ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XV [2017] – Fascicule 2 [May]

ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

[1.]Helmut BRUNNER, [2.]Mario HIRZ, [3.]Andreas WURZER

CONSIDERING INFLUENCES OF SUSTAINABLE PRODUCTION IN EARLY AUTOMOTIVE ENGINEERING PHASES

[1-3.] Graz University of Technology, Institute of Automotive Engineering, Graz, AUSTRIA

Abstract: Sustainable product development is an important influencing factor in automotive engineering, whereby life-cycle assessment (LCA) methods are an indispensable basis for detailed evaluation of environmental impacts. Comprehensive evaluation is very complex and lots of information is not available in advance of mass production. This leads to the question, how impact assessment results can be transferred to the beginning of the development process, where important decisions about product and production characteristics are made? The present paper discusses approaches for life cycle estimation and decision support in the early concept phase of automotive engineering. Learning from experiences in industry, approaches are presented and discussed, stepping to a more sustainable product development.
Keywords: sustainable product development, early concept phases, automotive engineering

1. INTRODUCTION

Besides purely economic aspects acting in the automotive industry, customers and legislation recognize influences on ecology and society. Consequently, these facts have to be considered by manufacturers as well. Among others, ecological factors consider the consumption of energy and resources and the effects of produced substances on the environment. Social factors represent the involvement of staff as well as the impacts of technologies on society. All these aspects have to be taken into account during the entire life cycle of a car, which includes the phases of conception, development, production engineering, manufacturing, the in-use-phase, and finally the phase of recycling and disposal. Global climate change, resource scarcity and growing pressure from relevant stakeholders have stimulated the automotive industry to integrate sustainability considerations into their business activities. These considerations have to start already in the early phases of product development, since in this phases up to 80 % of product characteristics, costs and the majority of environmental and social impacts are determined [1].

1.1. Development processes in the automotive industry

During the last decades, automotive development has been characterized significantly by a growing share of intelligent components, increasing technical complexity of vehicles and vehicle modules and steadily increasing model ranges. The manifold model type involves the development of different body styles, different propulsion systems as well as different comfort functions and interior configurations. Simultaneously, the production period and the number of produced units per car model decrease. According to [2], these increasing complexities of product technology and variety, as shown in Figure 1, challenge both the entire product development and the production processes.

Decreasing duration of product life cycles leads to demands for shorter product development times. Meeting this demand, the prevailing hierarchical structure of stakeholders in the development process gives way to an interdisciplinary network and exchange between the stakeholders in the future, as can be seen in Figure 2. The changes in product development strategies towards Cross Enterprise Engineering result in the establishment of a closely networked communication structure between various stakeholders in the development process.

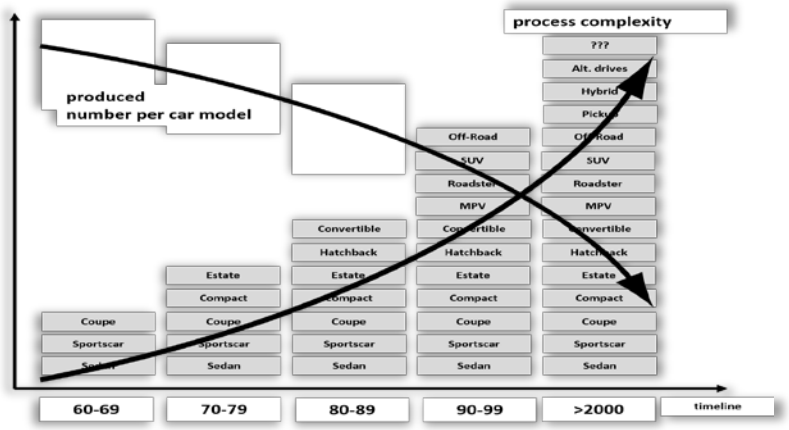

Figure 1 – Development of product and process complexity vs. number of produced units per car model [2]

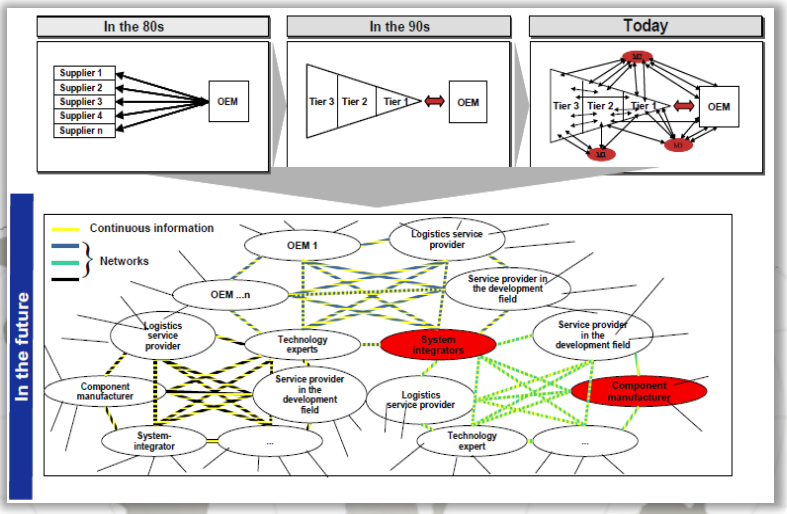

Figure 2 – Development of the stakeholder's roles in the automotive product development process [2]

In this stakeholder network, the automotive supplier's role (Tier) gains more importance. Sub-contractors are stronger involved in the product development process. Nevertheless, they need to meet technical, environmental, economic and social requirements, predefined by original equipment manufacturer (OEM). In this way, a deep integration of manufacturer and supplier from early development phases on is required to tap the potential of modern development processes and to handle the rising complexity of automotive product ranges.

1.2. Sustainable Product Development in the Automotive Industry

Currently, sustainable automotive product development focuses on existing directives to ensure compliance with material prohibitions and environmental regulations in vehicle production and end of life. One example for legal conditions is the ELV-directive of the European Union, which addresses the end-of-life treatment of vehicles [3]. Another focus of legislative lies in the reduction of greenhouse gas emissions and pollutants during operation. Therefore, the legal conditions are described in [4]. Considering the in-use phase of a car, most important fields of research in the area of energy demand and emissions reduction are

- mass reduction by lightweight construction (using high-strength alloys, light metal, fiber-reinforced plastics, multi-material construction),
- increasing the efficiency of conventional internal combustion engines,
- hybridization and development of alternative drive systems, electrification of the powertrain.

Furthermore, key aspects for beyond research and development can be detected in the fields of

- active and passive vehicle safety,
- infotainment and comfort functions,
- car to X communications,
- automated driving functions.

While observing the technological trends in automotive development, a reduction in resource demand for the production of high-technology components cannot be expected. One example is the demand for critical raw materials (CRM) for electronic components, as it is needed for the electrification of the

powertrain. Besides securing existing resource supply strategies, new ways of covering resources and increasing the efficiency of material flow and value creation cycles for different materials need to be found. One example includes the use of multiple materials in the body of a car, depending on the technical properties and mass reduction potential (multi-material design). In a car body, bonding is one of the state of art- methods in permanent connection of different materials. This construction method is limited in its optimization for recycling, which challenges the recovery of various raw materials from end of life- vehicles (ELV). Another challenge applies to a number of critical raw materials in electronic devices in the vehicle, such as sensors or actuators.

In addition, a critical evaluation on the current use of resources needs to be done. One example for this includes the use of aluminum in the body of a vehicle for lightweight design. Due to the lower mass and a decreased resulting driving resistance in comparison to a conventional steel body, a lower energy consumption in the in-use phase can be determined. However, the additional expenditure for the production and provision of aluminum can compensate the energy saving potentials during use. According to [5], a positive assessment over the entire life cycle cannot be assumed in general.

These examples demonstrate the essential importance of an overall consideration of life-cycle related aspects in the product development process. The integration of eco-design approaches and strategies for sustainable product development can contribute significantly to the reduction of resource consumption and increasing the efficiency of material cycles [6, 7], facing future challenges in sustainable production.

2. INDUSTRIAL EXPERIENCES

The upcoming stronger involvement of sustainability-related product characteristics into the product development processes results in new challenges for different stakeholders. The change of roles and responsibilities in the development processes gave birth to a series of workshops in Graz, focusing on the implementation of eco-design and sustainable production approaches in current development processes, guided by the Styrian Automotive Cluster (ACstyria) [12]. Following experiences from these workshops, especially small and media enterprises see themselves in an area of conflict between an increasing amount of legal and customer (OEM) related requirements, especially regarding development, production times and flexibility. Participating companies underlined the difficulty of addressing and positioning sustainable development-related decision-supporting criteria and actions within the value chain. As a summary of discussions with participating companies in the conducted workshops, three lacks of research were detected. These are

- a lack of information in early development phases,
- a lack of a holistic approach for decision support concerning sustainable production and
- challenges regarding the implementation of new sustainability-focused approaches in companies' individual decision making and development processes.

2.1. Lack of information in early development phases

Early stages in product development are of particular importance for cost reduction and improvements regarding sustainability, since the influence and saving potentials are the highest in these stages of development [1]. Figure 3 illustrates the entire life cycle of a car, which includes the phases of research, conception, development, production engineering, manufacturing, the in-use-phase, and finally the phase of recycling and disposal. In the early development phases, quantitative tools such as Life Cycle Assessment (LCA) are hardly applicable. LCA results can only be calculated at the end of the product development process, if the necessary detailed product information is available. Besides this, traditional eco-design methods have major limitations to address the right actors and to support the product development process optimally. Lack of information, high uncertainty and complexity during front-end development impede a successful integration of sustainability-based decision-making. Information about the effects of production are available after start of production (SOP), but they are needed during the early phases of development to enable

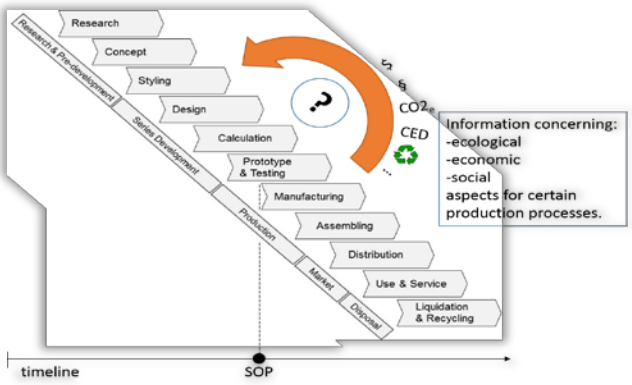

Figure 3 – How can information concerning sustainable production be transferred to the early phases of product development?

comprehensive evaluation in conceptual development. Hence, there is a significant research gap regarding solutions that effectively tackle the challenges of early sustainable product development. The question is how can information concerning sustainable production be transferred to the early product conception and development phases in automotive engineering?

As can be seen in product related environmental declarations automotive manufacturers, e.g. [13] [14], observations in this way are state of the art in automotive industry. Nevertheless, according to interviews with experts during described workshops, time effort for data acquisition and evaluation is relatively high. In the most cases, product related environmental declarations are based on a comparison of environmental effects and life cycle considerations of actual products with their direct precursor. Therefore, data from processes, which haven't changed with the product evolution, can continue to be used, which enable a reduction in data acquisition effort. However, with the development of a new product, data acquisition needs to be conducted from the bottom up, since there is no basis from preceding processes available. Furthermore, early product conception and development phases are often marked by a comparison of different concepts and their production processes. Therefore, data acquisition may need to be done not for one, but for various concepts, which is another challenge.

2.2. Lack of a holistic approach

Facing the above-mentioned challenges concerning ecological, as well as economic and social sustainable criteria in the product development process, existing holistic approaches for the integration into current development processes show limitations. LCA results mainly focus on environmental effects and do not provide information about approaches for improvements. Relevant aspects for decision-making in the developments process, like criticality and security of supply of resources and materials, cannot be illustrated with the method of LCA [8]. Hence, LCA methods are of limited suitability for the sustainability-based optimization of product characteristics and production development processes.

On the contrary, qualitative eco-design approaches like the eco-design checklist in [9] pretend principal coherences and can be applied in early conception and development phases. Because of the large number of trade-offs between different development principles, a qualitative approach, purely based on principles, can lead to suboptimal solutions in decision support.

A holistic approach for the attendance along the entire product development process is missing and needs to be developed. This approach needs to serve information in every step of the process, according to its individual requirements – based on qualitative and / or quantitative methods. The challenge in this development lies in the detection of a common approach, which is able to consider demands from different process architectures in different companies of the network.

2.3. Implementation of sustainable development approaches in existing decision making and development processes

Another challenge for the establishment of a sustainability-focused development process includes a successful implementation in corporate decision-making processes. As studies in [10, 11] show, methods and tools for decision support with respect to sustainability need to be adapted and optimized to individual corporate processes and demands. As shown in Figure 2, changes in product development strategies towards Cross Enterprise Engineering additionally challenge the integration of sustainability-focused development approaches in existing development processes, since decision-making bases on corporate individual processes and do not consider common or standardized approaches. Therefore, the question is, where and in which stage in the process are those decisions made that influence sustainability-related criteria?

3. APPROACHES TO FACE THE EXPIRIENCED CHALLENGES

Based on recorded experiences with sustainable product development from different stakeholders in the automotive industry, three approaches have been derived, to face the described challenges. These approaches will be explained in the following chapters.

3.1. Provision of information in early product development stages

Focusing on intra-company data acquisition, a first approach to face the challenge of missing information in early product development phases in automotive industry involves the understanding and analysis of each step in the production process in different areas. This step requires careful observation and analysis of each production steps for individual components. Next, an actual state of disaggregated processes needs to be defined. The definition involves qualitative aspects, but no quantitative production data is used to define the related values in a first step. An important influence in this phase includes the consideration of personal observations and experiences of the production

manager. When defining the actual state, the consideration of process steps and the influence of the product itself play an important role.
The next step includes an identification and definition of neuralgic points in the production process. These critical points are characterized by the degree of interaction and dependence with / from the process of product development. A neuralgic point in the production process can be defined as a point, which is strongly influenced by the product development. For example, with technical or legal based changes in the development, regarding the design or material-mix, e.g., a relatively high impact on the production and individual process areas can be expected at certain stages. This trade-off may only be compensated by a relatively high financial or time effort, resulting in a compensation of an expected saving potential in the beginning. Examples are explained in 1.2. If changes in the production cycle as well as the product life cycle have this negative effect, this detected weak point in the value chain may represent a spot for further research and development needs, to increase production efficiency with respect to interactions with the product development. Since this strategy does not focus on a certain product, its results can be carried out to similar production processes.

3.2. Development of a holistic approach

Based on experiences regarding the lack of a holistic approach for considering sustainability in production processes in product development, one approach includes the provision of decision support tools for early phases of concept and design. Since existing methods, like LCA or eco-design tools, do not satisfy the demands of information support, new models and methods need to be developed, which are able to consider evolutions in the value chain. The process efficiency is aimed at every possible improvement in the manufacturing processes along the supply chain. Potential for recycling of raw materials, materials and products are finally collected at both the process level and with respect to the end-of-life phase of a product, considering recycling, remanufacturing and reuse options. A successful implementation of these tools depend on the delivery of data and information from and to different stakeholder. Therefore its success does not only depend on the tool and provision of data itself, but additionally on the following approach of investigation of interactions in the developments process.

3.3. Analysis of existing decision making and development processes

With changes in the development process and value chain, automotive supplier gain more importance and are stronger involved in development. With the integration of sustainability-focused approaches in the corporate strategy, new and innovative competences can be generated, ensuring competitiveness and a valuable partnership with the OEM. Furthermore, the generated know-how can be efficiently transferred along the entire value chain within a well-defined network of stakeholders. Hence, the development of a cross-sectional stakeholder network, as can be seen in Figure 2, is not necessarily a further obstacle, but can be seen as a chance for integration of sustainable product development strategies in the state of art development process.
A first step to answer the question, where and in which stage in the process decisions are made, that influence sustainability-related criteria, is a comprehensive investigation of the needs of information in every step of a current product development process. Another important step, on the contrary, is the determination, which information is available. Therefore, the most necessary step for a successful integration of sustainable product development strategies in state of art and future development processes is to deliver the right information at the right time to the right person. In combination with the approaches in 3.1 and 3.2, explained tools need to be integrated, enabling a time- and cost- effective exchange of interests for different stakeholders in the value chain. In this exchange, the OEM has to keep the leading role, the supplier delivers product related data.
An interesting aspect is the consideration of legal boundary conditions and flow of corporate know-how across different companies. According to interviews in conducted workshops, this is one of the main concerns when focusing on future innovative cross-sectional development processes. A careful definition of legal boundary conditions needs to be developed for each involved participant in the value chain, which results in additional need for research.

4. CONCLUSION AND OUTLOOK

The present paper focuses on future developments and changes in automotive engineering process hierarchy and deals with the integration of approaches for a more sustainable production in automotive industry. Based on experiences from companies, 3 research questions have been detected, which need to be answered for a successful implementation. The presentation of three approaches forms the basis for the development of instruments for decision support in product and component design, for communication and raising awareness in order to support strategic management decisions in single

enterprises as well as across the value chain, focusing on a more sustainable production. Following the arguments, with the combination of the three approaches, the highest chances for a successful implementation of sustainable product development strategies can be expected. Nevertheless, further research questions need to be answered. One example is the consideration of legal boundary conditions and flow of corporate know-how across different companies.

Note

This paper is based on the paper presented at The International Conference Management of Technology – Step to Sustainable Production (MOTSP 2016), organized by the Faculty of Mechanical Engineering and Naval Architecture, Croatian Association for PLM and the University of North, in Porec/Parenzo, Istria, CROATIA, June 01–03, 2016.

References

[1] Mascle C., Zhao H. P.: Integrating environmental Consciousness in Product/Process development based on Life-Cycle Thinking, International Journal of Production Economics 112(2008).
[2] Eigner, M., Stelzer, R.: Product Lifecycle Management: Ein Leitfaden für Product Development und Life Cycle Management, Springer-Verlag, 2009.
[3] Directive 2000/53/EC of the European Parliament and of the Council of 18th September 2000 on end-of-life vehicles. L 269–43, 34–42
[4] UNECE R101, Regulation Nr. 101 of the United Nations Economic Commission for Europe (UN/ECE), 2007.
[5] Schnöll, H.P., Brunner, H., Zottler, H., Hirz, M., Ramsauer C.: CO_2 Reduction Potential of CFRP-Bodywork Concepts considering Production and In-Use Phase, Proceedings of the International Conference Management of Technology - Step to Sustainable Production, Brela. 2015.
[6] Zimmerer, C.: Nachhaltige Produktentwicklung, Disserta-Verlag, Hamburg, 2014. Romli, A., Prickett, P., Setchi, R., Soe S.: Integrated Eco-Design Decision-Making for sustainable Product Development, International Journal of Production Research, 53(2014)2, 549-571.
[7] Mancini, L., Sala, S., Góralczyk, M., Ardente, F., Pennington D.: Life Cycle Assessment and Criticality of Raw Materials: Relationship and Potential Synergies, 6th International Conference on Life Cycle Management, Gothenburg, 2013.
[8] Brezet, H., van Hemel C.: Ecodesign: a promising Approach to sustainable Production and Consumption, UNEP, 1997.
[9] Bertoni, M., Hallstedt, S., Isaksson, O.: Value Assessment of Sustainability hotspots in Conceptual Design: an Aerospace Study, International Symposium on Tools and Methods of Competitive Engineering (TMCE), Budapest, 2014.
[10] Waage S. A.: Re-considering Product Design: a practical "Road-Map" for Integration of Sustainability Issues, Journal of Cleaner Production 15(2007), 638-649.
[11] Styrian Automotive Cluster (AC Styria), www.acstyria.com/en/, 2916-03-20.
[12] Umwelterklärung 2012/2013 BMW Standort Regensburg, BMW AG, Regensburg, 2013.
[13] Umwelterklärung 2012 Standort Salzgitter, Volkswagen AG, Wolfsburg, 2012.