Sustainable Life Cycle Management in the Thermoset Plastics Processing Industry

Stephan Raab-Obermayr, Anja Kossik, Bernd Gastermann, and Markus Stopper

***Abstract*—Manufacturing Enterprises represent the core of our economic system. These companies have to face challenges that emerge out of seemingly conflicting interests on a daily basis. On one hand, they are held more and more responsible for ecological and sociological problems, on the other hand a manufacturing company needs to produce in a profitable and cost-efficient way in order to remain competitive. This paper deals with this conflict by focusing on sustainability and its three dimensions: ecology, economy and social aspects. To further specify the presented sustainability principles by use of a case sample, the actual status of an Austrian plastic producing company will be surveyed in the course of this paper. This manufacturing company produces toilet seats from a thermoset raw material called Duroplast in a pressing process. Following the analysis of the company's actual status regarding sustainable life cycle management a conceptional closed loop recycling system based on the previously depicted principles is developed. Essential improvements in the execution of production processes are outlined and measures for efficiency increase in the production lines are presented. The necessary interactions beginning with the raw material producers down to the end-customer are shown and are included into the presented closed loop recycling concept.**

***Index Terms*—Sustainable Life Cycle Management, Green Manufacturing, Manufacturing SMEs, Thermoset Plastics Processing, Closed Loop Recycling**

I. Introduction

Economic growth causing an unrestricted increase in resource consumption represents - in combination with the growing world population - the main global challenge of our present time and for the future. One might get the impression that this well-known and extensively discussed situation is not of paramount importance as it is tackled rather hesitantly by businesses, politics, and our society. Our economic system is based on constant growth and if we really want to further pursue this strategy, a paradigm shift must take place, decoupling growth from resource (material) and energy consumption. It should be obvious that the notion of endless economic growth is simply not plausible. However, to achieve such a change in mindset, it is important to start thinking and acting in resource cycles. First of all, distributed material/products must not be destroyed, but reused by some form of recycling or reprocessing. This paper examines the product lifecycle from design to disposal by example of a manufacturing company in plastics industry. Based on a status quo analysis of the currently applicable processes, optimization proposals as well as a concept for a recycling management system are being developed.

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II. Problem Statement

Each day manufacturing companies have to meet various challenges in order to remain competitive and to succeed in the marketplace. In this process, it is necessary to continuously assess, which competitive advantages can be achieved with how much effort and in which areas. In the interest of a sustainable corporate development, this paper addresses the question, which technical methods and solutions of the sustainable life cycle management (LCM) concept are suitable for medium-sized companies in the plastics industry in general, and for the company MKW in particular.

III. Aspects of Product Life Cycle Management

In a product design process, many decisions have to be made regarding the design, cost, and lifetime of a product. The choice of component suppliers with their economic, ecological, and social impact is already roughly made with the product idea – an early phase of the production process – and is eventually fixed after the conceptual design phase. Even the utilization phase of a product and the subsequent disposal by the customer influence environment and society. Unfortunately, the product use philosophy that is still partly valid today – manufacturing, usage, and eventual disposal of the product – represents a rather limited perspective. It is inadequate for the future in causing futile waste of resources and environmental problems for following generations. [1]

Considering a product's entire life cycle belongs to the new repertoire of product development and management. Manufacturers must understand that their responsibility does not end with product sale. Although products are typically maintained through service or guarantee contracts during their usage phase, companies eagerly withdraw from their

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obligation to take back and dispose of used products [1]. This chapter addresses the strategic orientation of a manufacturing company in the form of a recycling management system, and presents the relevant disciplines in the design of a sustainable product life cycle together with potential solutions.

A. *Strategic Orientation of an Enterprise*

Five types of environmental-based strategies exist for industrial enterprises, with environmental protection measures ranging from "no measures" to "all conceivable measures". In practice, however, mixed forms of these strategies usually occur. [2]

Defense-oriented strategy: With this strategy, no or no significant environmental protection measures are taken. Even legal requirements are not met in some cases, as they can be countered either by lobbyists, by negotiations with authorities, or by passing them on to suppliers. In the short-term, the cost of environmental protection can be saved, but in the long run the company is threatened by image loss or even business bans due to the lack of legality.

Output-oriented strategy: Here, only the bare necessities are done to comply with legal requirements. The strategy does not affect the production processes or other business sectors that cause waste and emissions. Instead, these are eliminated by means of downstream environmental protection measures (end-of-pipe technology), which are very advantageous in the short run and can be implemented quickly. There are also fewer risks due to the production processes not being affected. However, competitive disadvantages are posed by new regulatory frameworks and other changing conditions like intensified environmental protection requirements.

Process-oriented strategy: This strategy classifies as a transition point from defensive to offensive orientation. It takes precautionary environmental protection measures, mainly in the area of production, that might even exceed legal requirements. Obsolete production machines are modified to decrease emissions and waste (clean technology). Higher investment costs and associated risks in the short-term could eventually result in greater long-term competition advantages, for example lower disposal costs when environmental protection requirements are reinforced.

Reutilization-oriented strategy: This is a downstream environmental protection measure for the closure of material cycles for products and product waste, carried out by disposal partners. In the short-term, this is very advantageous because the know-how for disposal is usually not available in the company and outsourcing only requires little planning. In the long-term, there is the risk of becoming dependent on waste management companies. Furthermore, competitive disadvantages towards cycle-oriented competitors achieving better cost advantages, can arise.

Cycle-oriented strategy: This strategy provides the maximum achievable environmental impact. Sustainable management involving all stakeholders creates intelligent material cycles. This strategy also requires extensive planning and implementation in all production areas and even includes the product life cycle. In the short-term, it leads to high costs and risks but the resulting high ecological quality can only be offset against the operating expenses if it leads to an economic competitive advantage. However, governments still have to create appropriate frameworks that require respective action.

B. *Holistic Life Cycle Management*

In a holistic life cycle management, all phases of the product life cycle together with their different actors involved must be represented by process and information flows. The challenge of a spatial, organizational, and temporal offset (for example design and recycling) of the parties must be addressed [3]. The main objectives of a holistic life cycle management, considering the full product life cycle and even surpassing company boundaries, are [3]:

- minimization of costs and optimizing revenues
- minimization of risks (uncertainties, long periods)
- minimization of environmental impact

In addition to the coordination of flow-oriented processes of the respective parties involved, the volatility and dynamic in the various areas such as the procurement market, factory systems, sales market, etc. must also be considered.

C. *Life Cycle Concepts*

The product life cycle can be divided into a preparatory phase, a market phase and an after-market phase that can also overlap in time [4]. In order to close the cycle, the product must be recycled to an earlier state subsequent to the after-market phase. According to [2], the following four concepts exist for the extension of the product use phase:

Life span extension: The goal of this product use concept is to prolong the period of use of a product through various technical measures like the reduction of wear with better or higher quality materials.

Product use extension: This concept does not depend on the extension of the technically feasible product life span (as with the concept above) but on the actual period of use as can be achieved, for example, by technical upgrading or retrofitting.

Usage interval optimization: Hereby, an attempt is made to increase the usage time or the frequency of use within the product's ordinary life cycle (e.g. by product sharing).

Intensity enhancement: In contrast to the usage interval optimization, the focus here is on increasing the intensity. The unused time between the usage intervals is not considered but the product is intended to better exploit its potential by making it possible to be used simultaneously.

<u>Life Cycle Design</u>: By integrating life cycle thinking into the development process, the awareness for sustainable management is to be raised. The eight action strategies of Brezet and van Hemel are designed to reduce the environmental impact through the product life cycle and provide a comprehensive search field that is to be gradually integrated into the innovation process [5]:

- selection of material
- reduction of used resources
- optimization of production
- optimization of distribution
- extension of the product life span
- optimization of a product's end-of-life
- redevelopment of product concepts and strategies

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Economic, ecological, and social aspects must be considered in sustainable product development. The problem, however, lies in the operationalization and comparability of the various dimensions and their conflicting objectives. Therefore, qualitative assessment (e.g. by cost-effectiveness methods) is used in combination with quantitative measures (e.g. total performance index) in practice. [3]

Life Cycle Related Management Disciplines: In the following paragraphs four different disciplines for the various product life stages are presented [3]:

Product Management: Includes product program design at a strategic level, and product planning and development at an operational level [6]. Decisions and measures in life-cycle-oriented product management must be taken, considering all phases of a product's life (life cycle strategy).

Production Management: Includes the production program design at a strategic level, and the product planning at an operational level [6]. Sustainable production encompasses all processes that serve production, provision, and recycling of products and services either directly or indirectly. It further includes environmental protection that is operationally and technically feasible, as well as operational environmental management [7].

After-Sales Management: Describes services that are used to ensure, increase, or restore practical utility of an already sold product (cleaning, maintenance, repairs, disposal, etc.).

End-of-Life Management (EoLM): This is the central element of closed-loop economy and includes the planning, supervision, and control of products at the end of their economic or technical lifespan. It deals with the collection or dismantling of components, their recycling or reuse, and the proper disposal thereof [8]. The implementation of an effective EoLM demands coordination and information from preceding product life phases of all actors in the sense of an extended supply chain management [3].

D. Cycle Management

EoLM is essential for the closed material cycle of closed-loop economy and refers to the post-utilization phase of a product that includes disposal and redistribution according to economic, ecological, and legal aspects. When products have reached the technical end of their useful life, they are referred to as end-of-life products. Similarly, end-of-use products are subject to obsolescence that causes the product to be purposefully disposed of [3].

As already mentioned, EoLM is a key element in the implementation of a closed-loop economy, where the product returns into the production process or into the utilization phase after its life cycle [9]. This concept is implemented in so-called closed-loop supply chains, which allow to distinguish between a circulation of either whole products or individual components that are directly supplied to a further utilization phase. The concept further allows to distinguish between the disposal of raw material removal as well as the conversion of energy.

E. Recycling and Collecting

Redistribution includes the necessity and applicability of dismantling and processing procedures as well as the collection of disused goods. The recycling potential of a product is determined by the high quality of processed materials and low material diversity. Generally, various companies with different core competences (logistics, disassembly, recycling, etc.) are involved in the recycling process and are organized in networks [3]. The potential of a product to be disassembled has a decisive influence on the dismantling costs, whereby dismantling has to be carried out to a minimum degree according to the legal requirements [8]. A maximum degree would mean complete dissolving of the entire product structure. An optimum dismantling degree is achieved by the greatest possible added value, whereby the consumed working time is to be contrasted with the revenue that can be generated from disassembled components or materials. [3]

IV. Case Study of Industrial Company MKW

In this chapter, the manufacturing company, its products, current business processes, as well as status quo are presented, in order to eventually deduce a concept for a life cycle management in the upcoming chapter.

A. Strategic Company Processes

MKW Plastics is a subsidiary of MKW corporation. The company's expertise lies in the production of plastic components made from the thermoset raw material Duroplast. The main product line of the company comprises high-quality toilet seats. At the Austrian headquarter the company's main organizational process flow from order entry to the customer can be described as follows: three manufacturing teams (pressing, injection molding, mold manufacturing) represent the value creating process. Upstream sales teams (incl. product management and design) represent the interface between customer and production, downstream logistics (interface between production and customer) are outsourced. Procurement, administration, IT, and marketing teams support the main processes.

B. Product Development

In addition to the company's proprietary products, MKW mainly delivers to customers, who manufacture sanitary ceramics. As a system supplier, MKW receives a request to produce the toilet seats matching a particular model, whereby concrete requirements and design specifications are usually already provided. Sales and product development clarify the basic conditions for order acceptance and implementation by means of a checklist. If the contract is accepted, product development initiates a new project, dealing with order execution from product development (CAD), to the assembly of a master model, the production of the required molds, up to the delivery of a first series.

C. Raw Material, Parts and Providers

Duroplast (urea resin UF 131.5), which is used by the company analyzed in this paper, belongs to the group of amino resins. Due to their chemical structure, they are capable of forming irreversible three-dimensional crosslinks by means of a polycondensation reaction [10]. Duroplast is characterized by the following properties [11]:

- high mechanical strength, stiffness, and surface hardness
- high surface gloss

- very good electrical properties
- susceptibility to high humidity
- low dimensional stability due to high mold shrinkage
- not permitted for molded components coming into contact with food or beverages

In the first step of the production process, the resin condensation is carried out in the reactor at 20-100° C and a pH value of 3.5-8.5. The water-soluble crystalline urea is dissolved in a 30-40% aqueous solution of formaldehyde, starting a gradual reaction between the two components. The urea combines with the formaldehyde through polycondensation and separation of water to urea resin. After filtration, the chlorine-free bleached alpha-cellulose is mixed in a blender with the urea resin for impregnation. The resulting mixture is then dried in a continuous dryer to pre-condens the water contained in the resin to a certain degree. It is then intermediately stored in silos where a ripening process takes place, in which the resin can enter the cellulose as a function of time. After this process, the basic product - also referred to as "popcorn" due to its appearance - is eventually finished [12], [13]. Popcorn is then ground to a particle size of <50 μm by a pre-mill for further processing after this ripening process. Afterwards, particles reach the ball mill where they are further ground to a size of <20 μm. In this process step, the material is admixed with various additives and dyed with color pigments. Basically, the plastic would now be ready for further processing, but at this processing stage it is only available as very fine powder. However, as customers demand low-dust and uniform granulates with good pourability for their processing, the powder has to be further compacted into said granulate.

Four raw material producers are based in Europe: BIP (GB), Ercros (SP), Körfez (TR), and Chemiplastica (production sites in IT, TR, and SWE). The selection of the suppliers for the respective MKW production sites is primarily based on the purchasing price in relation to production quality of the goods. The quality of the raw material and its specific properties during further processing are yet another set of problems related to the selection of suppliers. Although all manufacturers produce according to the previously described method, they achieve different material properties and qualities that only become noticeable by increased defectives and reworking at later production stages. Although test methods exist that allow to determine raw material quality, only little information for production-related process parameters can be inferred from this data. Therefore, no definitive correlation can be deduced. The problem is inherent to the measuring methods for determining the rheological properties, which allow for a rather high tolerance.

The assembly of toilet seats requires additional accessory parts that are not produced by MKW. Purchased parts include metal-zinc diecasting parts and rotary dampers used for the slow close function. The main challenge in procurement of accessory parts are the versatile rotary dampers, because these are subject to high-quality requirements and have strong influence on the toilet seats' cost per piece. Currently, the layers are exclusively purchased parts that are procured and produced in China or Japan. The decision for these suppliers was made primarily based on price, but it also entails substantial disadvantages for production (e.g. non-transparent and long communication paths, long delivery periods, problems with specification changes, production downtime due to complaints, problems in production control) as well as increased administrative overhead.

D. Production Processes

The production at the MKW sites in Austria and Slovakia is controlled and operated based on a hybrid production planning and control system (PPCS). The first part of the system is generic production without relation to the customer (customer-anonymous). It includes processing of raw material, manufacturing (pressing) of Duroplast parts, and their subsequent deburring. This so-called Make-to-Stock (MTS) system ranges up to the intermediate storage of semi-finished products, which are placed into stock by the PPCS. The second part of this hybrid PPCS is classified as Make-to-Order (MTO). Here, semi-finished products are removed from the intermediate storage, assembled, and packaged with other components such as hinges and dampers. The final products are then available for delivery in the finished parts warehouse. In such a hybrid system, which is also known as Make-to-Assemble (MTA), the customer decoupling point is of high importance in variant management, since customer-specific manufacturing can only be performed from this point onwards (i.e. the intermediate storage). At MKW, semi-finished products (seats and lids) are produced by Duroplast pressing. Different machine types with varying automation degrees are used for this purpose. Machines can be classified as automatic presses, multi-platen presses, or individual presses. The pressing process comprises the following tasks and substantial process steps:

- Preheating/preparing a required amount of molding mass
- filling the cavity (the mold) with molding compound
- closing the pressing tool (the male mold)
- plasticizing and shaping the molding compound
- hardening process with potential venting
- opening and demolding of the pressed part
- cleaning of the pressing tool
- deburring of the pressed part

The pressing operation of the urea material is basically identical regardless of the type of press used. The three-dimensionally crosslinking raw material is brought to a chemical reaction at about 150° C and with a pressing force of up to 500 t. During the pressing process and the resulting polycondensation reaction, water is split off. The process begins with the melting phase of the material. A pressure of 3500 kN is then applied for about 20 s while the polycondensation and shaping take place. This results in vaporization of water as well as formaldehyde, which can escape by a brief (approx. 25 s) opening movement of the press. The remaining process serves to harden the pressed part. The resulting volatile water vapor and formaldehyde are dissipated into open air via a central suction system.

In the semi-finished part storage, which represents the interface between the initial production and the later assembly and packaging, components are stored and removed based on the "first-in first-out" method. It is also used to decouple the working contents of the two areas since production (the bottleneck) is run in triple-shift operation

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while assembly and packaging is run in two-shifts. At the Austrian manufacturing site, this semi-finished part storage is automatically filled according the chaos principle and operated as a high-shelf storage with software support.

E. Packaging and Distribution

At the packaging or assembling station the half-parts are completed to a product according to customer orders. At MKW Austria this procedure is performed by a packing line. The operator positions the assembled product and its spare parts into an automatically prepared carton box, which is then closed and individually printed on by the machine. Additionally, the readily packed product is palettized and foil wrapped for transport. Palettes are stored in the finished parts warehouse, where they are commissioned for delivery by truck. The logistics department plans all transports respecting quantities, delivery time and place. All transports are performed by an external freight forwarder.

F. Waste Management and Disposal

During pressing a process-related production waste, the burr, is generated, incurring at a rate of 3.6% of the charge weight. Defectives are produced parts that cannot be re-paired by reworking. Defectives mostly occur in the pressing process and consists of porous parts, parts with fissures as well as burr and dirt inclusions. The raw material supplier has a significant influence on the production of defectives due to lot-by-lot fluctuations of the rheological properties. The average rate of defectives is 5.16% of the produced parts. Due to the specific properties of Duroplast, material recycling by forming, melting or dissolving is impossible. Currently only a re-introduction of the material as filler after comminution is available. A procedure for efficient chemical cleavage is still under investigation. As Duroplast production requires adding considerable amounts of fillers and reinforcing substances (up to 80%) this would provide a possible application. The cured material must be micro-milled, a recycling method called particle recycling. The particles can be added to an amount of up to 30% [14].

Production waste, namely burr and defectives, is collected and disposed separately. Burr is collected by external waste disposal companies at the respective productions sites and is used as secondary fuel in cement plants or in incineration plants. The collected defectives are sold for a small charge to recycling companies that comminute them to a granulate, used as blast-cleaning additive for varnish removal.

V. SUSTAINABLE LIFE CYCLE MANAGEMENT CONCEPT

Sustainable Life Cycle Management (SLCM) cannot be accomplished by isolated measures but requires a paradigm-shift as well as a complete modification of valuation criteria in manufacturing enterprises. It is obvious that a generally valid “patent remedy” for sustainable development, simply does not exist. On the contrary, each company together with its stakeholders has to develop and apply its own concept. This concept needs to be adapted by iterative optimizations taking place in specified time intervals. Based on the previous assessment of the actual status, this chapter outlines a SLCM system for products manufactured in the analyzed company by Duroplast pressing.

A. Strategic Direction

Irrespective of the optimization of singular process steps, an overall new strategic orientation of the company MKW is necessary for the implementation of a SLCM for its main product, the Duroplast toilet seats. As previously discussed [15], certification and key indicator systems for the two sustainability dimensions, ecology and social aspects, are available. MKW is already active in both areas without explicitly positioning itself as a sustainable company.

To achieve this goal, the ISO 140001 framework presents a suitable certification system regarding environmental issues [16]. It not only provides an ecologically guided process control, but also the necessary key indicators that are accepted as sector-independent benchmarking parameters. In the German-speaking countries there exist several (nationally or regionally supported) consulting and implementation programs like Ecomapping, EMASeasy, EMAS-Konvoi, EcoStep or Ökoprofit that are intended to support companies when introducing environmental standards. Additionally, the calculation of the Product Carbon Footprint of the product Duroplast toilet seat according ISO 14067 would be reasonable, as comparative data for other plastic products are available, which could help to classify MKW’s products either into the category environmentally friendly or harmful. These data could support the cooperation with the involved stakeholders like the raw material providers or the manufacturers of sanitary ware, as they back up the respective arguments with quantitative parameters. Guidelines for the social dimension are also available, like the ISO 26000 framework for social responsibility [17], the SA 8000 (Social Accountability Standard) or the German Sustainability Codex. These measures and values can be defined in the frame of an updated Vision and Mission Statement that is based on sustainability principles and can then be implemented within the Corporate Social Responsibility Management.

B. Raw Material

Toilet seats are produced and marketed from various materials like MDF, wood, polyresin, Duro- or Thermoplasts. When compared to other materials, Duroplast, as used by MKW, shows numerous advantageous properties regarding the quality criteria demanded by the customers. One of its biggest disadvantages, as far as recycling is concerned, is the fact that its processing is irreversible. Therefore, Duroplast cannot be re-used as primary raw material. Another factor are lot-by-lot variances leading to an increased production of defectives. As discussing alternative materials would go beyond the scope of this paper, solutions for the currently used Duroplast Urea 131.5 and the applied pressing process are outlined.

Re-use as primary raw material: Re-use of cured Duroplast is currently only possible by particle recycling, where the material is re-integrated into the raw material production process as a filler. This option is neither applied by the presented producers nor are their production facilities suited for such a process. In order to achieve specific progress in this regard, a joint effort in the form of a cooperation project between producers and customers is necessary. Currently cured Duroplast is used as secondary raw material for various blast-cleaning substances. Due to its excellent insulation characteristics, respective applications in the building industry (i.e. filling material for bricks) could be feasible but need further evaluation.

Lot-by-lot variances: The production of defectives, mainly due to lot-by-lot fluctuations of raw material properties, represents a significant cause for waste of resources and energy. This illustrates, why the production process of the raw material needs to be improved regarding a constant quality level. Therefore, higher consistency of the used basic substances and optimization of the production process (e.g. by online-monitoring) have to be achieved. Additionally, more reliable data for rheological properties must be provided so that manufacturers can adjust their machine settings accordingly. Further energy savings in Duroplast production can be achieved, if the processing of the material into its granulate form by dry or moist compacting treatment were avoided, as Duroplast already provides the required properties before this step. However, this would require new manufacturing technologies applying Duroplast powder.

Burr-free production process: During pressing a process-related burr is spilled from the mold. In order to minimize this production waste, the molding material must be weighed-in precisely and be evenly distributed in the cavity. The correct distribution ensures short flow paths of the material and therefore reduces material spill-over. Further reduction can be achieved by attaining small clearance in mold construction. For burr-free pressing the clearance has to be reduced so far as to totally prevent any leakage of Duroplast resin. There exists an interesting approach, where the mold is equipped with an additional heating system located at the edge of the burr formation. When closing the mold, the clearance is reduced by higher temperatures and the resin will not leak as it is cured faster in the heated parts. Another solution for burr-free pressing lies in the development of new mold types, where the clearance is basically non-existent by applying additional locking force. The interior surface of the cavity is covered by some sort of membrane, generating the additional internal pressure on the material. Both innovative mold-related approaches are under development and still require further testing.

C. Procurement

Procurement plays an essential role by ensuring the purchase of goods and services necessary for production and providing correct quantity and quality at the specified time and price. It has pivotal influence on pricing of the manufactured products and is therefore installed as an instrument for optimizing cost efficiency (and in turn profit maximization). In contrast, sustainable procurement also respects additional criteria, which in total provide a different basis for decision making. The goal of such a procurement strategy is the generation of competitive advantages that are beneficial for consumer and society. It is not contradictory to established targets like cost and risk optimization, as sustainable products can be produced at a favorable price due to the reduced depth of value added. Additionally, changing from global to local purchasing decreases delivery times, failure risks and logistics costs. With a purchasing volume of 3,200 t annually, Duroplast represents a cost factor of strategic influence at MKW. Considering the supplier market, the four presented providers possess a monopoly position. This leads not only to a dependency of the purchaser but also leaves him with limited negotiating power. Therefore, in a first step it is necessary to evaluate, which of the four raw material producers could be the best partner for establishing a closed-loop recycling management and the implementation of particle recycling in the future. This mutual goal can only be achieved with a long-term partner, creating a win-win situation for both parties. The issue of fluctuations in raw material quality also needs to be addressed in a joint effort.

D. Product Development

The main issue regarding sustainable product development is the dependency of MKW on the manufacturers of sanitary ware, who limit the scope of action with their restrictive specifications. Parameters are primarily set by the ceramics producers and only secondly by the consumer. Even with MKW's proprietary brands the dimensions and the fixation type of the toilet seat on standard ceramics must be considered. If it were the strategic decision of MKW to broaden their scope of action in product development, the relationship between toilet seat and ceramics manufacturers would have to be changed fundamentally. The feasible solution for this problem lies somewhere in the middle: both companies need to cooperate on equal terms to find and realize a sustainable solution for a combined product.

E. Production Process

The MTA production strategy is the basis for a structured course of action for specific optimization measures that are necessary for the efficiency increase of single production steps. Only by structurally dividing the processes, it is possible to address the implementation difficulties of the Green Manufacturing [18] approach like technological barriers or a lack of assessment methods and to apply planning and control instruments for each production step. It is easier and more transparent to assess the implications of an improvement by means of key indicators.

Pressing Process: Apart from the already presented concepts for burr-free pressing, potential optimization steps for minimizing the production of defectives are presented in this chapter. To compensate for the abovementioned lot-by-lot variances of the raw material causing quality loss during the pressing process, the machines have to be equipped with additional technical features compensating these fluctuations. Currently variances are corrected by the operators based on their long-term experience and their implicit knowledge through iterative press settings. Each iteration cycle produces a defective part until the right parameters for an optimum result are identified. As a process control during pressing is missing, the operator will only know the result once the step is finished. Two approaches are available to address this issue. Collecting and analyzing data converts implicit knowledge into explicit know-how. Therefore, all machine control parameters that are available and are influencing the pressing procedure need to be recorded and their influence on production quality continuously documented. Using neuronal algorithms these data can then be evaluated online and will generate optimum process parameters over time. The second approach requires process evaluation during pressing. Currently the operator assesses quality criteria visually. For generating a feedback control

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system, measuring physical variables from which information about the rheological properties is derived, is inevitable. Machine settings influencing these variables must also be recorded. Sensors that indirectly measure the rheological properties in the cavity of the mold are available for cavity pressure, temperature, hardness and dielectric properties. The resulting data must then be evaluated regarding their significance for the rheological behavior of the raw material.

Production Machines: When analyzing the actual status of MKW at the three production sites, the following topics where identified to have an impact regarding efficiency increase and reduction of energy consumption of the presses:

Standby energy consumption: Presses should be turned off, when not in operation (main switch). The mold heating needs to be turned on only two hours before production start earliest (heating phase).

Mold Insulation: Insulating the mold, the hot plate, as well as the runner plate would reduce heat emission.

Optimization of mounting: Downtime and production of defectives when starting the press can be minimized by specific mounting.

Preventive maintenance: By implementing preventive maintenance measures, presses must be kept fully functional.

Prevention of idle status: After ventilating, the hydraulic engine has to be turned off for the remaining time of the pressing process, as no further movements are performed. This measure would result in time reduction (2 min/cycle).

Targeted use of formaldehyde suction: The suction system should be equipped with a gate valve that is only activated when gases are released during pressing.

Process surveillance: As discussed previously, sensors in the mold for online-surveillance of the process are needed.

Air consumption: Currently the molds are cleaned with compressed air before commencing the pressing cycle. Production of compressed air is energy intensive. Therefore, it could be avoided by the installation of fans.

Optimization of cycle times: Currently cycle times are set longer than necessary by the operators, to ensure constant production. Sensors could define the precise timing for the end of the cycle and the opening (venting) of the press.

Production Facilities: Production halls are heated with a central gas heating system. This is only necessary during production-free times in winter, as the Duroplast presses themselves generate enough heat. The installed air suction system removes the resulting gases, by first filtering them and then discharging them to the outside via an air-air heat exchanger. The in-coming fresh air supply is also directed through the abovementioned heat exchanger and is warmed up by the excess heat generated in the production process. The conventional neon lighting system was substituted by LED lighting, which is regulated by the existing KNX bus controller. The bus represents the central element for automated control of various facility technologies (i.e. light domes, energy consumption meters, alarms etc.). It is by far not integrated into facility management to its full capacity. Therefore, further applications are suggested. Offices could be equipped with presence detectors for the regulation of heating, air condition, and window shades. It could also turn off/on the light or monitors based on actual office usage. Different scenarios customized to the occupants could be programmed to optimize the employees' comfort.

Production Energy Consumption: Based on a total load profile the analysis of electricity consumption showed a verifiable energy wastage that originates from turning on the heating for the pressing molds too early and turning it off again too late. This results in potential savings of 70,720 kWh per year, which is equivalent to the annual energy consumption of 14 average Austrian households. Further reduction can be achieved during the production free time, as the basic load is still 12% (35 kW). Deeper analysis needs to reveal, which consumers can be turned off during that time or which of them cause the basic load in the first place. Corresponding measures need to be evaluated. An additional criterion for a sustainable company is the source of energy supply. Changing to a provider for eco-friendly electricity from renewable energy sources is recommended.

F. Distribution

The main goals of sustainable distribution processes are summarized in the following three measures that are part of all known Green Logistics [19] strategies: avoidance of unnecessary transports, optimized use of distribution network capacities, and utilization of transport cooperation and synergies. These measures represent a portfolio of options for the reduction of the CO_2-Footprint of intracompany logistics. As MKW outsources most of their transportation services, they have to be acquired not only based on price but also on environmental key indicators provided by the freight forwarder.

G. Usage Phase

The end-customer (consumer) has an important influence on the extension of the toilet seat's usage phase. Usually, the product is replaced before it reaches its technical end of life. As far as sustainable development is concerned, the societal acceptance of a sufficiency strategy [20] needs to be the goal, as it requires a re-thinking of purchasing behavior and the handling of goods. A manufacturing company alone will not be able to introduce a respective change in behavior and attitude without the support of society and legal regulations.

H. Redistribution

At MKW, an EoLM is completely missing. This system has to be considered a core process for closed-loop recycling management and comprises the collection and return of products at the end of their usage time. As such, a respective concept must be implemented, where the end-customers can send back used toilet seats. This hurdle can only be overcome by manufacturing companies, when a guiding political framework is existing. From the infrastructure point of view, suitable collection points and logistic pathways (Reverse Logistics) need to be developed. Otherwise the used products will still be disposed of in the domestic refuse. After collection, the products need to be disassembled. Duroplast parts must be cleaned and prepared for re-introduction into a new product life cycle.

I. Disposal and Waste Recycling

Due to the suggested concepts for burr-free pressing the respective waste product will either not be generated at all or reduced to a minimum. The reduction of the production of defectives is based on the suggested optimization measures for raw material producers. Other procedures presented for the pressing process itself comprise the transformation of implicit into explicit knowledge and the introduction of tools for process monitoring by online-feedback control systems. In the analyzed company, the re-distribution of end-of-use products needs to be ensured by an EoLM. Only then a closed-loop material recycling of the collected products and their reprocessing by the raw material providers in the form of a particle recycling procedures will be guaranteed.

VI. Conclusion and Outlook

Step by step into a livable future! This challenge has not only to be met by manufacturing enterprises but by the whole global community. The common goal of the manufacturing industry needs to be the development of environmentally friendly products, by simultaneously preserving our resources and by using raw materials even more efficient through recycling management. This target, a transgenerational mindset, has to become the guiding principle for a healthy and sustainable development, not only in Europe but worldwide. This paper shows that economical an ecological sustainability can be achieved, when suppliers, business partners, employees and consumers are integrated into the design of the whole supply chain.

The goal of this work was the development of a recycling management system for the plastic producing company MKW. The presented system needs to be referred to as "conceptional", as many details for its concrete applicability and implementation still have to be tested. It could be demonstrated that especially without the initiative of the company owners for a sustainable corporate development and without the cooperation of raw material providers, who play a key role in this concept, the system would not be feasible in the outlined case study. From an ecological perspective, the raw material Duroplast can at least be labeled as problematic, especially as the production of its basic materials is environmentally questionable. Further-more, contrary to Thermoplast, Duroplast is not re-usable by melting. Currently re-use of this material is only possible by particle recycling, a process not employed by raw material providers for the time being. A search for alternative recycling processes for Duroplast did not provide satisfying results. This indicates that considerable research still needs to be done in this area. Therefore, it is recommended that the presented results are applied to new and alternative raw materials that provide recyclability in the first place.

Currently manufacturing enterprises try to achieve sustainable production with existing facilities and materials, as was also shown in this work. Therefore, concepts for production processes reducing the resulting waste and minimizing burr were developed in the course of this paper. Measures for process optimization that lead to an increase in efficiency within the value chain - as suggested by the Green Manufacturing framework - were outlined.

The implementation of an EoLM has to ensure that products are recycled at the end of their usage time. All these measures will improve the current situation but if they are installed in an isolated manner, their impact will not be sufficient from a sustainability point of view. Plastic producing companies still using Duroplast must to take the initiative, if they intend to improve in this regard. Sustainability could then make a fundamental contribution to strengthening their competitive-ness. Even though sustainability issues tend to fall by the wayside in the day-to-day management, it is therefore still worth reflecting their compatibility with the core business.

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