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DRIVERS FOR LIFE CYCLE PERSPECTIVES IN PRODUCT REALIZATION

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ABSTRACT: *The global increase of manufacturing activities and the need for sustainability calls for manufacturing strategies and technologies with reduced environmental impact. On the basis of industrial experiences and academic reviews, this paper presents an elaborated framework presenting drivers for life cycle considerations in product realization within the manufacturing engineering industry. The framework considers the total life cycle of the product and production system with the phases of material processing, production, usage and afterlife. For each phase the drivers for an increased life cycle perspective is reviewed by the categories of cost reduction, value increase and regulatory initiatives.*
KEYWORDS: *sustainable manufacturing, life cycle, product realization, review*

INTRODUCTION

There is a long seen need for an environmental, economic and social sustainable society, meeting the needs of the present without compromising the ability of future generations to meet their own needs [1]. Focusing on environmental sustainability, it has lead to emerging legislation and industrially accepted emission targets. Meanwhile, a global wealth increase is evident. Through the means of globalisation, values are created worldwide with a worldwide 36 % increase of GDP in current prices over 1998-2008 [2]. By increased welfare the product demand increases, leading to increased manufacturing activity – we have seen a 42 % increase of manufacturing activities worldwide 1998-2008. In figure 1 the increase in economic activity in current prices within manufacturing over 1998-2008 is presented for the largest manufacturing countries. For instance China has seen an unprecedented manufacturing increase over the recent decade.

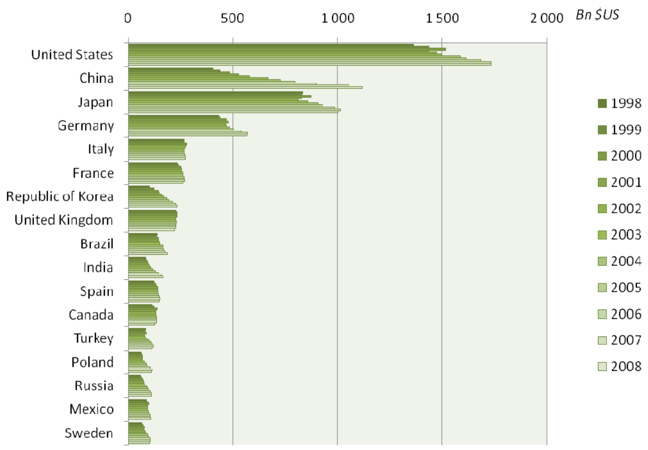

Figure 1. Manufacturing activities 1998 - 2008. Data from UNSTAT [2].

These two trends, the need for sustainability and the globally increasing product demands and manufacturing activities drive the need for technology and strategies that globally will reduce environmental impact of manufacturing. There is a need of large improvements in terms of resource productivity - "doing more with less". The challenge is to reduce non-renewable material and energy usage by absolute numbers, in a fast increasing economic activity.

The resulting change in the manufacturing landscape requires companies to reconfigure both their business and manufacturing strategies in order to cope with the new pressures [3]. Production factors like energy and transportation are becoming more expensive and increasingly regulated. It may, for example, force companies to even more consider their manufacturing footprint as well as their supply system. A trend towards manufacturing close to market with more local sourcing may well be one consequence of the need for reducing transportation within the supply chain. Such examples of environmental considerations are of strategic nature, related also to the business model.

This paper reflects on technological possibilities to address this global challenge for sustainable manufacturing, based on industrial and research challenges. A framework is presented representing drivers for life cycle perspectives in product realization for the manufacturing engineering industry.

INTRODUCING A FRAMEWORK FOR LIFE CYCLE PERSPECTIVES IN PRODUCT REALIZATION

It is generally accepted that environmentally conscious actions need no longer be seen only as challenges and contrary to financial considerations. On the contrary, it can be the basis for competitive companies contributing to global environmental improvements. The environmental issues can be viewed as either constraints or opportunities for competition [4]. As Hart suggested; "the basis for gaining competitive advantage in the coming years will be rooted increasingly in a set of emerging capabilities such as waste minimisation, green product design, and technology cooperation in the developing world" [5]. As concluded in [6], sustainability can be classified *as an order winning or an order qualifying objective depending on market, society and technology, using the terms coined in [7].*

Competitiveness can be described as creating great value by low costs, under the values, costs and preconditions given by the market place. Improvements in competitiveness can thus be focused on three options; (1) improving the value function (as a function of the choices the decision maker can control), (2) decreasing the cost function (also a function of controllable variables), but also (3) influencing the feasible region for solutions, constraining all actors on the market place. By proactive actions on the constraints such as legislation, regulations or praxis, a new market landscape can be formed.

By using these three perspectives on competitiveness; value, cost and market place precondition, actions for leverage on environmental sustainability are described in Figure 2. The framework considers the total life cycle of the product and production system with the phases of material processing, production, usage and afterlife. For each phase the drivers for an increased life cycle perspective is reviewed by the categories of cost reduction, value increase and regulatory initiatives, as illustrated in Figure 2. This is an elaboration of framework and efforts for sustainability approaches presented earlier in [8], [9].

The purpose of the framework, and the paper, is to by a review present an overview and pinpoint specific drivers contributing to a more life cycle focused perspective in the product realization process.

MATERIAL PROCESSING PHASE

One of the major influences in the creation of modern products is the development of materials and materials processing techniques.

□ Value increase

The underlying philosophy in this perspective is to increase customers' perception of value by an increased environmental focus in material selection and processing.

Figure 2. Illustrating the framework for life cycle approaches on product realization

From a value increasing perspective, the material properties are in focus. The development of new materials has accelerated so rapidly that most material available for today's product designers has been developed in the latest 100 years [10]. It concerns greater materials properties of engineered polymers, ceramics, metallurgical alloys and composite materials. The increased functionality at no increase in overall costs has been realized in magnetic thin film storage, high-strength automobile panel, miniaturization of silicon transistors etc. However, there is still large anticipated potential and industrial growth by advanced composites, advanced ceramics, novel polymers and alternative materials.

From a sustainability perspective input is needed in the product design phase. Specific techniques and guidelines on selection of material and production process, product life cycle management, ease of maintenance and remanufacturing with sustainability in focus are areas that need renewed attention from a research perspective.

□ Processing cost decrease

The properties, durability and economy of traditional materials have improved dramatically over the past decades. This is a quiet revolution as the average customer does not perceive the change due to the continuous nature of the improvement [11].

The costs (in constant prices) of metals and minerals have fluctuated heavily over the latest decades. Initially the prices decreased by a factor two over thirty years, 1970-2000 (see figure 3). However, since 2000, the price of metals and minerals has increased drastically as illustrated in Figure 3. The World Bank reports that China has been a primary driver of metals prices in the 2000s and has become the world's largest consumer of metals as well as its largest steel producer [12]. Between 2000 and 2008, China's consumption of key metals such as aluminium, copper, lead, nickel, tin, and zinc grew on average by 16,1 percent a year. Outside China, metals demand rose by less than 1 percent a year.

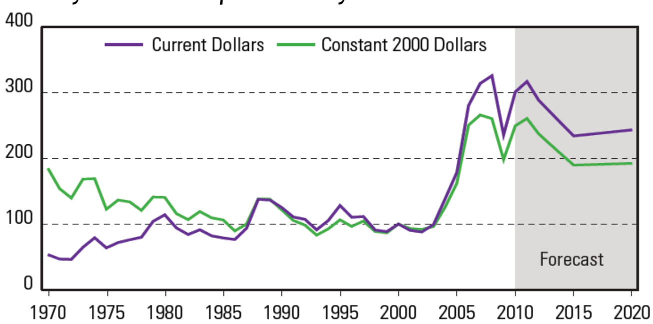

Figure 3. Metal and Mineral price indices (2000 = 100). Source World Bank [12]

In order to cope with this drastic increase in material costs in the latest decade, the yields within materials processing have increased dramatically. There have been large reductions in the processing costs of traditional materials. The needed steps towards a more sustainability focus in materials processing is to accelerate the reduction of the processing costs of the renewable materials such as bioplastics, natural fibres and non-fossile based composites as well as techniques for replacing fossil based energy generation by CO2 neutral generation such as solar, wind and water as well as energy storage techniques.

- **Regulatory initiatives**

Instead of regulating material content, most regulations focus on companies to be responsible for products at the end of their life cycle. This allows for creativity by companies and teams to not only go for renewable material but can drive the whole design process. The design process changes as the product will return to the manufacturer in a closed loop.

However, the often energy-consuming material processing activities are subject of legislations in terms of e.g. energy costs. The Kyoto Protocol contains legally binding commitments for the industrialized countries to reduce their emissions of greenhouse gases by a total of at least 5% [13]. In this total effort, the manufacturing industry has an important place. In Sweden, the industry contributes with 11% to the CO2 emissions. In a recent governmental commission the target is set to reduce the industrial oil consumption by 25-40% [14]. The EU is committed to green growth through the Lisbon strategy from 2000, later materialized in the Göteborg strategy. The European Commission initiated a development and wider use of environmental technologies through implementing the Environmental Technologies Action Plan (ETAP), with 28 defined actions to be implemented at European, national, regional or local level. [15].

PRODUCTION PHASE

A competitive production system has in many cases been the basis for a successful industrial activity, with the industrial revolution and Toyota as merely two examples. Skinner emphasised the strategic importance of manufacturing, by stating "..what appears to be routine manufacturing decisions frequently come to limit the corporation's strategic options, binding it with facilities, equipment, personnel, basic controls and policies to a non-competitive posture, which may take years to turn around." [16].

- **Value increase**

It is possible to create added value for the customer by sustainability actions within the manufacturing process. An illustrating example is organic agriculture products where the customer is willing to pay a price premium, due to the sustainability actions in the food production process. Within manufacturing this type of actions correspond to both added values for the customer, such as local manufacturing giving fast customer response and customisation, as well as fulfilling qualifying regulations and sustainability expectations from the customer on the supplier's manufacturing process.

Enabling features include developing manufacturing technologies for agile and sustainable manufacturing system as well as standard interfaces enabling rapid and customized manufacturing system setup. On a production system level, further development is needed within environmental impact assessment and certification tools as well as system modelling and solutions for local manufacturing providers.

- **Cost decrease**

Cutting cost by efficient resource utilization is also in line with sustainability efforts. The most appropriate process is the most resource efficient. The key is however to make it appropriate over time. The concept of lean manufacturing deals with resource efficiency and waste elimination of all kinds, and can also have positive impact on sustainability, elaborated upon by e.g. the US Environmental protection agency [17].

On a manufacturing process level, the machining, assembly and logistic processes should be further developed towards zero-emission and high energy efficiency. Researchers and practitioners have advanced the knowledge within areas such as net shape manufacturing processes [18], dry or cryogenic machining [19], sustainable metal working fluids [20] as well as novel assembly processes and reverse logistic approaches. The specific focus for an increased sustainability perspective is processes for minimal energy and material usage.

Methodologies and decision support tools for process sustainability evaluation need further development, considering manufacturing footprint and supply chain aspects [21] as well process parameters and key performance indicators for sustainable manufacturing. One specific dimension is energy efficiency monitoring, where a number of indicators are presented in the literature e.g. energy efficiency in terms of energy per output (energy per tonne, etc), energy per $ of GDP (or profit, etc), or energy cost ($) per $ of GDP (or profit, etc) [22]. However, the evaluation of energy efficiency is ultimately a comparative exercise; to make meaningful decisions about energy efficiency the measured efficiency of a process must be compared to a benchmark [23]. An effort to estimate the linkage between energy efficiency and productivity is presented in [24].

Life cycle analysis on a system level during the product design phase is a strong area within research and practice [25]. Enabling features in need of development include next generation of integrated design processes for production and product considering life cycle aspects, modularity schemes and reusability aspects of material and components.

- **Regulatory initiatives**

Increased awareness, importance and understanding of environmental management systems (EMS) have demonstrated relationships with sustainability, competitiveness and institutional practice [26]. The EMS has become established as mainstream business practice for manufacturing companies. In support of EMS, a European Eco-Management and Auditing Scheme (EMAS) as well as the ISO 14001 has been developed on the roots in various European environmental auditing programs [27].

Within the ISO 14000 family a number of standards have been established, supporting the sustainability efforts. The performance measurement efforts earlier mentioned have strong links to environmental evaluation methods of manufacturing systems within ISO 14044: Environmental Management - Life Cycle Assessment – Requirements and Guidelines [28].

In addition to general environmental management systems and auditing schemes, specific regulations exists concerning material use, e.g. toxic substances, such as US Toxic Substances Control Act (TSCA) [29] concerning the reporting, record-keeping and testing requirements as well as restrictions relating to chemical substances and/or mixtures, addressing the production, importation, use, and disposal of specific chemicals. Also the transportation of hazardous materials is subject to strict regulations.

Companies can choose to adopt different positions ranging on a continuum from re-active environmental strategic positions following regulations, to pro-active positions where competitive advantages are sought for. Either way, the environmental concern requires manufacturing industries to develop strategies, technologies and practices that will reduce the environmental impact on both global and local scale.

USE PHASE

During the recent decades, the "greentech" (or "envirotech" or "cleantech") sector has emerged and grown with business based on products, services and technologies with a sustainability focus in their use phase.

- **Value increase**

A typical proactive sustainability action is to develop product and service solutions with neutral environmental impact while used. The actions are closely linked to material and technology development creating customer value. Examples are alternative fuel solutions for vehicles or energy saving technologies that implies a higher value for the customer. Actions focused on the product, specifically for industrial products, can also lead to fulfilling new future regulations and environmental expectations from the customer.

Enabling features include introducing products based on CO2-neutral materials, replacing fossil based materials, technology development for creating environmental and energy preserving offerings and business development including product service solutions for total life cycle sustainability.

- **Cost decrease**

The ideal situation is to develop and offer products and services lowering the cost for the customer in use phase as well as contributing to positive environmental effects. Products leading to higher energy efficiency and closed loops of material and energy will contribute to a more sustainable future.

Looking at areas in need of development, the product realization from design, throughout production, use and after life must be interlinked. Local manufacturing could be a bridge between the production and use phase of a product, creating a complete product service solution based on software services and feedback of information from use to improve product and production system development.

As new emerging renewable materials will be in use, processes enabling sustainable services must be explored for e.g. products based on light ultra high-strength steels and polymer composites, which today require a complete replacement when damaged.

- **Regulatory initiatives**

From regulative authorities a large number of initiatives are in place presenting incentives for the use of more environmental sustainable products. Guidelines, tax credits, legislations and regulation concerning energy consuming industrial and consumer products are presented on national and international level.

AFTER-LIFE PHASE

The life span of products is constantly decreasing as consumers' need for new products increases. A key aspect for increased sustainability is to create closed loops for product retake and reuse of material and components. The afterlife phase requires additional focus. The general definitions on activities in the after-use phase are illustrated in Figure 4.

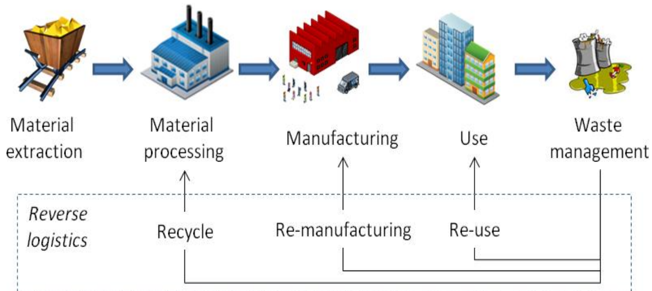

Figure 4. Terms here used for materials handling in after life phase

- **Value increase**

The possibility to retrofit and refurbish products could be increased and to a larger extend presented as value increasing abilities in consumer and industrial products. Products need to be designed considering multiple life cycle use and retrofit potential. It is argued for a more proactive view on remanufacturing and identifies general environmental pros and cons with remanufacturing, such as the material resource perspective [30]. They further review literature concerning the environmental impacts of remanufacturing. Through product design based on component and material reuse, more drastic value increases can be gained.

An even more comprehensive review of literature regarding green supply chain management is presented in e.g. [21, 32], including the aspect of green manufacturing, remanufacturing and reverse logistics.

- **Cost decrease**

The concept of remanufacturing is often quantified in terms of cost advantages and referring to activities designed to reclaim value from a product at the end of its useful life. Industries that apply remanufacturing typically include automobiles, electronics and tyres. In a comparison between the remanufacturing of a traditionally-designed XEROX copy machine and a copy machine that was designed to facilitate remanufacture, the energy savings for the model which has been designed for remanufacturing equal a factor of 3.1 and materials/landfill savings equal a factor of 1.9 [31].

Enabling features include the design and industrialisation of products for multiple life cycles, as well as manufacturing processes for reuse/ remanufacture of material and components, especially fossil based material. The needs of improved technologies, increased automation as well as economic and technical viable systems and concept for pre- and post-fragmentation recycling processes are evident [32]. The information and logistic aspects are vital, supplying information required for reassembly etc as well as feedback from production and maintenance to product and production system redesign.

- **Regulatory initiatives**

From governments and authorities, the industrial waste handling is highly regulated. The Resource Conservation and Recovery Act (RCRA) [33] in US controls hazardous waste from the "cradle-to-grave" including the generation, transportation, treatment, storage and disposal.

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) [34] provides a US federal "Superfund" to clean up uncontrolled or abandoned hazardous-waste sites as well as accidents, spills, and other emergency releases of pollutants and contaminants into the environment. Later the Superfund Amendments and Reauthorization Act (SARA) of 1986 reauthorized CERCLA to continue cleanup activities around US. Several site-specific amendments, definitions clarifications, and technical requirements were added to the legislation, including additional enforcement authorities. Also, Title III of SARA authorized the Emergency Planning and Community Right-to-Know Act (EPCRA).

The Waste Electrical and Electronic Equipment Directive (WEEE) [35] is the European Community directive on waste electrical and electronic equipment which, together with the RoHS Directive became European Law in February 2003, setting collection, recycling and recovery targets for all types of electrical goods. "Users of electrical and electronic equipment from private households should have the possibility of returning WEEE at least free of charge". Also, the companies are compelled to use the collected waste in an ecologically-friendly manner, either by ecological disposal or by reuse/refurbishment of the collected WEEE. In addition, the European Parliament decides in 2003 upon the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) [35].

CONCLUSIONS

By describing a brief overview of approaches for an enhanced life cycle view on product realization, it is clear how the focus in product and process development to an increasing level must move towards the later phases of product realization. By to a larger extend considering the use and after life phases, a shift towards a sustainable future can be made. Based on industrial challenges and the proposed structure for environmental actions, more detailed research challenges can be identified for specific actors and sectors.

The need for environmental sustainability creates both restrictions and opportunities for the manufacturing industry. Products and transports/ logistics have been first in focus for environmental impact improvements. However, to reach a total effect, the manufacturing process also needs to be looked upon from an environmental perspective. The process industry can work as inspiration in some aspects with their long experience in energy efficiency efforts due to high energy consumption and potentially polluting processes.

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