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Eco-design processes in the automotive industry

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Abstract
Every year approximately 70 million passenger cars are being produced and automotive industry is much bigger then just passenger cars. The impact of automotive industry on the environment is tremendous. From extracting raw materials through manufacturing and assembly processes, exploitation of the vehicle to the reprocessing irreversible, extensive environmental damage is done. The goal of this study is to show how implementing eco-design processes into supply chain management can reduce the impact of automotive industry on the environment by e.g. reducing the use of the fuel, increasing the use of recycled materials. Focus is on evaluation of current state, environmental impacts and potential improvements for design, raw materials, manufacturing and distribution and end-of-life phase.

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1. Introduction

According to Wards Intelligence study the population of vehicles in 2016 stood at 1.32 billion. Those include passenger cars, trucks and buses. That number grew dramatically since 1996 when the population of cars stood at 670 million (Petit, 2017). The most drastic grow was noticed in Asia-Pacific region. The boost in demand had to be met by manufacturing companies. Not only the use of non-renewable resources increased but also pollution and waste. Nunes and Bennett in their article pointed out that the biggest environmental hazard comes from utilization (Kapstustka et al., 2020), on the other hand, minimizing transport may lead to unsatisfied demand for selected groups of goods (Baryshnikova et al., 2020). Massive amounts of fossil fuels are being consumed by vehicles every year (Bennet, 2010). Pollution is a big concern as it impacts humans and nature. Air pollution can cause cardiovascular problems, allergies and asthma attacks, conjunctivitis, bronchial diseases and even lung or skin cancers. The consequences on environment are just as great: acid rain and global warming. Acid rain can damage not only plants but also buildings. They also acidify soil and water what causes an increased amount of heavy metals in them that get absorbed by plants and animals and in the end by humans. Mamali et al. (2013) explains that greenhouse gases, are responsible for a climate change. In the production phase most damage is created by high energy consumption. Last phase of life of the product is also problematic because of the waste. If it is not handled properly it can come to contamination of the soil. Waste created during production can also be a chemical threat to the environment (Bennet, 2010; Szegedi et al., 2017). Minimizing waste (of various types) indicate that the processes of material and information flow require improvement based on a set of tools, e.g. quality management or lean concept tools (Klimecka-Tatar and Ingaldi, 2020; Urban, 2019). Therefore our main motivation was to study potential improvements in polluting automotive industry.

Herrmann et al. (2019) and Cerdas in their book describe Life Cycle Assessment (LCA) as a method to assess environmental impacts of product and service systems over the whole life cycle. It helps with decision making on every level. Before performing product or process eco-design the benefits and motivation factors should be analysed. That helps the eco-design team with analysing and identifying the strategies suitable for the product development. Those factors arise from the manufacturing company as well as from external factors such as policies and markets (Venkatachalam et al., 2018). The common life cycle assessment approach (from ISO 14040 and 14044) distinguishes four essential steps needed in all types of studies: goal and scope, life cycle inventory, life cycle impact assessment, and interpretation. First step is defining the framework of a study and its functional unit. Life Cycle Inventory (LCI) is a register of material and energy flows. Life Cycle Impact Assessment (LCIA) classifies LCI records depending on their environmental impact. LCA is an evaluation step that aims to improve the whole assessment (Cerdas, Herrmann, Schebek, 2019). There is many advantages of LCA among which can be mentioned: 'throughout whole life of the product' perspective, considering major ecosystems and all their parts, it is a universal method possible to adapt to different sectors and industries, helps develop environmental statements and introduce eco-labelling schemes (Mamali et al., 2013). The LCA method applied in automotive industry can help with the reduction of pollution, waste and amounts of fossil fuels used. The aim is to create ecological sustainable production process for the vehicles to make them more environmental friendly by changing the design, used materials, manufacturing methods and processes as well as by making them easier to reprocess. LCA has been used as an effective environmental management tool in many studies. For example, LCA was used to compare the environmental impacts of different automobiles (Allenby et al., 1995), in the paint industry (Dobson, 1996), to reduce the environmental impact of automotive batteries (Robertson et al., 1997), to compare different forestry operations (Berg, 1997), in the metal-processing industry (Finkbeiner et al., 1997) etc.

The beginning of the eco-design concept is dated in early 1990s in Europe (Roy, 1994). However, the first studies about the production and material life cycle were carried out thirty years earlier. They were focused on energy efficiency, raw material consumption and slightly on waste management (European Environment Agency, 1997). Eco-design is defined as "the integration of environmental aspects into product design and development with the aim of reducing adverse environmental impacts throughout the whole product's life cycle" (ISO, 2011). Eco-design reduces the environmental impact caused by consumption and production activities, whether the main motivation for their development or deployment is environmental or not (Kuzman, Rajat, 2016). It takes into account issues related to environmental safety and health over the product life cycle (Kafa et al., 2013). Eco-design allows the firm to play a proactive role with respect to regulations, to adapt to them and remain competitive in countries where the authorities require producers to take back their products at the end of their useful life (extended responsibility). Eco-design can enhance the firm's image and improve relationships with various stakeholders: financial, environmental groups, neighbouring communities, and so on with a potential to be reused or recycled at end-of-life (Plouffe et al., 2011; Ulewicz and Blaskova, 2018). All activities of the company in the field of eco-design re-quire financial security - which results from securing initial capital function by resources capital (Otola and Grabowska, 2009). The company's activities also require public ac-ceptance in the field of modern technologies - eco design usually involves the need to implement "clean" solutions (Ingaldi and Klimecka-Tatar, 2020; Obrecht et al., 2020; Panza et al., 2019)

In this study four parts of life cycle of a product will undergo an analysis and eco-design improvements. There will be shown environmental impact and possible solutions to improve sustainability of the design are examined. Our goal was to present simple potential solutions and to evaluate the magnitude of impact on environment related with specific measures in specific phases of the automotive supply chain.

2. Experimental

A literature review was carried out to examine the theory of eco-design and the situation on the Polish automotive market as well as to examine potential improvements. In this research the methodology used was case study of a BMW Z4 production process. Subsequent production steps, materials and processes adapted as well as possible environmental threats were investigated. Ecodesign method was used to define impacts within specific processes. An analysis of the subsequent stages of car production was carried out to examine the risks and potential improvements.

3. Results and discussion

3.1. Automotive Industry in Poland

In recent years Poland has attracted a massive amount of foreign investment in the automotive manufacturing sector. Due to that it has become one of the major manufacturers of cars, car parts and components in Central and Eastern Europe. At the same time, automotive manufacturing has developed into one of the leading industries in Poland. Furthermore, Poland is the region's largest automotive market in terms of sales and services. Data of auto manufacturers reveal that their combined output corresponded to 666.600 passenger cars and light commercial vehicles (Piechocka et al., 2018). Automotive industry in Poland generates 8% of GDP. Technology that optimizes production is artificial intelligence driving the development of autonomous cars have a key impact on the industry.

The Polish automotive manufacturing is almost entirely export-oriented. For that reason the sector's shape depends heavily on the economic situation on foreign markets. Growth in Poland's automotive production in recent years was caused mainly by extensive investment outlays. In 2017, capital expenditures of automotive manufacturers in Poland amounted to PLN 6.7 billion. In terms of investment outlays, automotive manufacturing remains one the key sectors of industry, accounting for 13,76% total outlays in this part of the economy. In 2017 automotive production incurred the second highest investments outlays in the entire manufacturing industry, being behind the food production (PLN 7.3 billion), being a significantly larger branch. Together with employment growth, there was an increase in average monthly gross wages and salaries in automotive manufacturing (Piechocka et al., 2018). However environmental concerns were not seen as the priority especially if not demanded by principal.

3.2. Life Cycle Assessment in automotive industry

Some measures should be taken under consideration while planning eco-design for a product. We can divide them into phases according to product life cycle.

Design

In the middle of industrial revolution material selection was based on technical demands for example: price, temperature stability, density, strength of material etc. The focus was also on the optimisation of parameters like weight, cost design and thermal distortion. However, the change in industrial environmental policies in recent years caused the change of major emphasis. It is now put on the technologies that allow reducing the environmental aspects. The companies still find pollution prevention as economically beneficial (Vinodh and Jayakrishna, 2011; Ulewicz and Mazur, 2019).

The latest trend is the application of lightweight constructions in car manufacturing. For meeting policies and customer demand, the application of high strength materials is one of the promising possibilities. Applying high strength materials (high strength steels like DP1000, TRIP780, aluminium alloys, e.g. AA7021 or AA7075) allows to meet many of the requirements. The higher strength results in the use of thinner sheets. Mass reduction results in lower consumption with increased environment protection. However, the lightweight production may not be the cheapest one. Manufacturing of different materials requires different machines and processes. To fulfil increasing rigorous environmental restrictions the research activities about low-cost environmental manufacturing are one of the most important (Tisza and Czinege, 2018).

The reduction in weight helps also with reduction of fuel used by vehicle as approximately 75% of the average motor vehicle's fuel consumption is caused by vehicle weight. The weight of the vehicle affects handling, braking and reducing power requirements. Eventually it leads to downsizing of vehicle components. Das et al. stated that vehicle weight is the key source to achieve significant reductions in the life cycle energy consumption and greenhouse gas emissions as the rolling resistance and acceleration forces are directly proportional to vehicle weight. Some studies (Kobayashi et al., 2009; Bastani et al., 2012; Mayyas et al., 2012) show that a 10% reduction in vehicle weight can result in a 6%–8% fuel economy improvement (Karpat et al., 2014).

Summary of current state and environmental impact of design phase is presented in Table 1.

Table 1. Current state and environmental impact of design

Current state	Environmental impact
Mass of products has been increasing steadily	The use of raw materials is increasing
Products use fuel and gas, bigger and bigger engines are produced	Increased emission of CO_2
Complicated designs with a lot of features	Many elements increase weight of the products as well as there is more elements that will need replacement in case of a damage

There was a cost comparison was made by Roth et al. (2001) and his co-workers to analyse the economy of aluminium substitution. The mid-range baseline material prices is $1.50/lb for aluminium and $0.35/lb for mild steel. The forecast made is that the significant increase of aluminium materials in body panels will lead to the decrease of the relatively high aluminium sheet material prices and at the end it will make the aluminium substitution more favourable. The cost of an aluminium body-in-white normally exceeds the cost of steels considering only the cost of structure itself. However, the overall vehicle manufacturing cost is smaller. When the fuel savings benefits of reduced mass of lightweight aluminium are taken into account, the total lifetime usage costs can influence cost parity or even a net benefit related to conventional vehicle constructions (Tisza and Czinege, 2018).

Raw materials

The production of secondary aluminium alloys is much more cost-efficient in comparison with the production of primary aluminium alloy. The production of secondary aluminium alloy saves energy. Recycling aluminium makes use of a valuable commodity, reduces carbon footprint, helps satisfy an increasing demand, etc. The aluminium can be easily and endlessly recycled without quality loss. The chemical composition and the mechanical properties of the secondary material are comparable with properties which are required from primary alloy. The evaluation of the microstructure shows that secondary material contains the same structural components as the primary alloy. It is very important to mention that most of the aluminium being produced today enters long-life products like vehicles and building products. With average lifetimes of about 15 to 20 years for vehicles Most of the aluminium will not be available for recycling for many years. As a result, access to aluminium scrap is very limited (Bokuvka et al., 2016; Ingaldi and Czajkowska, 2019).

Summary of current state and environmental impact of raw material selection is presented in Table 2.

Table 2. Current state and environmental impact of raw materials

Current state	Environmental impact
Use of least ecological but cheap sources of energy	The source of electrical energy is usually coal or nuclear plant
Use of hazardous materials	Use of toxic chemicals and paints creates toxic waste
Small percentage of use of materials from recycling	Many elements could be regenerated or recycled. However, usually there are newly manufactured products used

The improvement of energy efficiency is one of the main issues under consideration. Huge efforts in the manufacturing industry have focused on reducing the energy consumed by the different pieces of equipment or changing the processes. However, in next years this will not be sufficient anymore. New European Union policies require increased energy efficiency (by 20 %) to cut the greenhouse gas emissions by 20 % while raising the share of renewable energy used in the European Union to 20 %. Along with the progression of the nuclear phase-out and the increasing share of renewable energy sources, the sensitivity and awareness for the changes in the energy system is rising. Current energy management systems cannot exist and need to be improved in order to manage energy more efficiently. In automotive industry energy prices drive manufacturing costs and lead to innovations. Energy management systems are now primarily energy accounting systems and actual management of energy sources is still not applied widely in the industry. In response upcoming, real energy management systems should be structured. They require new functions focusing on relevant scenarios in the automotive industry (Franz et al., 2017).

Manufacturing and distribution

Usually manufacturing and distribution are separated in this type of analysis. However, a lot of measures is the same for both processes. They also cover each other as transportation is also a part of manufacturing, packaging is used during manufacturing as well as for distribution purposes. Therefore I will analyse them together for this research.

There are many aspects of a manufacturing process that needs to be considered – e.g. forming speeds, transfer times, holding pressures, lubrication requirements, tooling, cooling, etc., for - mentioned in section A. Design - substituting aluminium. In manufacturing of body-in-white parts, forming processes were assumed as primary manufacturing process. "For both aluminium and steel structure scenarios mean mostly press line and tandem sheet stamping. Required press tonnage is assigned to each component based on material, area, and thickness. The number of presses in a press line required to blank, form, and trim each part is also assigned based on material, part design, and complexity." Press tonnage also influences equipment power and floor space requirements (Tisza and Czinege, 2018).

Hines and Taylor (2000) refer to seven wastes that are similar to the Toyota Production System and are defined as waste of: overproduction, defects, unnecessary inventory, inappropriate processing, excessive transportation, waiting, unnecessary motion and poor workplace organization. The Japanese word "muda" is used to describe these wastes as resulting in non-value adding to product or service. A broader view could also include the added dimension of environmental impact. Almost all of them have a potential environmental impact resulting from use of resources to protect product, additional processing, or disposal of product. Even the item unnecessary motion could result in increased processing time and therefore poor use of resources (Bird and Kochhar, 2009).

In the automotive sector, both products and processes have been the subject of consideration to reduce their impact, yet it is also clear that annual worldwide production and sales of some 70–80 million vehicles is not environmentally sustainable. However, environmentally optimised products and production may have become. Progress made so far in product terms has focused primarily on emissions and fuel consumption. In production terms the focus has been on the reduction of paint-shop emissions, energy efficiency measures and reduction of waste (Katsifou and Nieuwenhuis, 2015).

The expectations of a sustainable manufacturing process are: energy consumption reduction, waste elimination/reduction, product durability improvement, health hazards and toxic dispersion elimination, higher quality of manufacturing, recycling, reuse, remanufacturing enhancement, development of renewable energy resources and energy consumption reduction. In order to design a sustainable manufacturing following objectives should be considered: design for repair, reuse, and recycle, design for waste and hazards minimization, design for product disassembly, design for continuous improvements, design for energy efficiency, design for remanufacturing, design for optimal materials use, design for cost effectiveness. This approach allows developing work practice and maintenance, process optimization, the implementation of energy-efficient technologies, raw material substitution, new technologies, new product design (Kishawy et al., 2018).

Summary of current state and environmental impact of manufacturing and distribution is presented in Table 3.

Table 3. Current state and environmental impact of manufacturing and distribution

Current state	Environmental impact
Manufacturing and distribution create waste	A lot of waste is being created while manufacturing, packing and distributing product
Most commonly used mode of transport is car/truck transportation	Car/truck transportation are flexible and commonly used. However, more ecological ones are train or multimodal transport
High stock of products	High stock requires a place and special conditions of warehousing. Use of energy is increased.

Reprocessing of the product after end-of-life

Utilization and conventional sorting and recycling techniques are not economically efficient to treat complex industrial waste. However, complex wastes derived from the automobile industry can be used as an input stream for the modification of steel surfaces. High abrasion and corrosion resistance steels have attracted much interest in industrial applications because costs associated with product failure can be minimized. Many surface hardening techniques have been developed to improve the abrasion and corrosion resistance of less expensive carbon steel. Unfortunately these techniques are in general not cost-effective (Pahlevani et al., 2017).

One of the main concerns in automotive industry is the increased awareness for environment protection. Recycling and life cycle considerations are regulated by legislation rules which prescribe that a significant percentage of vehicles should be reused. There is also End of Life of Vehicles (ELV) rule in the majority of countries stating the amount of waste produced by vehicles, and that hazardous waste have to be fully treated. As the results both steel and aluminium components can be recycled. The processability of alloys imply the use of high energy input to melt the alloy. Even though the primary production of aluminium generates more CO_2 than producing steel, reprocessing steel alloys produces nearly four times more CO_2 than aluminium (Tisza and Czinege, 2018).

Current industrial processes of recycling lithium ion batteries do not recover a proper amount of lithium to meet forecast demand from their manufacturers. Also current recycling processes are unnecessary energy intensive, complicated, and produce waste (Jeswiet, Sonoc, Soo, 2015).

End-of-Life Vehicles are usually scrapped for recycling or sometimes abandoned on the road. The devaluation of scrap metal, a poor vehicle registration system, weak legislation and the growth of cheap second-hand vehicles contributed to an increase in the amount of abandoned vehicles. Vignano et al. (2010) estimated that EU countries produced approximately 1.9–2.3 million tons of automotive shredder residue (ASR) annually. This makes approximately 10% of the total number of hazardous wastes produced and up to 60% of the total shredding wastes. Automotive shredder residue is composed of plenty of materials including metal, rubber, wood, dirt, textile, glass and up to 27 different types of plastics. Waste management and environmental legislations require high rates of reuse, recycling and recovery. The lightweight materials in the automotive sector cause problems like separating composites and polymers from metals. The industry has made giant progress on recycling technology but there is still a lot of challenges. Also the recycling and recovering process of composite materials is not easy. There is suggested that design for disassembly could be a prevention for that in the design process (Broughton et al., 2014).

Summary of current state and environmental impact of reprocessing the product after end-of-live is presented in Table 4.

Table 4. Current state and environmental impact of reuse of the product

Current state	Environmental impact
Not many parts are being reused	Many parts can be regenerated (e.g. Batteries) or recycled
Chemicals and paints create toxic waste	Hazardous waste can poison water and lands and create permanent damage on environment.

In the Table 5 there are proposed measures that should be taken under consideration in each step of supply chain management phases. The number of measures grows with the number of processes and resources used so this table can be further expanded.

Table 5. Measures for Eco-design divided on phases

Area	Measures	Current state	Potential improvement	Impact on environment
Design	Weight of the product and its parts	Mass of products has been increasing steadily	Lighter product means less material	Medium
	Consumption of fuel	Products use fuel and gas, bigger and bigger engines are produced	Using hybrid, biofuels, electric cars and lightweight constructions	High
	Number of parts	Complicated designs with a lot of features	Simplifying the design	Medium
Raw materials	Resources used	Use of coal plants and nuclear plants	Increased use of renewable energy	High
	Hazardous materials	Use of toxic paint	Use of eco and natural paint	High
	Use of materials from recycling	Use of newly produced materials	Reuse of materials from old cars (aluminium, plastics, etc.)	Medium
Manufacturing and distribution	Use of media (energy, water)	Use of coal plants and nuclear plants, use of fresh water	Increased use of renewable energy and wastewater treatment plant	High
	Amount of waste	Big amounts of waste from manufacturing, documentation, packaging	Use of multiuse products, electronical communication, lean manufacturing etc.	Medium
	Use of hazardous materials	Use of harsh and toxic chemicals	Use of eco and natural substances	High
	Pollution	Pollution from electricity and fuels	Use of filters and modern ecological machines	High
	Type of packaging	Single use packaging, multi packaging	Single, recyclable packaging	Medium
	Mode of transport	Use of trucks	Use of rail and multimodal transport	High
	Size and weight	Products are heavy	Producing lightweight vehicles	Low

	Documentation	Paper documentation	Electronical documentation	Low
	Stock	High stock of materials and products	Lean management	Low
	Intensity	Delivery of few vehicles at once, depending on mode of transport and customer order	More rare but higher quantity deliveries	Middle
End of life	Reuse of parts	Landfilling the parts due to difficult reprocessing	Use of new technologies that help with reprocessing	High
End of life	Hazardous waste	Inappropriate handling due to high costs	Raising the knowledge about handling and its consequences	High

As presented on Fig. 1 it can be seen that different phases have different impacts on environment. Manufacturing and distribution was assessed to be the most influential. On the other hand we can see that there is a huge potential for reducing the environmental impacts and risks. Again the biggest gap can be noted in manufacturing and distribution phase. This phase is also better managed by car manufacturers than e.g. raw materials or end-of-life, that is not directly managed by car manufacturers.

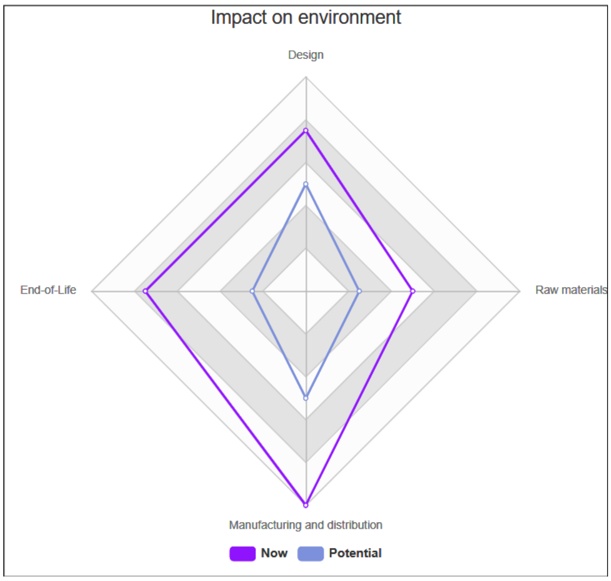

Fig 1. Impact on environment of phases of life of the product

4. Summary and conclusion

The importance of developing sustainable products is growing. Automotive industry is already focusing on reduced fuel consumption and cleaner production however there are numerous improvements that could be done in the process of supply chain management. Not only because of increasing policies and law restrictions but to save environment and limited resources as well as due to increasing customer environmental awareness. There is still a need for technology improvement to help make reprocessing old automobiles easy and cost-efficient. There should be a major switch to use renewable sources of energy. Strategies such as Lean Management are already being introduced to help with cost, waste and material use reduction. Some regulations require a given percentage of materials used in production to be renewable and this is and important framework for automotive industry. The most important are policies regarding hazardous materials as they state the biggest hazard for the environment.

Even though the environmental friendly manufacturing is not always the cheapest way for companies, they do care about environmental pollution and make investment in eco-design of the product and processes. It is a long-term investment that has not only ecological benefits but also influences public opinion about the company and helps with meeting customer and political requirements of the product which is of special importance in times of predicted green recovery in the European Union after economic crisis reflected by post pandemic restrictions.

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汽车行业的生态设计流程

關鍵詞

汽车行业
生态设计
供应链管理
业务流程
清洁生产

摘要

每年大约生产7，000万辆乘用车，汽车工业的规模远远超过乘用车。 汽车工业对环境的影响是巨大的。 从原材料的提取到制造和组装过程，从车辆的开采到不可逆转的后处理，都对环境造成了严重破坏。 这项研究的目的是展示在供应链管理中实施生态设计流程如何通过以下方法减少汽车工业对环境的影响： 减少燃料的使用，增加回收材料的使用。 重点是评估当前状态，环境影响以及设计，原材料，制造和分销以及寿命终止阶段的潜在改进。