with a CIE standard photometric observer of 10° considering the reflected light was used. The waviness was selected due to remarks of the subject group which mentioned a smooth and even surface as important high gloss attribute. The measurement of the surface flatness was carried out with a stylus instrument by using a diamante tip, further called pin, and a ball. Due to the radius of the ball the measurement results are mechanical pre filtered and very small surface variations are not considered. These waviness measurements were carried out according to DIN EN ISO 12085 with the Motif-Method to be very close to the percept surface of the customer. Due to the evaluation of the primary profile the method ascertains waviness values are closer to the reality [18 and 19].

Out of the dimensional results, presented in table 2 four new rankings of the samples were generated. The black surfaces were arranged corresponding to their gloss units, mean length of the waviness Motif Aw, mean depth of the waviness Motif W and the colour. Therefore the sample with the highest gloss, least waviness and smallest Euclidean distance ΔE to pure black (L=0, a=0, b=0) were placed on the first position [20].

Table 2: The mean dimensional results of the black high gloss samples

Sample	***Gloss units (20°)***	ΔE	***Aw (Ball) [μm]***	***W (Ball) [μm]***	***Aw (Pin) [μm]***	***W (Pin) [μm]***
Triangle	83,40	25,21	1203,60	0,28	1385,00	0,34
Square	80,19	25,19	1215,60	0,26	1336,20	0,20
Arrow	92,73	26,30	1243,40	0,28	1350,90	0,33
Cross	85,35	25,69	1317,80	0,46	1496,70	0,48
Star	90,93	26,19	1296,00	0,32	1407,70	0,76
Circle	65,82	25,21	1550,60	0,94	1591,90	2,34

Due to similar ΔE values a ranking according to these parameters is not expedient because it would just be possible by consideration of the first and second decimal place. Hence the green/red (a) and the yellow/blue (b) amount of the black surfaces were particularly observed [20]. As shown in figure 3 the colour location in the colour space varies considerably. The surfaces were also arranged according to these dimensions. Therefore the magnitude of the difference to pure black was used.

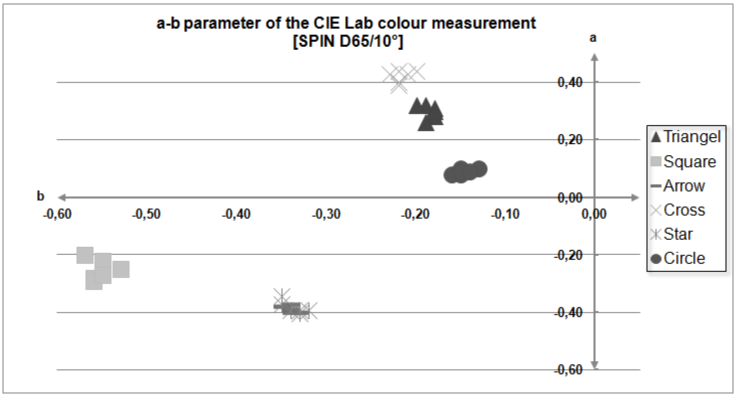

Figure 3: Colour location of the samples within the colour space

3.3 Evaluation method

The high gloss ranking done by potential customers on the day of the open house (table 3) is evaluated according to the DIN ISO 8587 [21] standard for ranking tests of sensorial analyses. An overall ranking was determined by the rank-sum of every sample. The rank-sum is calculated by the addition of all assigned ranking positions. With the Friedmann-Test, a hypothesis testing it was proved if the six high gloss samples differ from the customers´ point of view. Furthermore the occurrence of significant differences between the single samples was analysed by the LSD-Test (Least Significant Difference -Test) [21]. To detect any kind of ranking variation between different age groups, genders, and preferences regarding high gloss surfaces the average rankings of these groups were compared.

Table 3: Customer ranking of the high gloss samples

Ranking position	***Sample***
1	Triangle
2	Square
3	Arrow
4	Cross
5	Star
6	Circle

To analyse possible relations between the quality impression of the customers and the measurement results every measurement ranking was compared with the customer ranking. With the Page-Test (hypothesis testing) it was analysed if the panel of test persons conform the single measurement rankings, in a collective way. As well the correlation between individual customer rankings and the four measurement rankings was researched with the correlation coefficient of Spearman.

4 RESULTS

Out of the survey with 94 test persons it can be deduced that the main purchasing criteria for furniture are design, quality, price and function. Just 15 times the surface was mentioned although up to four statements were possible. In relation to the furniture surface merely the cleaning properties were mentioned infrequently. As shown in figure 4 important high gloss attributes for the panel are brilliance, an even surface as well as the absence of defects. For example bubbles, inclusions and scratches were defined as error by the proposity.

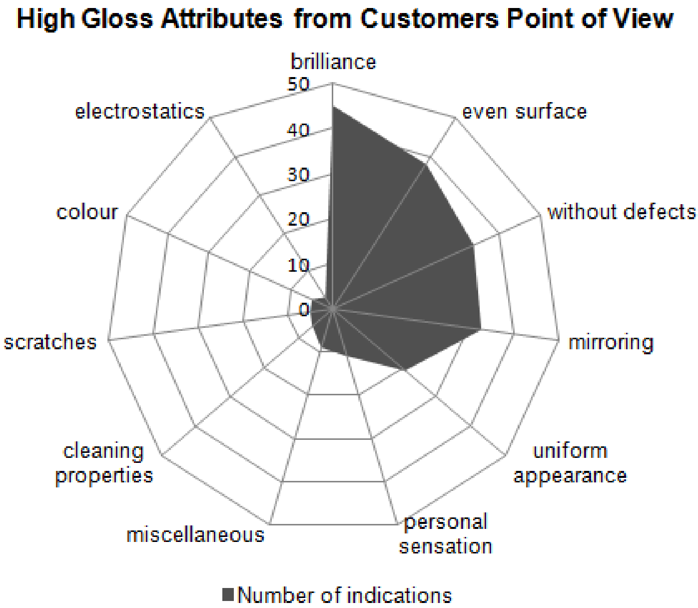

Figure 4: High gloss attributes from customers point of view.

4.1 Evaluation according to Friedmann- and LSD-Test

In general the subject group identified differences between the black high gloss samples and set up a ranking. The test persons built three categories out of the six surfaces within the ranking position often varied. Difference between the samples square and triangle, arrow and cross as well as star and circle aren't significant. A differentiation between the rankings of females and males, different age groups ore test persons with and without experience in the quality assessment of any kind of surfaces could not be noted.

4.2 Evaluation according to Page-Test

As mentioned in chapter 3.3 correlations between the customer ranking and the ranking based on the measurement values are analysed. In table 4 it appears that the collective subject group doesn't confirm the ranking according to the gloss units, to the red/green and the yellow/blue amount of the black colour. On the other hand the arrangement regarding the waviness measured with ball and pin were verified by the collective group ranking.

Table 4: Accordance between the measurement and the customer ranking according to the Page-Test

Measurement ranking according to	***Accordance between the subjective group and the measurement ranking***
W Pin	Accordance confirmed
W Ball	Accordance confirmed
AW Pin	Accordance confirmed
AW Ball	Accordance confirmed
Gloss	Accordance declined
a difference	Accordance declined
b difference	Accordance declined

4.3 Evaluation according to Spearman-Test

The coherence with the individual rankings of customers is analogous to those of the collective group. The accordance between the gloss and colour rank orders of the high gloss surfaces and the single customer rankings amounts less than 6 %. Consequently the quality impression of possible customers seems to be not influenced by these parameters. The correlation between single customer rankings and the rank order according to the average length of the waviness Motif is most significant. The degree of accordance is close to 80 %. As figure 5 shows all considered waviness parameters represent a passable correlation between the measurement rankings and the customer rankings of the high gloss surfaces.

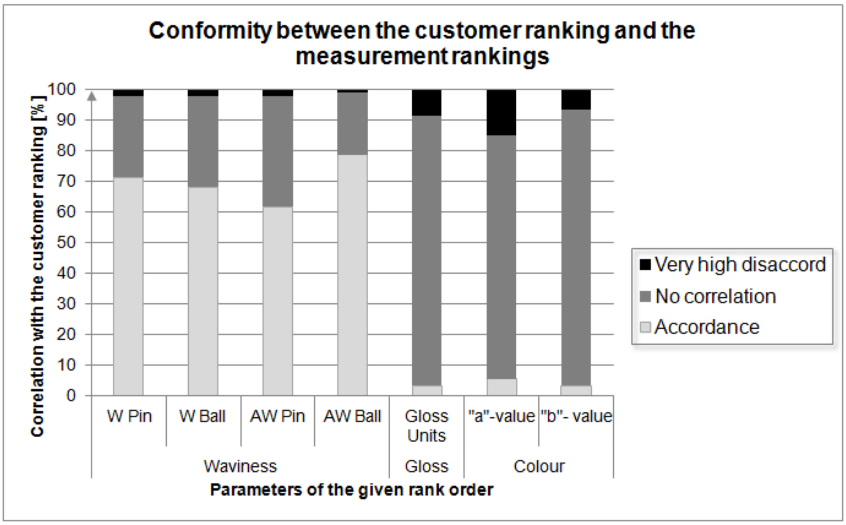

Figure 5: Conformity between the customer ranking and the measurement rankings according to the correlation coefficient of Spearman

5 CONCLUSION

Regarding the executed experiments and the survey which was carried out on the day of the open house the output parameters of the reflectometer and the spectrometer are not appropriate to insure proper quality from the customer point of view. To insure this proposition, further surveys regarding the quality impression of end users should be carried out also to complete the age distribution of the subject group. Furthermore it has to be considered that the quality impression can differ dependent on the global social class. These classes are distinguished by regional history, wages and lifestyle [22].In addition it has to be noted that the quality association depends on the horizon of expectations which is mainly influenced by experience and communication about the product [11]. Accordingly the quality perception of the end user regarding high gloss surfaces is influenced by seen furniture. In the context of the survey this parameter wasn't considered.

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A STRENGTH DESIGN APPROACH FOR CARCASS FURNITURE

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Abstract
To challenge the problem of missing calculations and standardized values for carcass furniture a new estimating design approach was developed. Aim of the research work was to verify if it is possible to implement a strength design, especially considering the use of wood based materials. In initial experiments simple corner joints were tested. The determined breaking forces were compared with calculated forces from different material strengths as shear strength, internal bond and bending strength and a triangle-shaped area in the breaking zone.

Keywords:
corner joint, strength design, internal bond, bending strength

1 INTRODUCTION

Furniture today has become indispensable in daily use. In each household, they are used in many ways. They are expected to fulfil their functions and an adequate security. To a special degree this applies to carcass furniture, such as cabinets, which usually have to carry large loads. For this reason particular requirements of stiffness and strength are made on this furniture. However, standardized values, calculations and test configurations hardly exist. Exactly therein lays the problem and task. For several decades, therefore, studies are performed on carcasses and especially at their corner joints. The aim was to support the designer's work and the work scheduling with simple values and formulas someday. This means that already during the design process a proof of the resilience and strength of the furniture can be delivered and so the function and quality can be ensured early. So far, the design of the corner joints in carcass furniture building is mostly still subject to pure experience values. Clear information such as the number and size of the fasteners or the strength of the panels are missing. So it usually results in an over or under dimensioning. This leads to avoidable material costs or non-ensuring of the safety of a piece of furniture.

2 STATE OF THE ART

A first guideline to test the quality and safety of furniture was established by the ISO standard 7170 [1]. It "[…] specifies test methods for determining the strength and durability of storage units that are fully assembled and ready for use, including their movable and non-movable parts" [1]. However, the standard refers to individually tested furniture and therefore cannot be used for general statements. In addition, materials and design are not considered further and also no requirements and maximum loads for the furniture and their compounds are defined.
The following extracts from the standard [1] confirm this:

- "[...] the tests are designed to evaluate properties without regard to materials, design/construction or manufacturing processes."
- "The test results are only valid for the unit/component tested."
- "Tests carried out according to this International Standard are intended to demonstrate the ability of the item to give satisfactory service in its intended environment."
- "This International Standard specifies test methods only. It does not specify requirements. These should be defined in a requirements document."

But in order to enable a general interpretation of carcass furniture taking into account the construction method and the materials used numerous studies have been performed in parallel. The focus was mostly on one part of the furniture: the corner joints, they are virtually the heart of carcass furniture. It largely depends on them whether a piece of furniture is stable and firm or not. Therefore, exactly this spot was frequently investigated for years and researched which factors having a significant influence on it. Until now this approach based on the corner joints always followed the stiffness design of the whole furniture (cf. ECKELMAN et al. [2] [3], GANOVIC et al. [4] [5] or KRÖPPELIN et al. [6] [7] [8] [9]). The stiffness itself describes the resistance of an elastic body against deformation by a force or torque. The stiffness of a body depends on the material, the elasticity of the material (modulus of elasticity or shear) and on the geometry. A comprehensive solution for the interpretation and dimensioning of the corpus furniture thereby, however, has still not been found.

3 A STRENGTH DESIGN APPROACH

Aim of the underlying research work is to break out in a new direction. For the construction and design of steel structures normally the strength design is used. It is a simple strength-calculation [N/mm²] of an applied force [N] over a certain cross-section [mm²]. The calculated values can be compared with general strength values of the material from various standards. The

strength design is not about the entire construct, but the behaviour and failure of materials.
The question is, if it is in this case and in so many others that easy to calculate and design a component correctly. Isn’t it possible to choose the same approach for furniture as well?
Unfortunately, it's not quite that simple. The problem lies in the material of wood or in the more specific case in the particle board or MDF. These are anisotropic and inhomogeneous.
However, this much simpler approach in comparison to the stiffness design should find its application exactly in this problem, using the general calculation of formula (1).

$$F = \sigma \times A[N] \tag{1}$$

But the classic strength design cannot be followed completely. It is not possible to establish a reference-strength at the end, because such values, as opposed to steel, for wood based materials are not available and highly depend on the direction of loading. Thus, each examined strength value must be converted into a force, which can be compared with the experimentally determined breakage force of the corner joint.
An estimating approach should be found for strength design with commonly available data to define maximum load values for the corner joint respectively the entire furniture. The data should be taken from available data sheets of the wood based composites from the producer.
The question is how a component, in this case the carcass corner, behaves under the impact of a specific force and when it fails. Moreover, how can this case be calculated?
A strength design is not related to the entire construction and its dimensions, but to the behaviour and failure of materials. Therefore the following factors must be determined first: Load assumption, internal forces, types of stress, types of material and points of failure.

4 EXPERIMENTS ON CORNER JOINTS

Basis of the studies was a blunt, simply dowelled corner joint made of customary 19 mm thick particle board. The panel sections used had the dimensions 200 x 170 mm² and were each provided with five drilled holes (diameter 10 mm) for the mounting in the testing machine. In addition, the specimens were provided with 8 mm drillings in narrow or broad surface for the dowel jointing. (figure 1 and 2)

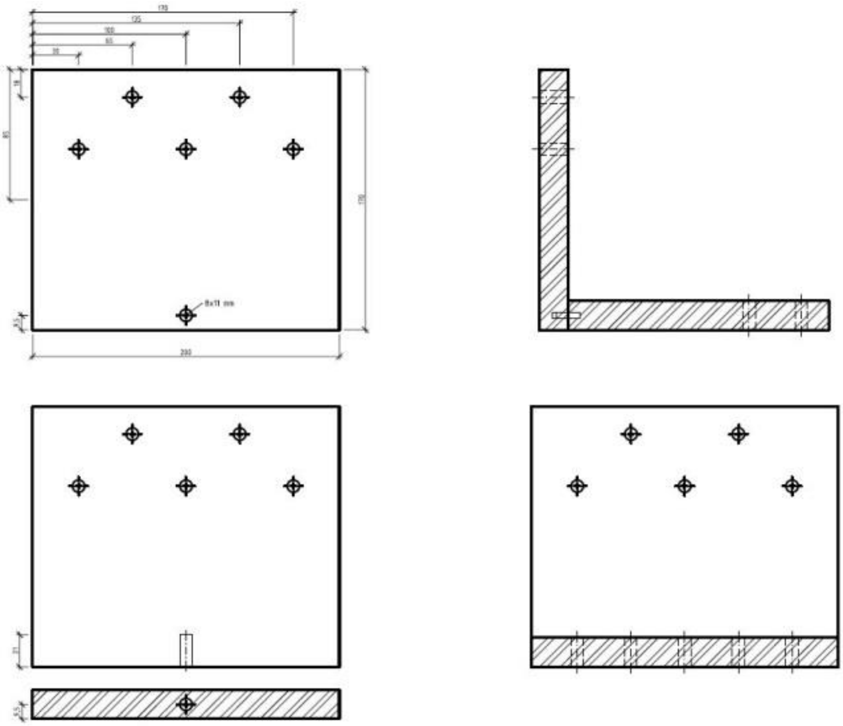

Figure 1: Drawings of the used plates and the assembled corner joint.

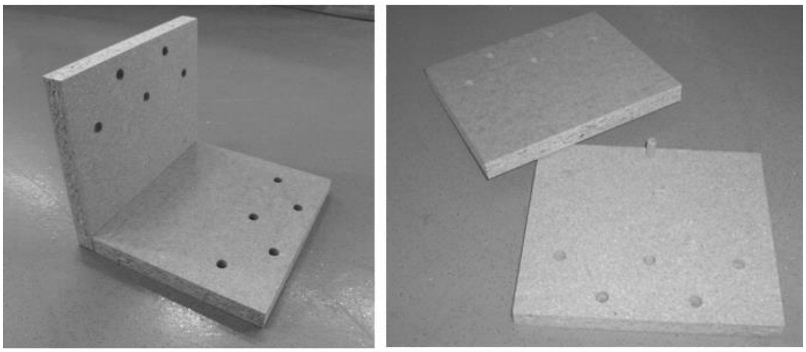

Figure 2: Corner joint: assembled (left), disassembled (right)

As fasteners customary dowels with the dimensions Ø8 x 30 mm² were used. The dowels were glued in with a standardly in industrial processes used PVA glue. This simplest connection is selected to keep the influencing factors as low as possible. In addition, specific degrees of freedom (figure 3) were restricted by the mounting and the mode of stressing (figure 4). Thus a movement in the X direction ($T_{(x)}$), meaning a simple extension of the dowel, and rotation around the Z-axis ($R_{(z)}$), meaning a bending of the corner connection were not possible.

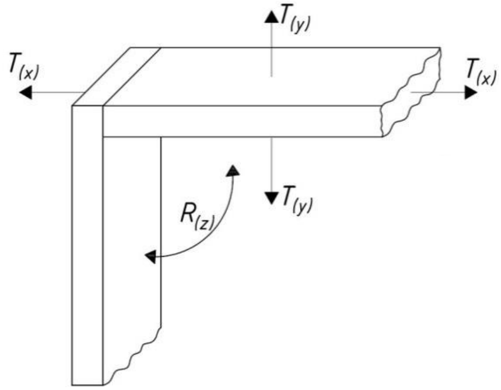

Figure 3: Degrees of freedom of a corner joint

The corner joint was clamped in a specially for this case designed mounting and tested in a universal testing machine (figure 4). The test specimen was stressed by tension until the breakage of the fastener or the bursting out of one of the two sample plates. The force was introduced in a way that the tensile force attacked directly in between the connecting joint.

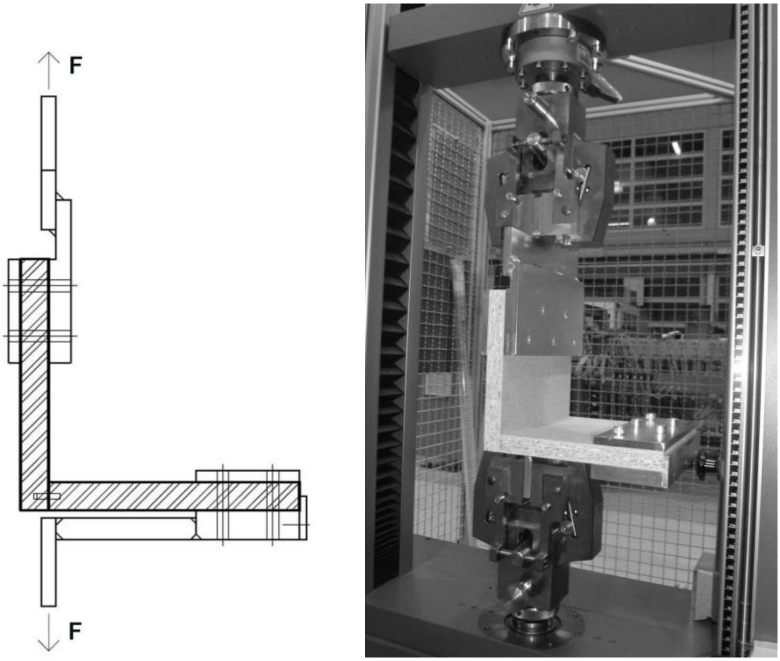

Figure 4: Special mounting for corner joint tests: drawing (left), clamped in universal testing machine (right)

For the majority of the specimens, as expected, the dowel lying in the narrow surface bursts out of the broad surface of the horizontal plate (figure 5). In a few cases, there were also outbreaks in the narrow surface of the vertical plate and by choosing a smaller diameter for the dowels also a fraction of the fastener occurred. The latter two types of fracture were not observed further, but it was concentrated on the outbreak of the broad surface.

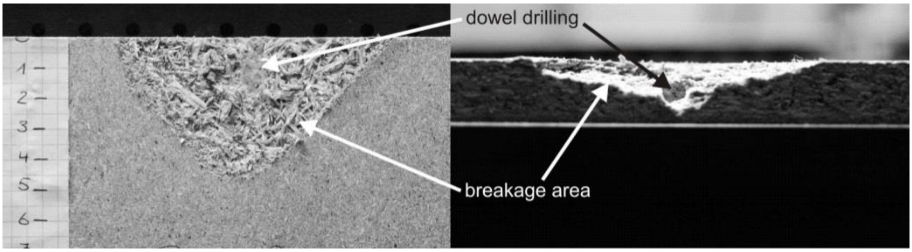

Figure 5: Dowel outburst of the broad surface of the horizontal plate.

The rupture started in the area of the dowel drilling within the core layer and ran funnel-like in about 45 degree angles to the surface layer, where this broke up. In the disrupted sample (in the panel plane) a slightly parabolic or triangular area was identified in the surface layer as well as in the area in which the dowel is located from where the breaking started (figure 6).

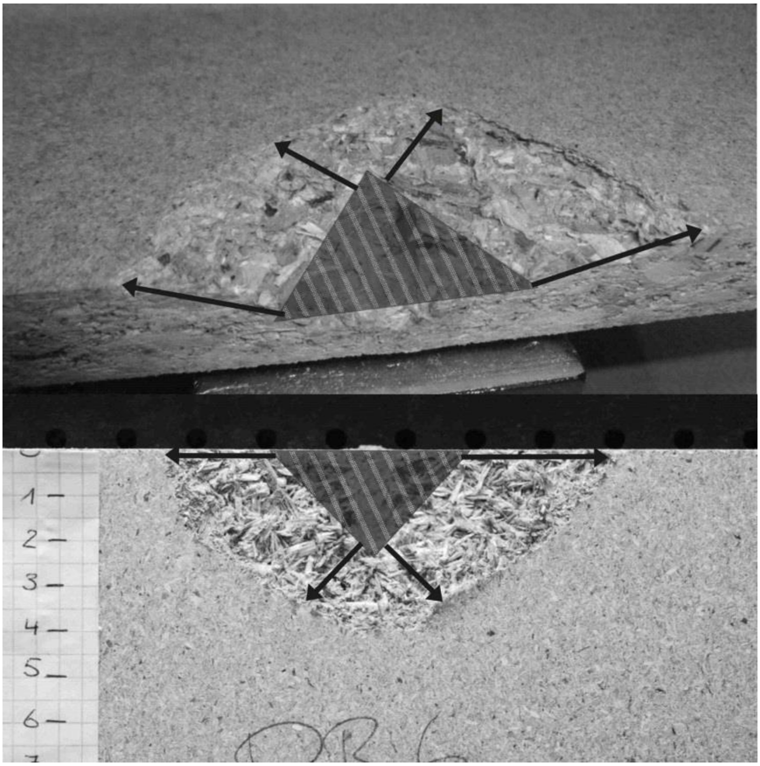

Figure 6: Fracture behaviour: triangle-shaped start of rupture, diagonal run of crack.

5 FRACTURE INTERPRETATION AND FORCE CALCULATION BY MEANS OF SHEAR STRENGTH AND INTERNAL BOND

In order to fulfil the request of generally available data and to be able to describe the fracture behaviour by these values the shear strength and internal bond values were used (figure 7).

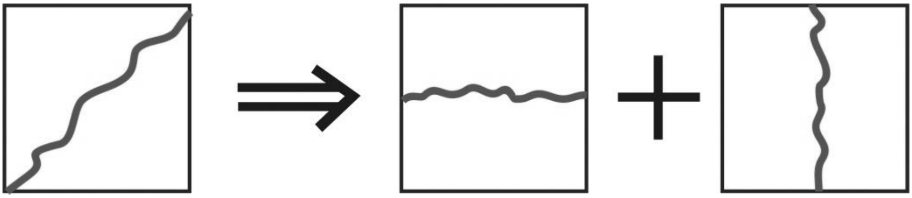

Figure 7: Diagonal fracture behaviour explained by shares of horizontal breaking (internal bond) and vertical breaking (shear strength).

The material parameters were separately determined from smaller samples as cuttings out of the panels of the corner joints in an undamaged area. The shear strength was thereby determined not according to the standard (DIN 52367:2002 [10]), but in three different modifications, to approximate the fracture behaviour which ran perpendicular to the panel plane.
For the following force calculation based on these strength values, the previously determined area of the triangle (figure 6) was used. The triangle was chosen instead of the parabola, since this is the mathematically simplest form, enabling the simplest calculation. The forces were first calculated by means of each individual strength and finally by the added values of shear strength and internal bond.
In order to make a statement about the usefulness of the calculated values, these were compared with the experimentally determined failure forces of the corner joints. For all calculations slight correlations could be revealed.
To use these values for subsequent calculations and to keep a certain security all values of the correlation line have to be smaller than the value one, i. e. all calculated values have to be smaller for estimating conservative calculation than those determined experimentally. This was only the case in the calculation by means of internal bond. The calculated forces from the shear strength values were significantly higher and would fall below the line only with a share of less than 10 %. For this reason, the shear strength was excluded for further examinations.
In conclusion of these experiments it can be said that the design or calculation of corner joints of carcasses by using a strength design is possible. The first approach shows that a calculation based on the internal bond is possible.
The approach was verified by a further series of experiments with modified corner joints. In order to eliminate other types of fracture, e. g. an outburst of the narrow surface, the vertical plate and the dowel were replaced by steel parts. For the horizontal plate, two different modified types of specimens were prepared in order to achieve certain images of failure and thus to detect particular shares of the breaking force. In the first version, the upper surface layer was grooved to the depth of the core layer (figure 8, left). The groove is triangle-shaped and adjusted to the triangle area determined in the previous work. This should eliminate the influence and

cohesion of the surface layer and put the focus on the strength component of the core layer (internal bond). The specimens of the second version were milled triangle-shaped from the lower surface layer up to the middle layer (figure 8, right). Here, only the strength component of the outer layer is determined and the effect of the core layer should be eliminated.

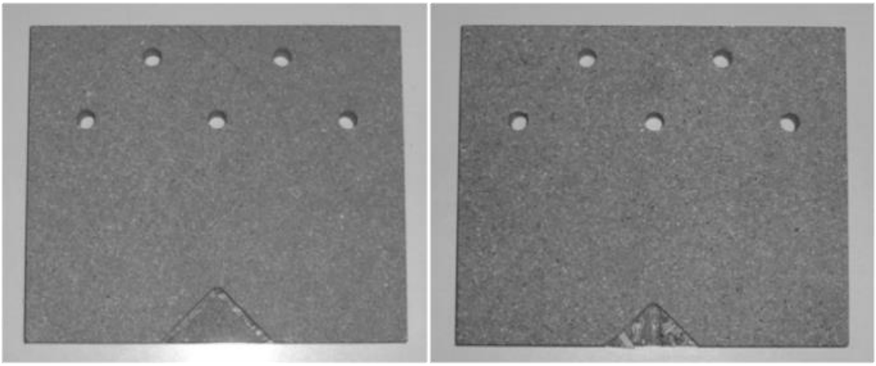

Figure 8: Plates of the modified corner joints: grooved (left), milled (right)

The determined fraction values were evaluated and compared with the previous results. The average force of the grooved samples (version I) amounts to about 18.5 % of the total breaking force in the first experiments on the corner joints. The force of the milled samples (version II) had an average share of about 81.5 % of the total breaking force of the first attempts on the corner joints.
The addition of the two force values (version I + II) approximates the breaking loads of the full corner joint testing. Thus, a comparison of the values and tests is given. The addition also shows a ratio of the breaking forces in grooved and milled sample of 1:4. I. e., the internal bond of the core layer has an impact of almost 20 % to the overall strength of the dowel break out of the plate.

6 FRACTURE INTERPRETATION AND FORCE CALCULATION BY MEANS OF BENDING STRENGTH

In order to define which other (strength-)parameters besides the internal bond have an influence on the fracture and the maximum force, further experiments were carried out.
After the exclusion of the shear strength, the bending strength was investigated as another possible factor. To obtain the strength value corresponding test pieces were taken from the panels, which were used for

the corner joints, for bending strength tests and then tested according to the standard (EN 310:1993 [11]). The bending strength was taken into consideration and tested, since the outbreak of the dowel from the broad surface opens or bends up the surface layer (figure 9).

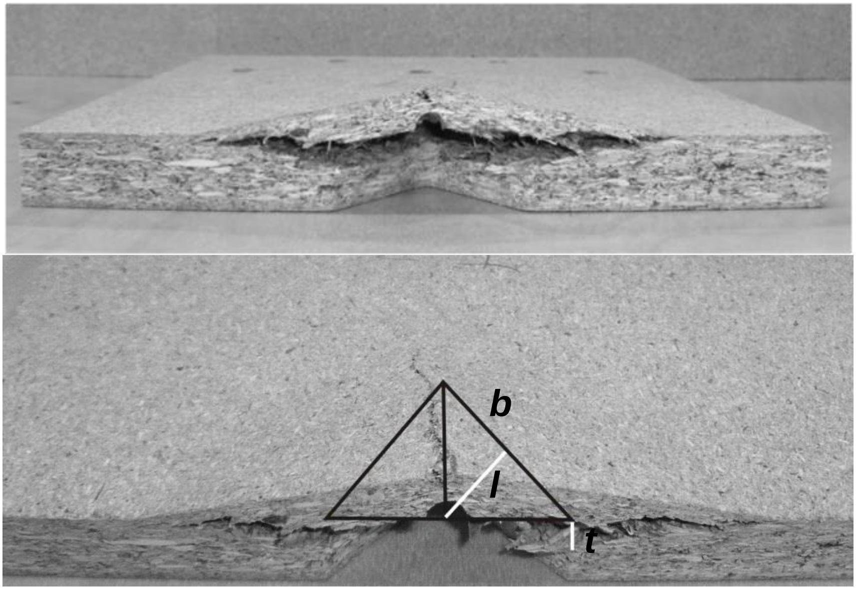

Figure 9: Bending up of the broad surface

As foundation for the calculating of the breaking force on base of the bending strength σ_B [N/mm²], the initially mentioned triangle is used again. As length l of the bending body the shortest distance from the beginning of the dowel drilling to the side of the triangle is used (14.85 mm), the width b is a side of the triangle (29.7 mm) and the thickness t is taken between the dowel and the surface layer (5.5 mm) (figure 9). The calculation of the maximum bending force F_B [N] is following formula (2).

$$F_{\mathrm{B}} = \frac{\sigma_{\mathrm{B}} \cdot b \cdot t^2}{6 \cdot l} \quad [\mathrm{N}] \tag{2}$$

The calculated mean bending force in this case of application reveals a share of about 15 % of the maximum breaking force of the first tests on the corner joints. This value has to be taken twice, due to the two bending sides. So these calculated values are significantly lower than the experimentally determined fracture forces of the corner tests. Therefore the

bending strength can be taken in consideration for a general computation as share of the total strength of the corner joint.
However, it should be noted that this calculation is very rudimentary. The process of bending up which has another lever arm at the front of the plate than at the dowel tip, hereby slips in only as an average value (length l, figure 9).
It also needs to be examined whether a clear correlation is present between the bending strength over the entire panel cross-section and the bending strength over half of the panel cross-section. This must be verified because the bending-up process in case of failure of the corner joint only takes place in the half of the panel and does not run all over the whole panel cross-section. Here the changed location of tensile and compression stresses and differences in the raw density of the core and surface layer may also be an issue. There still remain many variables to be solved.

7 CONCLUSION AND PROSPECTS

The present studies are unique in terms of the new approach. Simple dowelled corner joints were stressed by tension until the breakage of the panel. The determined breaking forces were compared with calculated values based on of the strength design. The calculation with a detected triangle-shaped area in the fracture and strength values of internal bond and bending strength provide good results. A final calculation admittedly is not possible yet, but the first approach shows that the path taken follows the right direction. The safety factor is still very high. By progressively refining with the assistance of other parameters, this value can, however, be steadily reduced.
Also again be pointed out that all studies follow the principle: "The design is done not as accurately as possible, but as accurately as needed." Therefore, the investigation and calculation approaches have been kept very simple and rough.

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ADVANCED DEVELOPMENT
THE FUZZY FRONT END OF PRODUCT DEVELOPMENT

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Abstract
In order to achieve sufficient innovation levels, handle increasing product complexity and at the same time preserve shorter development cycles, the establishment of advanced development is widely considered a fundamental step in the front end of the overall product realization process. Sometimes this stage has been given other names like pre-development and, depending on the respective industry, also technology development. Advanced development is often described as being fuzzy and blurred. An attempt is made in this paper to define advanced development in the front end of the product realization process and at the same time distinguish it from other functions in the organization. Thus, advanced development includes the pre-development of features and elements of new products but not normally basic research. Preconditions, regular problems and misuses of advanced development organizations are also described. Factors of successful advanced development organizations include a strategic focus, a consistent process model of advanced development and distinct project management. Probably the most crucial factor is an organizational integration that allows well balanced proximity as well as distance. If everything is organized accordingly, this enables a higher innovation rate, efficient product development and risk reduction. There is also less effort required during series development of products, the development time is reduced and there is focus on time-to-market as well as enabling simultaneous engineering frameworks.

Keywords
Front loading, product realization, reduction of complexity and time-to-market cycles, increase of innovation scope, idea and innovation management

1 INTRODUCTION

Entrepreneurial success quite significantly depends on innovative strength and a particular focus on development speed, engineering quality and development level, as well as product and development costs. Innovations provide a competitive edge, enabling the company to be faster and launch products earlier than its rivals. Thus, product development is in need of effectiveness and efficiency. Product development itself is becoming increasingly interdisciplinary, however in most companies processes are also becoming more clearly defined, for example in stage-gate models and in project management procedures.

The development of series final products has been experiencing an increasing acceleration over the last years, and yet at the same time the innovation steps are carried out in smaller increments to reduce complexity and uncertainties. This enforces process thinking and provokes development engineers to take increasingly smaller risks, attempting to make product development a ‘zero defect process’, which indeed is a contradiction in itself. In order to achieve sufficient innovation levels nevertheless and handle increasing product complexity at the same time as preserving shorter development cycles, the establishment of advanced development is widely considered an elementary and fundamental step prior to the overall product realization process. As every one of us well knows, every important moment in our life is characterized by a change. A change that could be big enough to transform our way of life, or, on the contrary, that could be so small that it is almost imperceptible. The same is true of a new product. In fact, it can bring innovations that could change our habits, or simply present some differences in its performance or aesthetics. Today, our world is characterized by continuous change, fast technology development cycles and short product life cycles. Therefore, if a firm wants to survive, it has to adapt to a fast changing world. The definition of new products, processes or useful and profitable services have to take the customer needs into consideration if they want to be launched in a market successfully. This determines the viability of a company in the future. It is here, where companies are immersed in this rapidly changing environment, that “Advanced Development” comes into play. In fact, the important part is to win! And for this, a firm principally has to achieve high quality products, high level performance and meet their time-to-market targets. So, as it is logical, it is at the beginning of a project, when there is only a general idea of what needs to be done, that the effort to optimize is low, however the effect on the whole innovation process could be very high. I In terms of costs this phase of pre-development is likewise important. It therefore seems obvious that all the relevant aspects involved in the introduction of a new product should be taken into account when making decisions in the pre-development phase. Consequently, it is possible that the high failure rates have often been related to insufficiencies, low management attention and poor financial support during the advanced development phase. This short article will describe the main aspects that characterize advanced development, the phases that define it, the organization around it (the people involved in this process) and the tools used to define it.

2 GENERAL DEFINITION OF ADVANCED DEVELOPMENT

Advanced development focuses on the front end of the production process, involving a greater competitive emphasis on technology, on product line management and on international coalitions. It includes the research, advanced engineering, technology and product planning that provides the foundation of every given development project.
Both product planning and development may be affected by new competitive pressures. Here, the principal challenge is to bring conceptual themes into the longer-term product cycle plans. Instead of only timing and capacity, such plan would address the evolution of product concepts so that the timing plan becomes the concept plan. The purpose would be to lay out broad themes of the product, including a profile of the target customer, identification of the target market segment and challenges in the character of the product. Thus the firm would address the changes in concept for a given model at the same time as dealing with conceptual and thematic relationships across models. Subsequently, product managers would use product and technology plans as input for developing a detailed and specific product concept. [1]
New product development itself must be carried out in compressed time spans. If development scope and complexity remain unchanged, increased trouble can be observed in the final phase of development projects, due to the need to work overtime to carry out troubleshooting and expediting. An inappropriate solution is often to reduce the content and complexity of the developed product or not to balance high complexity and content sufficiently by added resources inside product development or by external sources. Frontloading is one successful answer for the requirements of short product development cycles while not sacrificing the content and complexity of the final product, as shown in figure 1. Most of the uncertainties and unpredictability must be part of the front end of the overall innovation process, according to the old management saying of “failing early and cheap.” This leaves more predictable tasks for the product development projects and makes it possible for these projects to be managed as processes, as described in stage-gate or waterfall models. For advanced development that means that most of the uncertainties and risks are here in the early stages. Advanced development must therefore be able to handle these uncertainties, risks and even failures appropriately. Frontloading and the shift of effort to earlier phases are never a self-evident procedure and do not occur without sufficient pressure from the top. [2]
It is necessary to define the objectives to be achieved in advanced development.
Strategic objectives to be defined include the following:

- Creating major value for the customer
- Making the best use of the company’s resources

- Integrating the resources of sales, marketing, research and development and quality, as well as of production engineering and of principal suppliers.

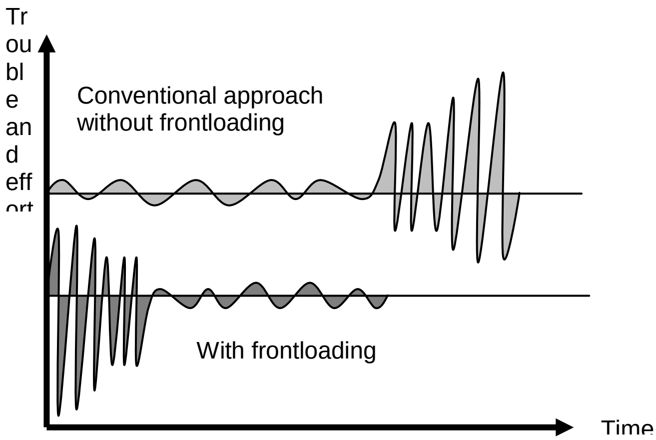

Figure 1: Frontloading effects in time and trouble reduction

Tactical objectives to be defined could be:

- Quality: to assure the development of a product with a maximum degree of customer satisfaction
- Precision: to develop a product presenting characteristics which strictly fulfill the specifications
- Efficiency: to make the best use of resources
- Innovation: to give the product new functions, new characteristics, new levels of performance and to increase the level of innovation that it involves
- Time to market: to reduce the time of product generation and launch.

Before starting to present the tools and methods which enable good pre-development in product realization, it would be interesting to bear in mind that this process leads to the definition of the basic functions of a product. This is only possible by considering that there are some influential factors which should not be underestimated. In fact, the presence of uncontrollable stresses which make our modern-day environment turbulent and uncertain, the input from customers and users, and the more controllable parameters of the product's design could modify the end product's output attributes.

For long-term success in a market, companies need innovative and competitive products, whether these innovations are just efficiency innovations to reduce costs and efforts, sustaining innovations which imply the improvement of existing products, or even disruptive innovations which change the complete market conditions. The foundation for innovative products is advanced development. So what is advanced development and what are the main tasks which must be carried out in this entity? The general scope of pre-development is often used to assess the technical realization of products and other inventive ideas for their feasibility and prepare them for series and market-oriented product development.

A further objective of advanced development after the appraisal of applicability is the introduction of new technologies in products and processes. Product concepts are designed for innovative products and prototypes are built. Rapid Prototyping is therefore a must in the early phase of product realization which makes it possible to fail early and cheap. Advanced development aims to anticipate the technical risks of the projects in series and market development and it is away from day-to-day business thinking, thus giving room for all kinds of ideas. It also solves technical and other problems before they can spoil the process of series development, and implements the long overdue standards, modularity and platforms with high functional quality and high quality interfaces, undisturbed and without pressure from orders or market introduction.

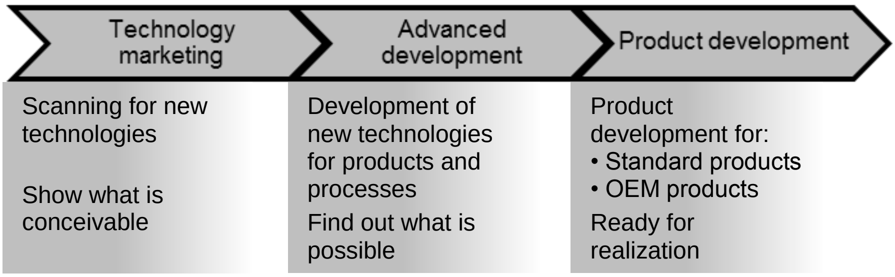

Figure 2: Positioning of advanced development (source: [3])

Advanced development is positioned between research or technology marketing and technology development and product development, as figure 2 illustrates.

Basic research and basic development which is focused on new materials and methods that are seen in research institutes and universities, are therefore normally not included. Also not included is, of course, series development, which also encompasses the finalization of market-ready products.

The successful establishment of an advanced development process offers companies the unique opportunity to reduce risks, costs and required development time, to recognize trends early on and therefore react quicker to market conditions. Factors of successful advanced development organizations include a strategic focus, a consistent process model of advanced development, and distinct project management which differs from general project management and project management in series product development. Probably the most crucial factor is organizational integration that allows well balanced proximity as well as distance.

3 STRATEGIC INTEGRATION OF ADVANCED DEVELOPMENT

The strategic integration of advanced development starts with the company's strategic targets, followed by building an innovation strategy which in turn leads to the strategy of advanced development with innovation management and the idea finding process. It is upon this basis that advanced development projects can get started. This makes it obvious that advanced development has to be at the core of innovation management and even the strategic management of the entire enterprise. Particularly the process which leads to advanced development projects is very risky and can be compared with the assessment process of venture capitalists. The assessment of advanced development projects therefore needs the involvement of strategic management i. e. the senior management of an enterprise. The process of the strategic integration of advanced development is shown in figure 3.

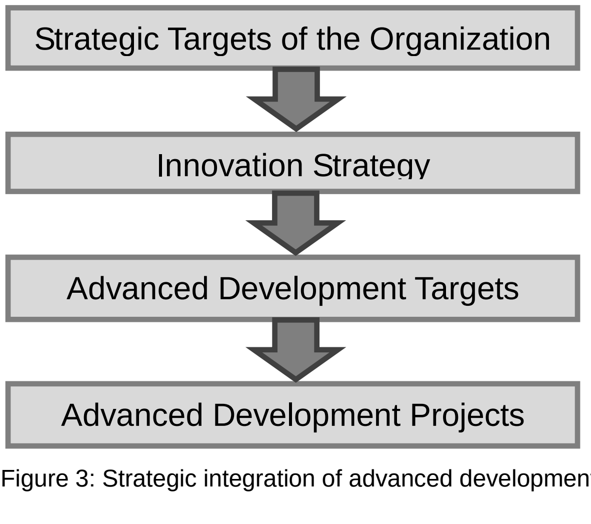

Figure 3: Strategic integration of advanced development

4 ORGANIZATION AND STRUCTURE OF ADVANCED DEVELOPMENT

Often a decision is necessary as to whether the integration of advanced development into product development or rather an organizational separation is more appropriate in the industry or firm. The way in which advanced development can be embedded within the organizational blueprint of a company is shown in the following figure:

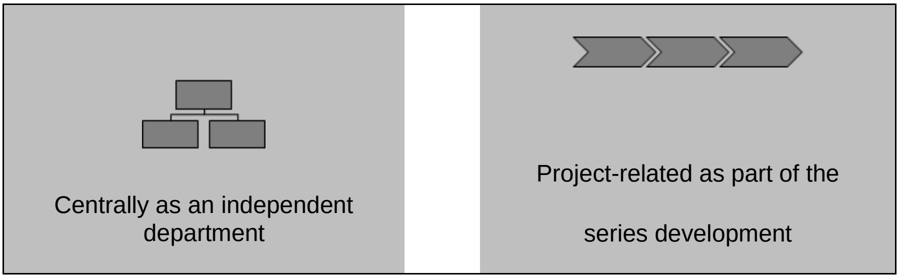

Figure 4: Organization by function or by process

Firstly, it can be organized centrally as an independent department. Major advantages of an organization with an independent advanced development entity can be achieved due to a clear distinction between the advanced development unit and series development. Capacities and resources can be allocated clearly and the risk of stealing capacities from the advanced development department is minimized.
Secondly, advanced development can be organized project-related as part of the series development. The advantages are mainly that there are fewer interfaces and departmental borders to consider, which ideally causes less cultural misunderstanding. On the other hand, this integration often causes problems with the allocation of capacities and resources in the advanced development stage, and the risk of minimizing the advanced development capacities due to stressful situations within series development is quite high.

5 IDEA GENERATION WITHIN THE ADVANCED DEVELOPMENT PROCESS

Generating, managing and changing information are an important initial part of product development. Sectors like Marketing, Sales, Research and Development, Technical Assistance or Quality Assurance can contribute to finding out and exchanging all the internal information and generating new ideas. In advanced development, the information from customers and suppliers is generated from outside of firms instead. Increasingly, companies want to get closer to their customers and understand their needs. Here, two methods can help the companies to collect data for the improvement of new products.

Increasingly, companies want to get closer to their customers and understand their needs. Here, two methods can help the companies to collect data for the improvement of new products.
One is “Information Acceleration” as a method that places potential customers in a virtual future environment and measures the likelihood of purchase, perceptions and preferences. The future environment is multi-media based and a customer can choose the information sources he or she would usually use to make a buying decision. [4]

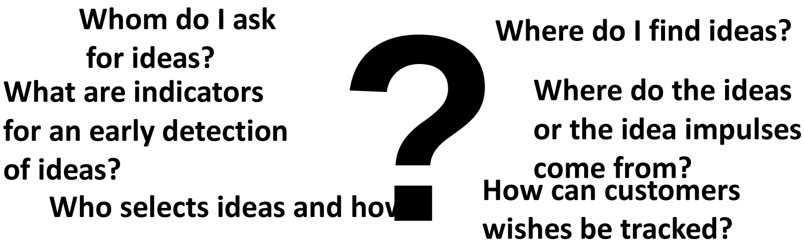

Figure 5: Questions concerning idea generation and selection

The other is the “Web Based Conjoint Analysis”. This is the most used quantitative method for concept testing. Basically, in a conjoint analysis a product is broken down into features with different characteristics for each feature. The aim of a conjoint analysis is to find out which characteristics of the features customers prefer and how much they value the features. It is a mathematical technique to reduce the amount of combinations of feature characteristics which have to be ranked or rated by customers. [5]
Virtual prototyping enables concept tests without building physical prototypes. As the costs for virtual prototypes are lower than for physical prototypes, more concepts can be tested within the same market research budget. The results with virtual prototypes should be compared to a small amount of physical prototypes.
For companies there is a big opportunity to make products or components sharing their know-how with suppliers by using a co-design approach. This means developing and producing components together with their supply partners. Especially since many products and technologies include highly specialized R&D knowledge, advanced development becomes one focus point for this outside-in open innovation aspect. The inside-out aspect of open innovation may also be a strategic policy for advanced development which can be achieved by selling not internally used ideas, patents or products originated in advanced development.
These large quantities of data will then be used by the managers to find out the best strategy starting from the product pre-development until the launch of the product in the market.

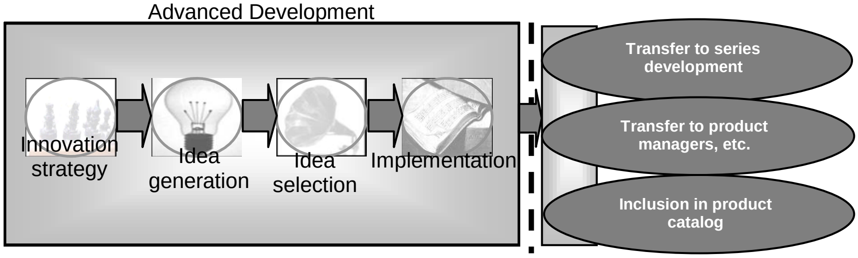

Figure 6: Idea generation, evaluation and selection as part of advanced development

6 PREREQUISITES AND SUCCESS FACTORS OF ADVANCED DEVELOPMENT

In order to implement a successful advanced development process, companies need to define a strategic direction which is the basis for their innovation and advanced development strategy. As product development is increasingly interdisciplinary it needs clearly defined processes, for example in stage-gate models and with a minimum of project management. Probably the most crucial factor for advanced development is the organizational integration that allows well balanced proximity as well as distance.
The following 8 elements summarize conditions and preconditions for advanced development processes which are proven by practical reference:

1. A suitable process model combined with appropriate project management provides a clear structure for advanced development.
2. As described in chapter 4, a decision about the integration of advanced development within the organizational blueprint is necessary. Positioning advanced development in between basic development and series development offers benefits when compared against a project-related organizational structure.
3. Strategic integration of advanced development starts with the company's strategic targets, followed by building an innovation strategy, which in turn leads to the strategy of advanced development.
4. Innovative ideas are the basis for innovative products. Possible sources for the generation of ideas can be a) group discussions with end users, b) quantitative surveys, c) discussions with subsidiaries, e) visits to dealer stores.
5. How can companies take the customer point of view into account and focus on it? Based on surveys, a definition of key buying and usage criteria of products can give helpful insights for further development. Of

course, this does not mean to simply ask consumers what they want. Instead, companies need to understand what job has to be done.

6. Based on the key buying and usage criteria of the products, companies are able to set the focus on future innovation areas for their products and on a proper development destination board.
7. Roadmapping provides graphical support for strategic planning. It allows companies to align technological capabilities with their production plans and business, so that strategy and technology goes hand in hand.
8. Derived from the road map, advanced development topics for the projects can be defined.

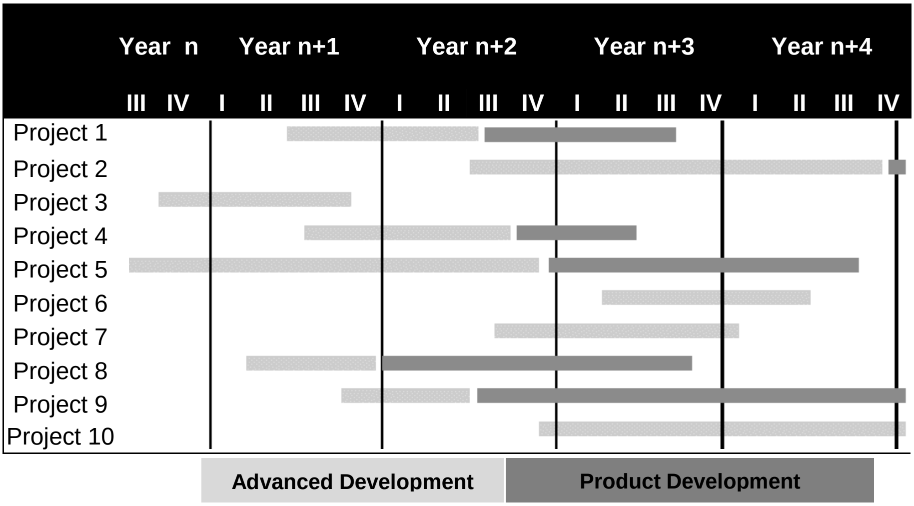

Figure 7: An exemplary road map showing the inclusion of advanced development

7 ADVANTAGES AND PROBLEMS OF ADVANCED DEVELOPMENT

Successful introduction and operation of advanced development offers a lot of opportunities, especially if it is organized adequately as an independent entity.

Companies have the opportunity to achieve a higher innovation rate when they focus more intently on areas where they might spot, anticipate, conceptualize, prototype test and pre-develop trends. This can lead to deeper insight into problems and problem solving, as well as, maintaining a high rate of learning, which directly or indirectly enables more R&D output.

As the risks in series development can be reduced through advanced development, this can result in efficient series product development with less

effort, reduced development time and iteration cycles as well as more emphasis on time-to-market.
Problems and misuses of advanced development organizations are observed in the following elements and criteria. In stressful situations (e.g. the phase directly before start of production) companies tend to steal advanced development resources to strengthen the series development process. As it is important to give the engineers involved in the advanced development process a certain amount of room to go bonkers without any consequences and to work on problems which seem to be disconnected with existing products or even the current environment, pre-development sometimes receives the reputation of the "ivory tower syndrome"; creating ideas with no reference to reality and being a home to weirdo characters and creative chaos.
Whenever the organizational blueprint is not clear and leaves room for interpretation not exactly defined interfaces to series development and insufficient exchange of information as well as a lack of acceptance within series development and other company functions may be a result.
As the realization of series products is the main focus of attention, advanced development might sometimes be treated as a second priority, as the advantages and benefits are not directly seen in the current situation of the company [6].
One of the biggest problems in advanced development is obviously performance measurement, since the output is not often directly marketable products. Benchmarking is made more difficult due to the fact that advanced development is filled with uncertainty and unavoidable failures and because the processes are not nearly as well predefined as they are in new product development. However, benchmarking is not impossible. Benchmarking of the entire innovation and product realization process has given many companies the impulse to set up and establish an advanced benchmarking entity. However, in order not to reduce advanced development to some kind of non-reviewed playground for creative but weird innovators, a benchmarking approach with a completely new set of criteria is required. Key performance indicators (KPIs), therefore, should cover the following areas of assessment:

- Resources: Also included are KPIs which evaluate staff in quantity and quality, equipment and budget.
- Values: KPIs will have to assess the backing of advanced development by the senior management and major stakeholders as well as organization's ability to tolerate failures.
- Structure and processes: A proper structure and adequate project management are KPI criteria in this field.
- Output: Since most advanced development projects do not directly lead to new products, KPIs like "revenue generated by young products" supply only a very long-term picture. Other KPIs such as the number of ideas, the number of successful projects, or the number of patents are

more appropriate criteria in the short-term. It is particularly important to include aspects of learning, gain in knowledge and intellectual properties in the output benchmarking criteria. The most often underestimated effect of advanced development is the time saved in subsequent, upcoming projects, and yet this is the best justification for all investments in advanced development.

8 SUMMARY AND CONCLUSION

Advanced development, the phase in the beginning of a product realization process, can be described as the fuzzy front-end. This phase may be a high-risk one and is by no means a zero-defect process; however it seems to play an important role for all firms that are willing to innovate, compete against other innovators and prevent falling behind. By means of advanced development it is possible to define what is conceivable, what could be a possible change that gives birth to a new product and define what is achievable. Technical research, customers, competitors and suppliers analysis, for instance, supply information about what job has to be done and what products are possible. The tools, methods and especially the people involved in this pre-development phase make the ideas achievable.
This then means that the company's degree of technological novelty can be as high as necessary in order to stay ahead of the competition, or that the firm then has the means to track technological progress, thereby identifying new opportunities and reducing time consumption. This integration of information and the means to make the best use of resources allow the company to reduce time, waste and consequently, cost.

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TOOL MATERIALS FOR WOOD WORKING PROCESS

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Abstract
For wear or corrosion protection of cutting tools in wood machining, the application of coatings is actually not common, but some previous works showed their efficiency. In fact, the coatings increase the life of the cutting tools, but on the other side their adhesion appears not sufficient.
In this paper a review of several proposals of coatings on a sintered tungsten carbide substrate tools are presented. During chip removal process temperature arises, the tool can be cooled with air only, and problems of coatings life, delaminating, arise with corrosion phenomena if some types of wood are worked.
Finally a new coating process ALD (Atomic Layer Deposition) is proposed to test. The coating process is a multi layer deposition on a sintered tungsten carbide substrate that should over pass the above mentioned problems.
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Keywords:
Wood-working tool, coating, wear, tool life

1 INTRODUCTION

Actually wood products have a very high demand in the world market. The wood industry is now faced with a strong competition in manufacturing furniture products in particular and machining increases for engineered materials that are wood-based or wood-composites also because of a reduced supply of solid wood and of structural problems.
At now tool materials commonly used for wood processing are: HSS, sintered tungsten carbide WC and polycrystalline diamond PCD.
After its introduction, the sintered tungsten carbide had improved the tool material performances working several types of wood composites and it is widely used at now. The sintered WC tool inserts are involved in several wear mechanisms during wood chip removal, the most common of which are in order: abrasion, erosion, micro fractures, chemical and electrochemical corrosion and oxidation.
Attention to tool wear behaviour is now mandatory in particular with the introduction of new wood-based composite materials that are more abrasive and, because of the higher cutting speed that are adopted, they also require frequent tool changes.

Coatings will improve the tool performance increasing the resistance to abrasion and to impact stress and their proper applications are described in following.
The paper starts with several proposals of coatings that are tested on various wood materials, plain wood and wood composites, and the wear resistance with the adhesion performance are analysed. Multi layers solutions are commonly adopted for many reasons: having enough coating thickness, adhesion improving, avoiding cracks, corrosion resistance material, …
Finally a new coating process ALD (Atomic Layer Deposition) is proposed to test. The coating process is a multi layer deposition on a sintered tungsten carbide substrate that should over pass the above mentioned problems. Such a deposition is exceptionally conformal: this means it is possible to coat a surface precisely following the substrate profile even in presence of cracks or high aspect ratio holes. Deposited films are nearly defect-free; the reason is that the growing process is strictly bound to surface adsorption:

2 HSS TOOLS AND COATINGS

Among the wood extractives of practical interest are the tannins, phenolic substances that are contained in major quantity in common European wood like oak, chestnut, pine and non european woods like wattle (*Acacia* genus), and hemlock (conifer).
By Winkelmann et alii [1] tannins have higher acidities which is the main cause of corrosion effects. The complexity of the evolution of the tannins decomposition produces acid molecules that increase with raising the temperature. In wood working the HSS tools are strongly subjected to corrosion because iron cannot build up a strong passivation layer against tannins acids, Gust and Suwalski [2]: the tannin-iron compounds are easily removed by mechanical stress due to cutting process and the corrosion effect increases. After the wood work the tool shows pitting effect due to corrosion that cannot be eliminated with re-grinding because new micro cavities emerge on the surface.
Therefore, steel tool wear in wood cutting takes place because of two events: corrosion and abrasion.
In order to improve corrosion resistance of steel substrate with hardness stability at high temperature process, multi-layer coatings are proposed and tested by Grips et alii in [3]. Physical Vapour Depositions (PVD), magnetron sputtering process, of TiN, CrN and TiAlN demonstrate to improve resistance to corrosion and wear, but, in any case, acid attacks cause demolition of the coatings due to imperfection of coating process: pores, micro-cracks, grain boundaries,…The study found that a multilayer coating TiAlN/CrN offers the best corrosion resistance and with an interlayer of Cr between the substrate and the film also adhesion is improved. The anti-corrosion behaviour has been evaluated and experimental tests showed that

a better resistance to corrosion that can be improved with the coating thickness. This is very difficult to reach for a single layer, so, with an additional interlayer of electroless Ni: ENi/Cr/TiAlN/CrN, the corrosion resistance has been improved by a factor of 33. The multilayer coating architecture has been introduced in order to reduce the columnar structure of the coated material and to block cracks in the interlayer border. Furthermore, the stress in the coating building is reduced and the adhesion to the substrate could be improved adding a transition layer between coating and substrate.
As before said, a good corrosion resistance is given by adopting a ternary nitride TiAlN coating with a CrN oxidising protection. CrN shows a better corrosion and wear resistance than TiN, thereby a CrAlN coating will offer higher performance with respect to tribological behaviour, Ding and Zeng [4]. Coating deposition starts with a Cr layer on the HSS substrate to guarantee adhesion, then a CrN transition layer with Cr- Al-N layer to prevent corrosion and finally the ternary nitride CrAlN. Final layer possess a high hardness 30 GPa that increase with the Al content and improve wear resistance, but with a slightly increase of friction coefficient. The wear resistance has been tested being about six time greater than CrN (see[3]).
Another work by Gilewicz et alii [5] proposes a PVD multi-layer coating, seven in this case of 400 nm each, using CrN and CrCN as an anti wear and corrosion resistance. A Cr sub-layer of 0,1 μm has been deposited on the HSS substrate to guarantee the adhesion of the multi-layer structure. Note that adding C to CrN, it reduces its adhesion to the substrate, but it decreases internal stresses and increases hardness, 28 GPa. Industrial tests have been carried out milling 6000 m of pine board: cutting speed 36m/s, feed rate 10 m/min, cutting depth 1mm.

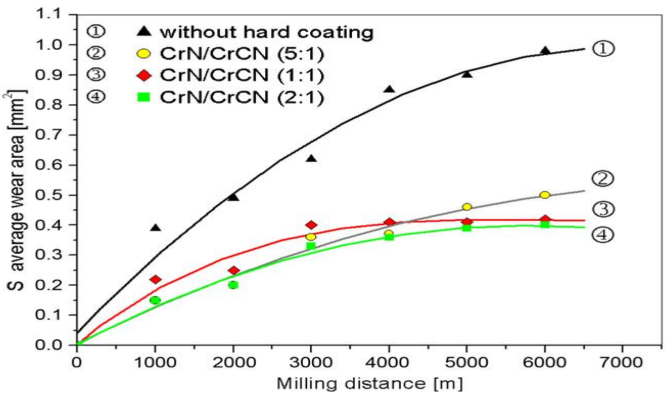

Figure 1: Multilayer wear on HSS substrate, from [5].

Comparing to HSS tools, the life time between two consecutive re-grindings, is about three times higher (fig.1). Thanks to Cr sub-layer the adhesion reached the highest values measured both by scratch test, 115 – 95 N, and the Daimler Benz test, HF1 – HF2.
Warcholinski and Gilewicz, carried out in [6] an industrial wear test working pine wood board and comparing the performances of multilayer coatings of CrCN/CrN and of TiAlN/TiN on HSS substrate. Seven couples of layers of 400nm each have been deposited by PVD process, total thickness ca.3μm. Same tests were carried out with TiAlN coating and uncoated tools for reference. Cutting conditions were: cutting speed 38m/s, feed rate 40m/min, cutting depth 0,7mm, cutting length up to 20 km.
Micrographs from [6] show the cutting edge and the rake face wear of the three materials: the coated tools have similar performance and about two times higher wear resistance in comparison, figg.2.-3., with HSS uncoated tool. CrCN/CrN coated tool gives a slightly better performance due to its higher adhesion resistance to the substrate.
In fact, adhesion to the substrate have been tested with scratch test and with indentation test giving both the higher values for CrCN/CrN. Scratch test: 105N for CrCN/CrN, 90N for TiAlN/TiN; Daimler Benz Indentation test: HF1 for CrCN/CrN and HF2 for TiAlN/TiN.
Authors remark that TiAlN/TiN coating exhibits an oxidation resistance up to 800°C and hardness of 25GPa at 700°C. The oxidation process at high temperature produces Al_2O_3, that provides high hardness, thermal insulation and protection from chemical and abrasive wear.

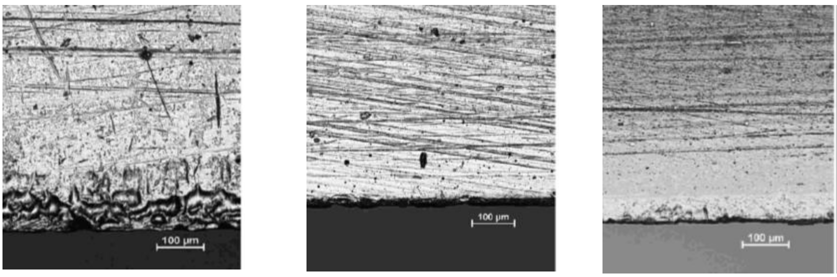

Figure 2: Wear for uncoated, TiAlN/TiN and CrCN/CrN coatings, from [6].

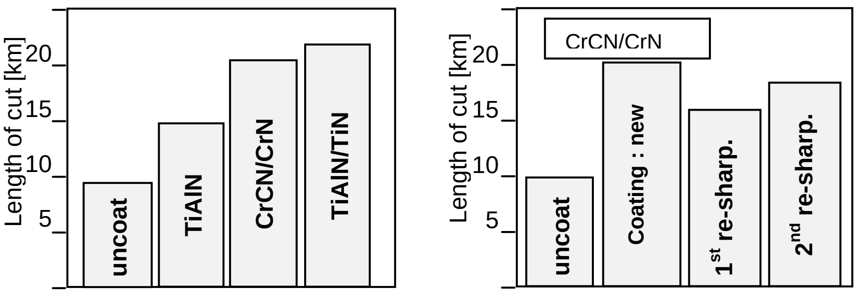

Figure 3: Length of cut for the tested coatings, from [6].

3 SINTERED WC AND COATINGS

Sintered WC carbides are considered a very good wear resistant tool material and a WC grain size of about 0.5 μm allows a sharp cutting edge with an ideal radius of 1 μm for a high quality wood working. WC shows very high hardness and wear-resistance to abrasion in working wood with any grain orientation and with knots and inclusions (silica). But, on the other side, the metallic binding phase, cobalt, reacts with tannin acids producing its dissolution and leaves the WC grains being removed during process.
A review of sintered WC tool life in wood working is discussed by Ramasamy and Ratnasingman in [7]. Authors confirm the degradation of the sintered structure, cobalt, due to tannin acids when machining Oak wood and the same thing happens if wood product like fibreboard is processed in particular if in presence of high moisture content. On the other side, strong abrasion wear is remarkable in machining MDF and particleboard where the mechanical action in the tool-wood contact produce an abrasion of the tool material due to crack formation and plastic deformation of cobalt binder (lack of adhesion).
Avoiding corrosion of coated WC inserts, ceramic materials has been proposed as alternative tool material by Kuebler et alii in [8]. Several authors in [9] and [10] proposed a Si_3N_4 ceramic based composites, CMC, material inserts, that offer higher hardness compared to WC and highest corrosion resistance. Cutting tests have been carried out comparing wear rate of WC and CMC inserts. Hard and soft wood and panels with alternating fibre orientation were used in tests that demonstrated a life time of the ceramic insert of about three times higher that one of sintered WC, producing the same worked quality surface.
Wear resistant coatings has been deposited by PVD method on WC tools and tested in MDF industrial working by Benlatreche in [11]. The coating was ternary nitride CrAlN with thickness up to 3 μm. Different content of Al has first been tested, from 5% to 51%, and best wear performance was shown with 5% Al.

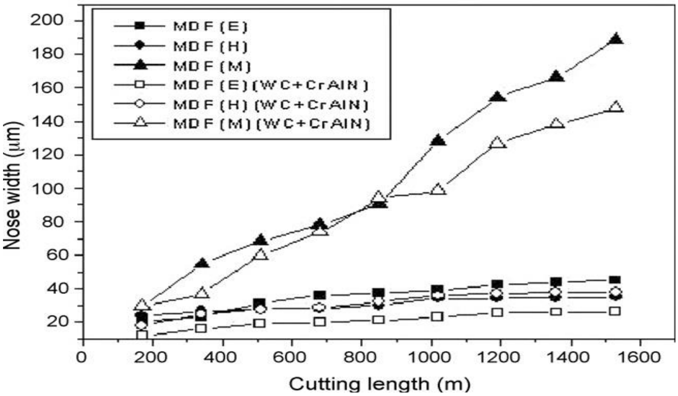

Figure 4: Wear tests comparing coated with uncoated tools, from [11].

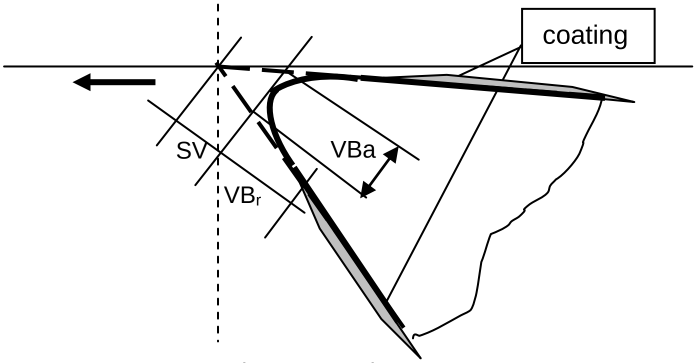

Figure 5: Tool wear measures.

This is because Al content increases the friction coefficient and requests higher cutting forces [4].
Cutting tests have been carried out working a 5,5 mm thickness MDF of three types: E standard, H waterproof and M fireproof. Cutting conditions were: cutting speed 38m/s, feed rate 15m/min for a cutting length of 1530m.
Taking into consideration uncoated WC tool as reference, the results showed a better performance with standard MDF, no variation with waterproof MDF and a slightly better with fireproof MDF that has a highest degree content of abrasive impurities. Wear measure is VBa, fig. 4. and 5.
In order to improve the impact resistance in working wood-based products and, in the same time, to obtain the highest adhesion of the coating on a cemented carbide substrate, Pinheiro et alii [12] studied and tested a particular multilayer solution. Different layer of coatings were deposited by a PVD procedure in alternate sequence: softer/ harder. This should prevent crack propagation of the brittle one, the harder, as a consequence of impact stresses during working wood-based products like oriented strand boards and wood particleboards. The coatings were of two types: titanium and chromium based, TiWN/TiW and CrWN/CrW that have been deposited in much architecture from 3 up to 21 layers. A monolithic layer of each of the harder materials has been also tested together with uncoated tungsten carbide for reference. The results show a better performance of monolayer coatings, but for only some hundred meters before being removed both in OSB and in particleboard working; cutting conditions: cutting speed 17m/s, feed rate 15m/min. Best performance has been seen for a lower number of coating layers in particular for three layers a noticeable increasing in wear resistance of about five times has been measured, fig.6. Similar behaviour, slightly better for multilayer coating, appears for all tools in the contact with the external layer of particleboard.
Bouzakis et alii [13] tested the wear resistance of a WC insert coated by a TiAlN with a high ion sputtering PVD deposition. This is a monolayer that shows a high hardness on its surface due to Al oxidation, a ceramic material

that protects against corrosion and offers a strong adhesion to the WC substrate: 3,600HV, up to 850°C operating temperature, 2-5µm coating layer thickness.

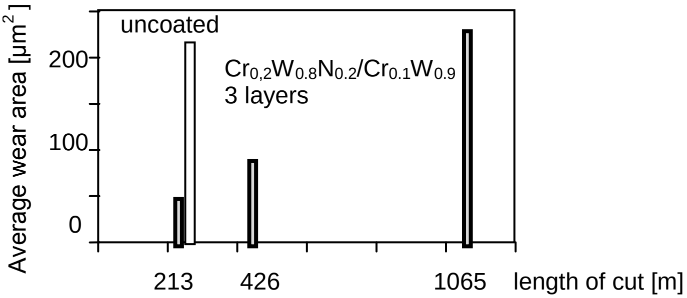

Figure 6: Average wear area for cutting tool coated by $Cr_{0,2}W_{0.8}N_{0.2}/Cr_{0.1}W_{0.9}$ 3 layers, from [12].

A grit blasting process of the substrate surface is a pre-treatment before coating deposition that enhances the adhesion [14]. Working experiments, cutting speed 14 m/s, feed rate 9,9 mm/s and cutting length of about 20 km, were carried out milling chipboard and showed that abrasion mechanism and adhesion strength are the main causes of wear and the tested coated tool had an excellent wear performance. In this case wear has been measured by SV+Br, fig. 5.

Darmawan et alii in [15] tested coatings of TiCN, TiN, CrN and TiN/AlN over sintered WC tools P30 grade. They worked a wood-chip cemented board comparing the performances with uncoated tool with cutting speeds from 30m/s up to 60 m/s. It is important that their experiments showed that the main cause of wear was determined by mechanical abrasion with a small contribution of chemical reactions at lower cutting speeds. At higher cutting speed he confirmed that only TiN/AlN was not susceptible to chemical reaction as Bouzakis said in [13].

Darmawan et alii [16] again investigated the delamination problem of coatings during working particle wood composite board. Coatings, on a K10 grade sintered WC, were based on TiAlN layer coupled with TiSiN, TiBN or CrAlN. These are new proposal coatings for their excellent properties of low friction coefficient, high hardness and corrosion/oxidation resistance. Working conditions were: cutting speed 41.8m/s, feed rate 0.3 mm/rev. After 1 km of cutting the TiAlN/CrAlN did not suffer any delamination and justification of such behaviour is its lower friction coefficient and oxidation resistance. In fact, the oxidation of Al contributes as a barrier to a thermal degradation due to oxidation of the coating that is accelerated at the higher process temperature up to 800°C.

4 DIAMOND COATING

PCD is a composite of diamond particles sintered together with a metallic binder and bonded to a WC substrate [17] or, by CVD process, C atoms are allowed to grow as diamond crystals on a suitable substrate. Diamond coating have been introduced in working composites wood materials like fibreboards and chipboards that are highly abrasive and cause a rapid decline if WC tools are used. In fact, it was found that the PCD coatings have a tool life more than 60 times greater than sintered WC. Miklaszewski et alii [18] analysed the damage by abrasion of sintered PCD coating working wood particleboard: cutting speed 40m/s. Chipping of diamond crystals were already detected caused by long cracks between grains, but authors found an additional mechanism due to something like slices, that are observed giving a peeling wear effect.

Other authors, Sheikh-Ahmad et alii [19], studied the delamination and chipping damage in a CVD diamond coating over a sintered WC substrate working MDF: cutting speed 61 m/s. The chipping has been ascribed as a premature event due to insufficient adhesion to substrate or/and to the presence of residual stresses in the coating. The problem arises to the need of a very sharp cutting edge for wood working, the occurrence of impact loading and lack of the edge strength as a consequence. Authors successfully attempt to reduce the chipping by a pre treatment of the sintered WC surface: honing the surface and then coating diamond, gave significant improvement to the adhesion resistance maintaining the cutting edge geometry, abrasive wear only, and reducing chipping.

Chipping, when working wood composite hard materials, in this case cement fiber board FCB and high pressure laminated flooring HPL, has been faced by Philbin P. in [20] with a circular saw working conditions: cutting speed 47 m/s and feed rate 0,4 mm/tooth max. Chipping occurs when micro cracks initiate with impact against working material if it is inhomogeneous and because of inclusion of hard materials, chipboard, producing inter-granular wear, grain cleavage, peeling and chipping itself.

The homogeneous FCB working reveals a dominant abrasive wear for the PCD coated tool with some micro voids due to the loss of diamond grains after the abrasion of the cobalt binder. In the case of HPL, a non homogeneous product made by HDF with top hard abrasive layers, the PCD coating shows a clear chipping loss in the side of the edge due to impact to the hard surface laminate.

5 CONCLUSION

Literature on progress of tool material for wood and wood-composite materials highlights that adopting tool material that are already employed in metal chip removal process cannot be simply transferred to wood furniture’s industrial production. Materials and cutting conditions are very different by the need of adopting highest cutting speeds; this bring to cause high temperature, 850°C, on the tool edge that cannot be cooled with liquid but only by air, impact loads and corrosion by acids from wood extractives. Actually the most employed materials are steel HSS, sintered tungsten carbides WC and polycrystalline diamond PCD, the last two due to the great diffusion of engineered wood materials like fibre-wood boards and chip-wood boards that are highly abrasive. Emphasis has been put on hard coating over HSS and WC base tool material for limiting wear, but problems arose on adhesion to the substrate for which some proposals have been submitted. In fact, Physical Vapour Deposition, which is commonly employed for tool coating, reveals such problems in particular binding with WC and particular pre-treatments have been proposed on the surface substrate. Corrosion seems being solved creating a ceramic barrier on the coating by means of oxidation of Al.

A proposal for a new coating procedure will be developed by labs of University of Trieste using an alternative technique to Chemical Vapour Deposition which is Atomic Layer Deposition ALD.

Compared to alternative coating processes, ALD is characterized by several interesting peculiarities:

- Due to the self-limiting nature of the process, production rate depends only on the number of cycles per unit time; as a consequence it is straightforward to control thickness with high accuracy and repeatability. It is common to have sub-nanometer thickness control.
- Deposition is exceptionally conformal: this means it is possible to coat a surface precisely following the substrate profile even in presence of cracks or high aspect ratio holes; this make easy to coat even porous or fibrous materials.
- Deposited films are nearly defect-free; the reason is that the growing process is strictly bound to surface adsorption: gaseous precursor react with all available surface sites, leading to an intrinsically uniform film.
- Films are extremely smooth: for a film with a thickness of tens to hundreds of nanometers it is common to have some nanometers surface roughness; roughness is mainly due to crystallites formation and growth, this means roughness finally depends on film thickness, but can be controlled with multiple layers deposition.
- Grain size depends too on film thickness and again can be controlled with tailored processing approach.

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PACKAGING OPTIMIZATION FOR FLAT-PACKED FURNITURE

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Abstract
Packaging systems for flat-packed furniture are becoming increasingly complex, due to the large product variety. Packaging supply chains are designed for mass production of standard sizes, resulting in the use of fillers, which is expensive in terms of materials and human resources. This paper shows how individual boxes can be calculated with the help of heuristics of container loading problems and subsequently, using the Postponement Strategy, be produced and automatically cut to size.

Keywords:
Packaging Optimization, Container Loading Problems, Postponement, Supply-Chain-Management

1 INTRODUCTION

Packing systems for flat-packed furniture are becoming more and more complex due to the increase in the variety of the products, short product life-cycles and the decrease in lot size of the furniture. Corrugated board production technology is, however, designed to produce standardized packing in large quantities. The use of standardized packing results in the need to use fillers for larger objects, or packing that must be manually cut to size. In view of the material consumption of packaging, this is a great waste of material, packing time is also greater, leading to a waste of human resources.
This paper shows an approach which enables the production of custom made, lot size 1 packaging systems. Chapter 2 shows the calculation of optimal packing sizes, using heuristics of container loading problems and Chapter 3 cutting the packing to size at the pack station, the right quantity at the right time. A conclusion completes this paper in chapter 4.

2 ARRANGEMENT OF FURNITURE PARTS

2.1 Introduction

The arrangement of furniture parts requires distributing the parts into several boxes and arranging the parts within the box, using the volume to full capacity.

The basic problem can be expressed as follows [1]:

1. Given is a three-dimensional packaging space, defined by length, width and height.
2. There are a finite number of solid parts, which must be placed into the box, the arrangement must be orthogonal and without overlapping.
3. The desired result is placement of parts with maximum use of volume capacity.

The aim of placement optimization is maximum use of volume capacity and minimum free space, as free space must be filled with cost-intensive packing material. Unnecessarily large packets also require more packaging time and incur higher freight costs.

2.2 Problem Types

Subject to the general set-up within the packaging company and the products they pack, there are a wide-range of problem types, which can be grouped as follows [1]:

Type and quantity of boxes

The placement optimisation may be restricted by space and weight constraints of a container. It may also be necessary to split the product or commission due to customer handling issues, haulage contractor or courier size and weight guidelines are a further reason for splitting. These cases are known as a Multiple Container Loading Problems [2].

Form of objects

The object form also informs the character of the optimisation problem. One can divide the objects into cubic objects and non-cubic objects, the non-cubic objects can also be called complex objects [3].

Uniformity of objects

The uniformity of the objects indicates which type of optimisation problem is present. If all of the objects are identical with regard to measurement, then this is known as a homogeneous optimisation problem. If the objects are not identical, it is a heterogeneous problem. If diverse objects are divisible into a few homogeneous categories, it is a weakly heterogeneous problem [3].

2.3 Heuristic Optimization Approaches

Container loading problems are resolved, in practice, with the help of heuristics [1]. They do not always produce an optimum result, but come very close to it, within a reasonable amount of time [4]. Heuristics offer a useful alternative if the problem is not otherwise solvable within a justifiable time-scale. Container loading problems, also known as NP-hard problems [5], are extremely complex. A problem is NP-hard when it is at least as hard as the hardest problems in NP [6]. These problems can only be solved in polynomial time.
In this section we discuss weakly homogeneous, two-dimensional container loading problem of Smith / De Cani [7], the weakly heterogeneous, three-dimensional container loading problem of Bischoff / Ratcliff [8] and the strongly heterogeneous, three-dimensional container loading problem of Gehring / Bortfeldt [3].

Homogeneous, Two-Dimensional Container Loading Problems

Homogeneous container loading problems ignores the third dimension when packing and reduces the problem to a two-dimensional container loading problem [1]. The positioning of objects, in this instance, is in layers. Each layer must effectively fill the surface area of the container and the height of each layer is constant [1]. Smith / De Cani describe a 4-block heuristic method to solving the homogeneous, two-dimensional problem [7]. This method begins by creating the first block in the bottom left-hand corner of the container, with the objects being placed horizontally in the container. A second block is created in the bottom right-hand side of the container, with the objects being placed vertically. The space available for the objects results from the residual length of the container and the sum of the width of the objects. The same method is then applied to create a third block in the top right hand corner of the container, where the orientation is horizontal. Finally a vertically orientated block is created in the top left hand corner (figure 1).

Weakly Heterogeneous, Three-Dimensional Container Loading Problems

Bischoff et al. give an approach to solving the weakly heterogeneous, three-dimensional container loading problem [8]. The so-called Layer Approach is based on homogeneous, two-dimensional container loading problem. This method uses the principle of building a layer at a time, from floor of the container upwards, each layer containing a maximum of two different box types. The placement of the objects (as with the homogeneous, two-dimensional container loading problrm) is in block form, using 1-block solutions for single box types and 2-block form for two object types [1]. Using this method new packing areas are created either next to, or above the packed objects (figure 2).

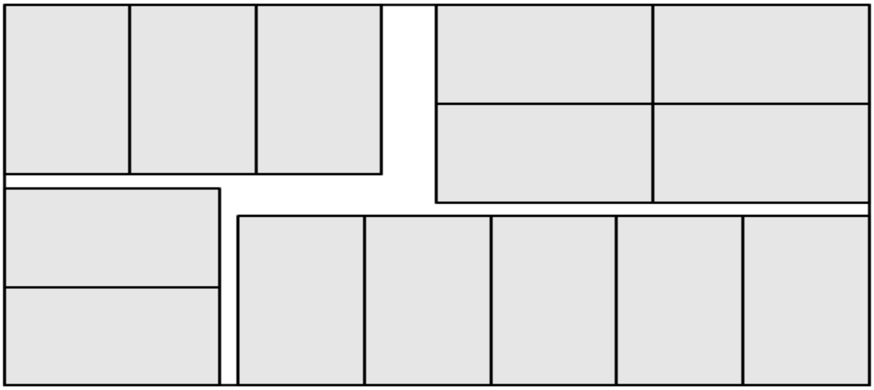

Figure 1: 4-Block Approach [1]

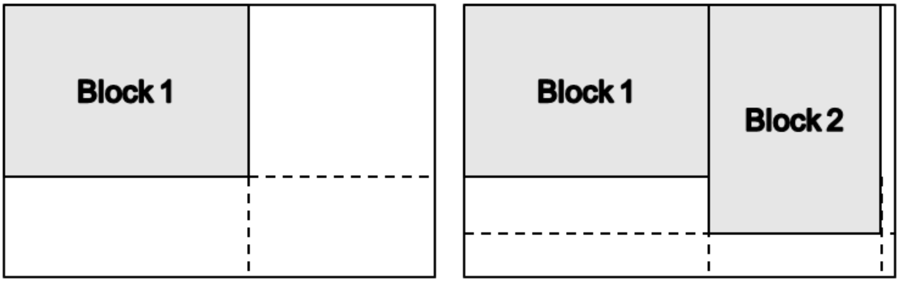

Figure 2: Creating Blocks with the Layer-Approach [1]

Strongly Heterogeneous Container Loading Problems

The two-step container loading problem of strongly heterogeneous objects, by Gehring et al. uses the Column-Building Approach [7]. Individual columns are built, which are then placed onto the container floor. In the first step, column building, one object is used as the foundation upon which further objects are placed, in doing so the complete surface area of the lowest object must be used and the placement of all the objects must result in a minimum of empty space. After the columns have been constructed, they are then placed into the container, which presents a two-dimensional container loading problem.
A further approach to strongly heterogeneous container loading problem is given by Bischoff / Mariott [8], applying the Wall-Building Approach which defines the back wall of a container as the surface area, which is then filled with vertical layers. This method is similar to the homogeneous object Layer Approach but one in which object depth is also accounted for.

2.4 Constraints of Container Loading Problems

Container loading problems must also take restrictions such as position, orientation, stacking stability, weight, balance and load stability into account. The constraints are considered by not producing stowing models which do not comply with them [9]. It is also possible, at a later time, to choose not only the option of maximum use of space, but also to apply the stowing constraints [9]. Bortfeld / Gehring define the constraints as follows [9]:

Positioning Constraints
Certain objects must be stowed in specific areas, e.g. they must be placed on the floor of the container.

Orientation Constraints
Storage requirements of an object may make it impossible to use up to five of the possible orientations.

Stacking Constraints
Stacking constraints are those where an object must not have another object placed above it.

Weight Constraints
The total weight of the complete load may not exceed a certain limit.

Balance Constraints
The distance between an object's center of gravity and the middle of the container may not exceed a certain percentage rate.

Stability Constraints
Stability constraints mean that the bottom of one object must, to a certain percentage rate, be supported by the top surface of another object.

2.5 Heuristics of Flat-Packed Furniture

The arrangement of flat-packed furniture is a weakly heterogeneous container loading problem, due to the placement of parts which are the same, or very similar to each other, e.g. sides, shelves, doors, into one box. For reasons of stability, the 1-block heuristic model will be used. The largest furniture part forms the basis of the box, therefore it has a positioning constraint. The next part will be that which covers the greatest surface area, this procedure is repeated until the weight limit (Weight Constraint) has been reached. As all furniture parts must be stowed flat, so they all have an orientation constraint. Parts, which must be particularly well protected, also have a positioning restriction in that they must be stowed between at least one further furniture part. Figure 3 shows the implementation of this produced by packaging design software, usage of such software-based packaging design increases the effective use of volume by almost 10%.

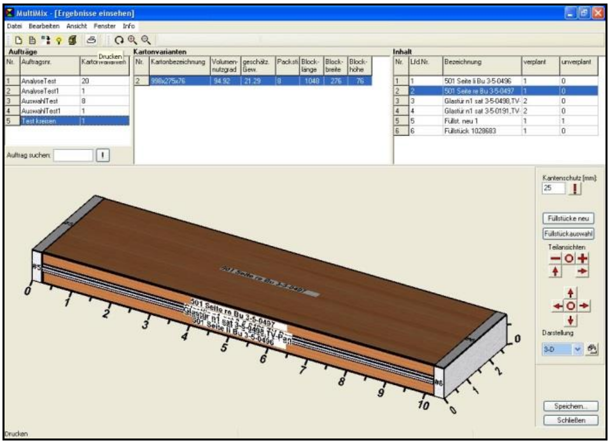

Figure 3: Flat-Packed Furniture Placement Optimization [10]

3 POSTPONEMENT

3.1 Introduction to Postponement

After calculation of optimum packaging, this is then individually cut. The postponement strategy is applied here. The postponement strategy is a system used to push the point of customization as far as possible towards the end of the Value Add Chain [11]. The aim of the postponement strategy is to push the point of customization, the Order Penetration Point (OPP), as far as possible towards the customer (figure 4).

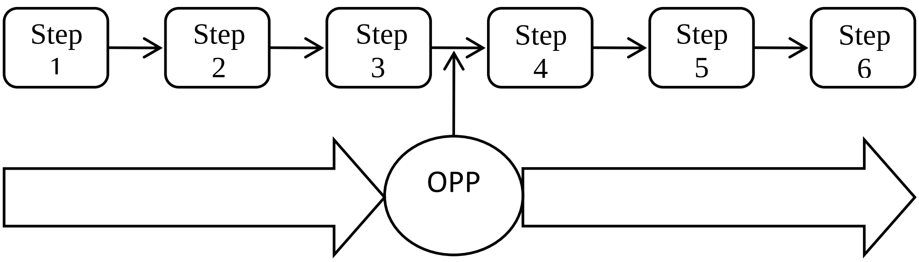

Figure 4: Postponement [12]

Heuseler: “In this way the complexity of the supply chain can be reduced, the risk of obsolescence, production and stock costs reduced, at the same time securing readiness to deliver.” [12]

3.2 Postponement in Packaging Supply Chains

Transposing the postponement strategy onto the packaging sector, means working with standardised raw materials for as long as possible, only adapting them after the first order has been placed. The standard packaging Supply Chain can be divided into the following, typical steps (figure 5):

Figure 5: Diagram of Packaging Supply Chain Organization [12]

Corrugated cardboard producers process paper into the raw material “corrugated cardboard”. After the production of the corrugated cardboard, followed by transport, this raw material is processed into individual boxes by a box manufacturer, commissioned by the packaging business, according to sales forecasts, therefore for a standard market, without a definite order from the end user. After further transport processes, the packaging is used by the packing company, then comes distribution, so even more transport processes before the end user. The implementation of the postponement strategy in packaging systems may happen in one of two ways: in manual postponement the raw material is cut by hand directly at the packing station, which has a negative impact on processing time. An alternative is machine postponement. Here the corrugated cardboard is stored in a continuous form on a palette and not pre-processed into customer-specific boxes, but processed at the packing station using highly flexible machines at the packaging company. Customisation is not only two steps later, but the two previous steps are completely eliminated (figure 6):

Figure 6: Automatic Postponement [12]

4 CONCLUSION

This paper shows a way to dramatically reduce the costs of flat-packed furniture packaging systems. Using heuristics of container loading problems for flat-packed furniture packaging construction, it is possible to achieve an average of 10% higher volume usage, whilst taking the various problem types and the relevant constraints into consideration. After calculation of the individual packaging, production takes place at the pack station automatically. By the use of the postponement strategy, customization takes place at the last possible point in the packaging supply chain. In this way Postponement enables a lean and short packaging supply chain.

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PROMOTING COLLABORATION – INTRALOGISTICS CHECK AS STIMULUS FOR SMES

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Abstract
The current situation is affected by globalisation of markets and the resulting increase in pressure from competition. Businesses must reduce their costs comparative to higher wages / salaries and increase the efficiency of the whole product manufacture process and value chain. This requires, among other things, a continuous review and optimisation of the internal intralogistics process. If one examines large businesses and enterprises, the level of intralogistical solutions appears to be extremely high. The situation looks quite different in small and medium sized enterprises, here intralogistics has tended to be sidelined. Employees, many of whom have been at the company for several years, tend to focus on production techniques. Process optimization happens as an aside, if at all. Day to day business does not leave enough time to look at the bigger picture. Although businesses are often aware that there is untapped potential in logistical processes, this is not systematically addressed. Constraints and reasons for this are many, above all lack of specific intralogistical knowledge and failure to use external know-how in this area. The logistic supplier check (LAC) is an approach that offers small and medium sized enterprises (SME) support in the instigation of change and optimization processes. Having already been evaluated in twelve businesses, it provides a good view of the current intralogistics situation in a company and provides impetus to initialize optimization processes in this area.

Keywords
Intralogistics, Quick-Check, Small and Medium sized Businesses (SME), Process Optimization

1 INTRODUCTION

Although it is acknowledged by many SMEs that process optimization is necessary, it is often not or only insufficiently planned and implemented. The Institut für Angewandte Arbeitswissenschaften (Institute for Applied Industrial Science, ifaa) regularly performs a trend barometer survey which shows that this topic is of interest to businesses. Four hundred and ninety two participants from economics, associations, scientists and other areas took part in the most recent ifaa trend baromoeter survey [1]. Process organization for instance, is of great importance to businesses, with approximately 80% of the respondents ascribing a high to very high importance to this topic (see figure 1).

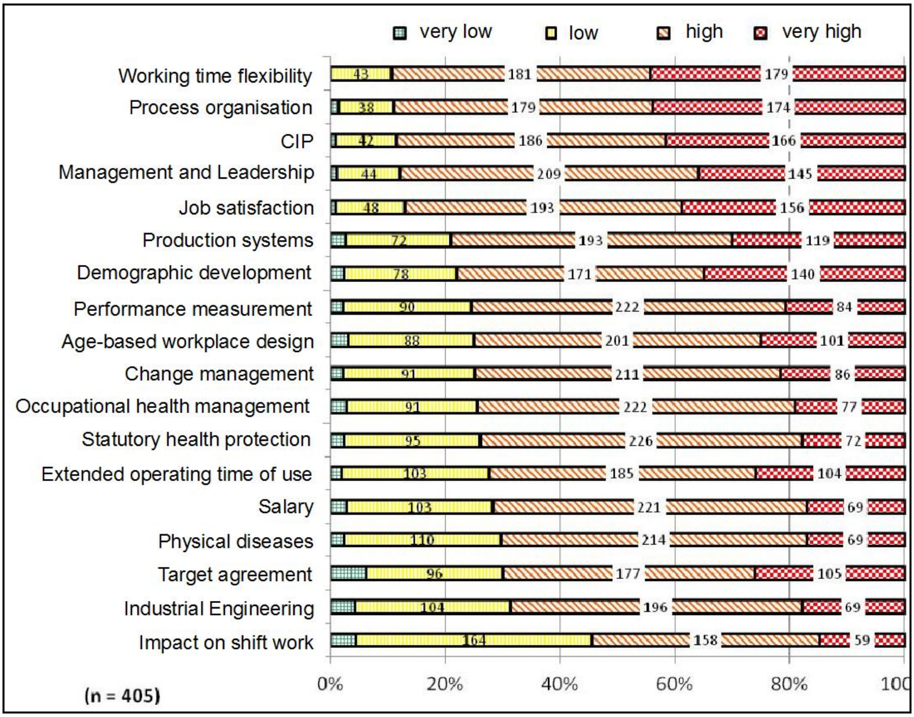

Figure 1: Results of the ifaa trend barometer [1]

However, a study in 2011 by the Institute for Employment Research (IAB), based on the results of the IAB establishment panel [2] (figure 2) presented a different picture. This clearly shows that, over all enterprise sizes process innovation is much less pronounced than product innovation. The larger the business is, the larger the share of enterprises that conduct product and process innovation. The correlation between the degree of innovation and business size becomes very clear when considering process innovation: almost 20% of the businesses with up to 249 employees show less innovation, this share increases greatly in businesses with over 250 employees, lying by almost 40% [2]. The smaller the business is, the less process innovation takes place.

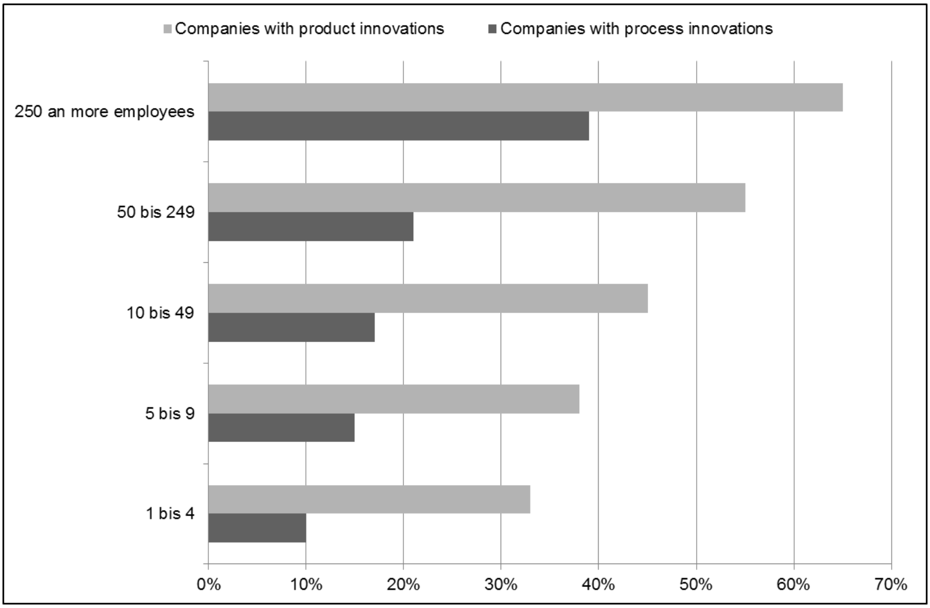

Figure 2: Percentage of businesses with product innovation / process innovation according to business size [2]

A survey of 55 mostly medium sized corporations, conducted by the Institut für wirtschaftliche und technologische Unternehmensführung (Institute for Economic and Technological Corporate Management, IWT) points out that there are many barriers to conducting process optimization. Led by business managers' lack of willingness to change, lack of project management knowledge, analysis, presentation and application methodology and methods for identification of potential.

2 MOTIVES AND CONSTRAINTS TO THE USE OF INTRALOGISTICAL SOLUTIONS

As mentioned above, there are many reasons for and constraints to implementation of intralogistical solutions, which can be divided into the categories environment, people and methods. In environment, for instance, it makes a difference whether the SME belongs to the supply chain of a corporation, or delivers directly to the end customer. Corporations often demand intralogistical process optimization of their suppliers and audit them, resulting in the necessity of optimization for SMEs.
Examining the "people" category, day-to-day operations which are much more intense in SMEs than in large corporations can be identified as a

constraint. Another example is the character of SMEs, which have been described using qualitative criteria in logistics literature; SMEs are often owner-managed, which can result in a different type of management to that of a business run by managers. Management-run businesses tend to focus on short-term profit and the company management can change companies in the event of failure. Owner-managed companies are a life's work, characterized by personal contact and a close relationship between owners, managers and employees [3]. Therefore readiness to take risks is often not as high as that of a management-run company, furthermore profit maximization and therefore continuous optimization, is not the primary focus. The lack of knowledge regarding intralogistics can be ascribed to "methods". Surveys of SMEs have shown that approaches to intralogistical process optimization are often unknown (figure 3).

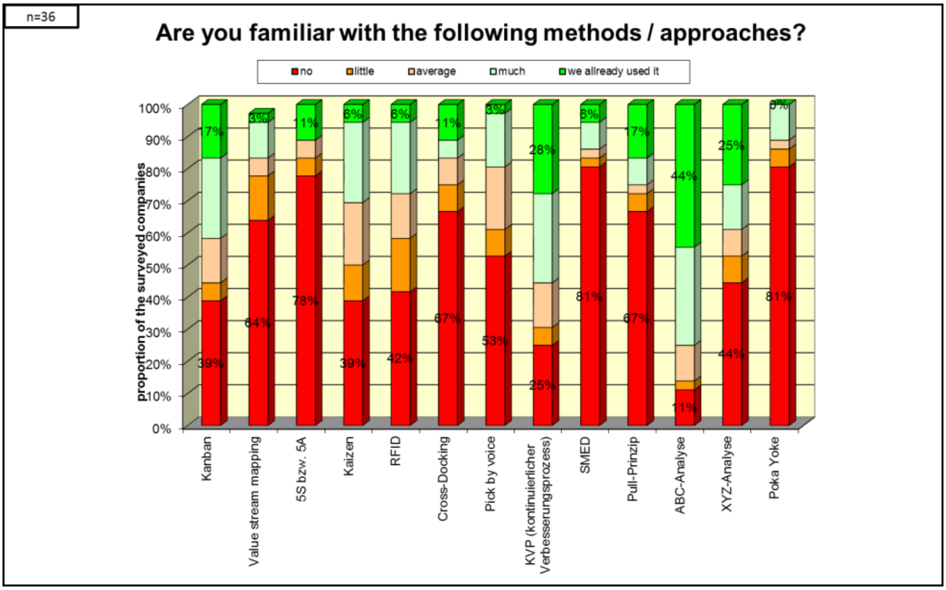

Figure 3: Survey of Methods / Approaches to Process Optimization

A survey of production managers has shown that even established logistics trade fairs are seldom visited by SME production managers (figure 4).

Figure 4: Survey regarding Logimat [4] / Cemat [5]

If managers do not know solutions, then they cannot use them. One possible approach to improving SME innovation may be a strengthening of cooperation with intralogistics solution providers. For example 90% of large enterprises use business consultants, but only 40% of small and medium enterprises [6].

So how can SMEs be encouraged to contact intralogistic solutions providers?

3 LOGISTICS SUPPLIER CHECK (LAC)

One approach to initiate change process in SME is provided by the logistics supplier check (LAC). This provides a full picture of the state of logistics within the company and also acts as a driving force to begin the optimization process in this area. LAC is divided into three categories: provider, specialist areas and competencies.
An important characteristic of LAC is cooperation between Organization, IT and Technology, according to Arnold [7] optimization potential results only from a combination of these fields, which are all essential elements of logistics processes. Therefore the first provider category includes the subsections Organization, Technology and IT.
The LAC results should not be directed towards the work of a single consultant, but be neutral and point to suitable intralogistical solutions providers who meet key identification factors. Therefore the provider’s solutions serve as the basis of this approach. The second category,

specialist areas, largely follows Logimat [4] and Cemat [5] subsections, which were determined as part of an expert workshop on their applicability within LAC. The following were defined as Technology and IT provider subsections.

Table 1: LAC Providers Specialist Area: Technology and IT

Provider Category	Subsection
Technology and IT	Warehousing Technology
	In-House Transport
	Work system design / Workplace design
	Information and Communication Systems
	Picking
	Packaging

In table 2 the organization subsections are shown.

Table 2: LAC Providers Specialist Area: Organization

Provider Category	Subsection
Organization	Lean-Methods
	Production management methods
	Further approaches

The third category within LAC is defined as competencies. The methods of the provider category Organization demonstrate the competencies of the providers that can apply these methods within each subdivision in SME.
One example of a competency is the milk run system, which within LAC is treated as part of the organization category (figure 5). Pictures, explanatory notes and short film clips assist the user with regard to categorization.

Figure 5: LAC Extract with film clip

In total, the LAC contains 9 subsections in Organization, Technology and IT. The user is presented with a network diagram with the values achieved by their company compared to the other companies who have used LAC (figure 6). Furthermore, they receive a list of providers in the categories that their business view as interesting.

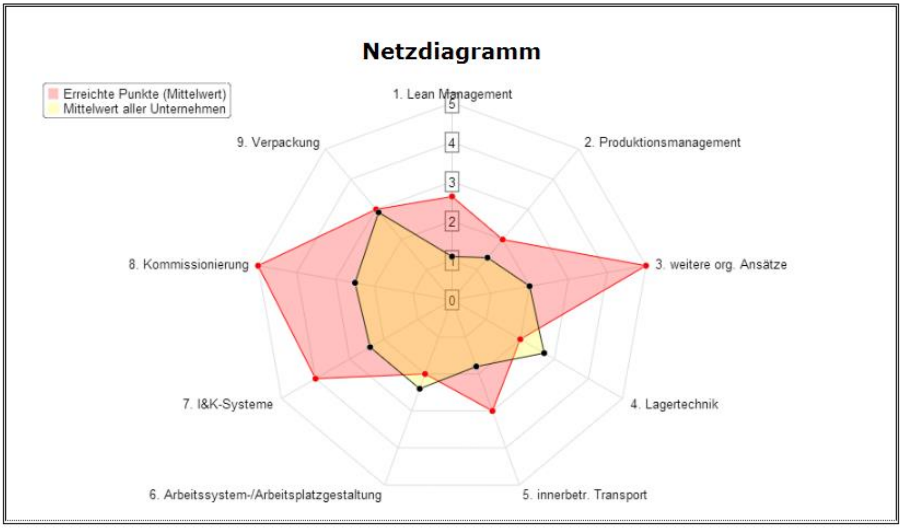

Figure 6: Network Diagram Result of LAC

4 LAC APPLICATION

The LAC has been applied in 12 businesses and within the framework of evaluation, constantly improved. Amongst the businesses were SMEs and large corporations. It was carried out by students with various levels of experience either from Ostwestfalen-Lippe University, or from Chemnitz University of Technology, and was supervised by experienced intralogistic consultants.

The results of the evaluations showed that the level of intralogistics solutions use varies greatly. From figure 7 it can be seen that businesses in Technology and IT subsections have a more focused approach. From this it can be deduced that there is considerable need for action in Organization.

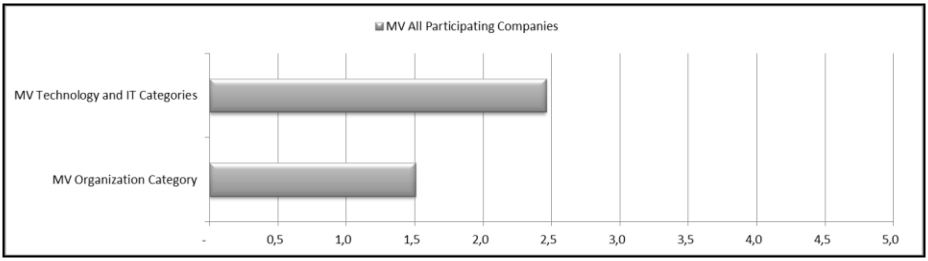

Figure 7: Mean Values in Categories Organization, Technology and IT.

Two companies were able to show a particularly high degree of intralogistical solutions use. One of these companies is a member of a corporation and has adopted the concern's production system, the other is a medium sized enterprise that has been consistently working on internal process optimization. Figure 8 shows the mean values of both of these companies, compared to those of all participating companies. It can be shown here that the top businesses have consistently optimized Organization, as well as optimizing Technology and IT.

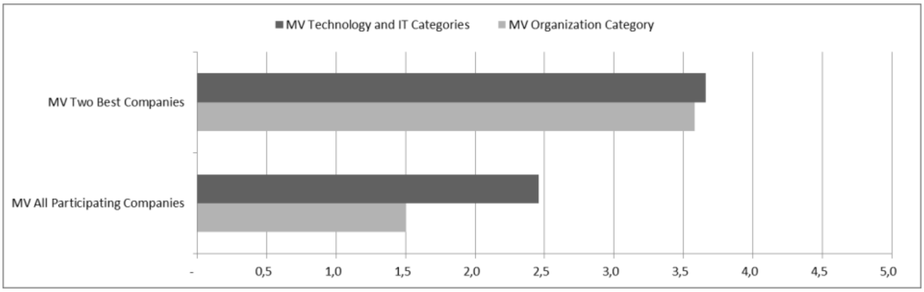

Figure 8: Mean Values (MV) of the two Highest-Scoring Businesses, Compared to all Participating Companies.

5 SUMMARY AND OUTLOOK

Evaluation of the LAC occurred in twelve different companies and was carried out by users with different levels of experience. The results of the LAC were positive, without exception, this estimation was confirmed not only by the consultants but also the companies.

The application of the LAC showed clear limitations during evaluation. Complex solutions are unable to be presented correctly and the potentials cannot be quantified. Furthermore, the solutions are not always immediately realizable and innovation as well as development must be continuously maintained.

Most significantly, the success of the implementation process depends upon those who are implementing it. If the business is willing to initiate change and optimization processes, then the LAC can act as a driving force, if there is no will to change, then no tool can help initiate it. Therefore it is all the more important to emphasize that the results of an LAC can be used, but must not. In many cases it is enough for the SME to facilitate strategic change processes

"one has to engage companies using their current situation as a starting point."

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