EFFECTS OF ENVIRONMENTAL IMPACT BASED ON ALTERNATIVE MATERIALS AND PROCESS SELECTION IN AUTOMOTIVE COMPONENT DESIGN

Alexandra Gallimore, Wai Ming Cheung*
Faculty of Engineering and Environment,
Department of Mechanical and Construction Engineering,
Northumbria University,
Newcastle Upon Tyne, UK. NE1 8ST

ABSTRACT

Recent literature in automotive research indicates that studies of the environmental impact mostly concern with metal-based components. Environmental effects are mainly analysed using "environmental performance indicators" and "life cycle assessment" techniques. Therefore a knowledge gap in the field of studying automotive plastic components should be conducted based on analysing material and manufacturing processes selection at the design stage. The research is focused on a plastic component previously unexplored and analyses it using tools that have not been employed for this application. A computer-aided tool was used to model the part and its associated sustainability function was used to analyse its environmental impact. The component was analysed using different materials and manufacturing processes, then redesigned to be more ergonomic. The improved component design was manufactured using rapid prototyping and a consumer preference survey was conducted to determine which component was preferred. The research found that by changing the material to high density polyethylene there would be approximately a 30% reduction in carbon footprint, 24% reduction in air acidification, 26% reduction in water eutrophication and 15% reduction in total energy consumption. Injection moulding is found to be the most sustainable manufacturing process.

Keywords*:* automotive component design; sustainable design; environment impact reduction; material and manufacturing process selection

1. INTRODUCTION

As automobile technology has advanced, there has been more focus on the safety and sustainability attributes of vehicle design. Material and manufacturing process selection is at the forefront of modern attitudes towards the automotive industry in the present day. As the world has become more concerned about the environment, global warming and greenhouse gases; the automotive industry has had to show they are saving resources, cutting down on waste and producing more 'eco-friendly' vehicles. Governments around the world have introduced more environmental laws, including EU Regulation No 443/2009 which sets an average CO_2 emissions target for new passenger cars of 130 grams per kilometre [1]. The target is gradually being phased in between 2012 and 2015 and target of 95 grams per kilometre will apply from 2021. Consumers are becoming more concerned with the environmental effects of their vehicles therefore automotive companies must implement more 'eco-friendly' initiatives in order to stay competitive.

For automotive companies to lower their environmental impact, changes must be made very early on in the design stages. Simply, the finished vehicle should be lighter and more fuel efficient than its predecessors, which can be achieved by selecting the right material for each automotive component. The amount of energy used to produce the vehicle and the amount of waste left over from production should also be reduced in order to have a more environmentally supportive product. This can be achieved by using the right manufacturing processes and making informed decisions regarding the supply chain of components. The automotive industry is collectively moving towards more environmentally conscious manufacturing by studying the life-cycle analysis of their products and improving the basics; material and manufacturing process selection.

* Corresponding author: wai.m.cheung@northumbria.ac.uk

The automotive industry is evolving to include more sustainable designs and products. This work focuses on an automotive component previously unexplored in literature. As most published works analyse electric cars and metal-based components. Therefore, the aim of the research is to provide a comprehensive study into how using alternative materials and manufacturing processes can minimise the effect a plastic automotive component has on the environment. It also aims to provide key information to automotive component companies regarding material selection which can be used during the design process in order to improve the sustainability of their products. It will enable product designers to quickly evaluate the environmental impact of their product and how to reduce it. The remainder of the paper is as follows: Section 2 describes the relevant literature; Section 3 highlights the proposed approach; Section 4 discusses case study; Section 5 presents the results and this follows by the conclusion and future work.

2. LITERATURE REVIEW

Relevant automotive research concerning environmental impacts is discussed as follows. Maxwell [2] provides an introduction to plastics and metals, design requirements, composites, processes and materials selection. The work was focused on automotive applications, comparing plastics and metals and examines plastics from an environmental perspective. Ashby [3] addresses global concerns of sustainable engineering, material choice when designing is the key to minimizing environmental impact. Happian-Smith [4] outlines the basic principles and builds up analysis procedures for the major aspects of vehicle and component design. Subjects such as designing with modern materials, ergonomics and failure prevention are covered in detail and future trends in automobile design are also discussed. Orsato and Wells [5] discussed how manufacturers could be more sustainable during the design, manufacturing, vehicle use and end-of-life stages of production. The paper also explains some of the economic, social and environmental pressures facing the industry.

Jasch [6] investigates environmental performance indicators (EPIs) and uses the new ISO standard, ISO 14031 and the EU EMAS regulation to show how they are used in a case study of a brewery. The author details how companies can respond to the new standard and how it differs from the previous regulations. This paper provides a large amount of information concerning ISO standards and how industries can comply with them. Thoresen [7] focuses on how industrial companies must use EPIs to be successful. The study suggests that companies should have higher than average environmental ambitions and should consider environmental impacts of all stages of the products life cycle. Mayyas et al [8] summarise the different ways that companies can approach sustainability. The authors investigate the design for X, end-of-life, light-weight engineering and material selection studies. The research explains the sustainability models currently being used in the automotive industry, including models from Ford, Volvo and Asian auto-makers.

Gungor and Gupta [9] present the development of research in Environmentally Conscious Manufacturing and Production Recovery. The paper discusses how a product impacts the environment at each of its life cycle stages and how by understanding the life-cycle of a product, better decisions can be made in the design stages. The authors also cover Environmentally Conscious Production and state that the production system must be designed and operated with minimum impact on the environment. Liu et al [10] explore the impact of the Chinese automotive industry on the countries environmental goals. The study uses a life cycle analysis (LCA) based analysis to split the impacts between the production and consumption stages and state whether the impacts are direct or indirect. The authors found that most of the environmental impact was at the indirect production and direct consumption stages. It was concluded that the growth of the automobile industry in China must be controlled to ease pressure on the environment. Murthy and Mani [11] investigate how sustainability and design are linked and how Computer Aided Design (CAD) software can aid in creating sustainable products. The authors explore where technology should be used when designing a product and the implications of using CAD tools in design and sustainability. The work also predicts future trends involving the future of using CAD including the idea that CAD will hasten the process of innovation and therefore that products will be outdated and turned into waste more quickly.

Research that focused on material and manufacturing process are summarised as follows. Girubha and Vinodh [12] focus on how the criteria for material selection are selected. Fuzzy VIKOR was used to evaluate an alternate material for an instrument panel. The objective was to find a rational method to select the best material for an application based on known material parameters and the requirements of the application. Environmental impacts were also considered and compared for four alternate materials. The study found that polypropylene could be used as an alternate material for the instrument panel. Johnson and Kirchain [13] studied a case where an automotive instrument panel beam was produced using stamped steel or die-cast magnesium. The study showed that material choice plays an important role, as the magnesium design afforded significant parts consolidation which led to both lower assembly and development costs. Renaldi et al [14] give an overview of how materials and components contribute to the total environmental impact of electric vehicles. The paper investigates the components of electric cars that are different from conventional cars, such as the battery pack. It was shown that the unique components will have an effect on the environment and they stress that a thorough LCA study should be undertaken to fully understand the impacts. Ipek et al [15] attempted to solve the problem of material selection using an expert system approach. This computer-based decision tool was used to evaluate specific material properties and match them to components such as the bumper, flywheel and implants. The authors found that polymeric materials were selected for the bumper, reinforced plastics or metal for the flywheel and stainless steel or polymeric materials for the implants. The selected materials were almost identical to previous authors which showed their approach to material selection was a valid one.

Wood [16] outlines the basic equipment and moulding processes used to produce plastic automotive components. The book also discusses the application of plastics in vehicles designed specifically to evaluate weight savings and minimise fuel consumption. Nouira et al [17] developed two mathematical optimisation models to show the correlation between the manufacturing processes for a component, the greenness of a component and the components demand. The study found that if a company offered two components, an ordinary one and a 'green' one, most of the customers picked the 'green' product and company profits increased. This paper is informative because it proves that even if costs increase slightly, consumers still prefer a more sustainable product. Raugei et al [18] compare the original manufacturing process using rivets and bonding to a novel sheet metal forming process called HFQ (solution heat treatment, forming and in-die quenching). The authors found that by using the HFQ process, the product was lighter which contributes to using less energy and therefore has less environmental impact.

Farag [19] explains how material and process selection impacts the design, cost and performance of a product. The book discusses the environmental impact assessment of materials and processes and the trade-offs that can be made when developing a new product or changing an existing model. It was essential to know the trade-offs that the book provided as this project involves them during the case study. Vinodh and Jayakrishna [20] explore the potential of environmental impact minimization using alternative materials and manufacturing processes. A case study was carried out using a stainless steel automotive component from an Indian manufacturing organisation. The results indicated that a change in material has higher influenced over the manufacturing process in reducing the environmental impact. Ribeiro et al [21] compared an original multi-material car component to the current component by analysing the environmental impacts throughout their life cycles. The component is part of the automotive brake system and the current component includes a new multi-material injection moulding process and the consumption of recyclable materials. The case study uses the Conditional Maximum Likelihood (CML) method to perform the environmental impact assessment and found that the current component exhibits lower results in all the impact categories.

The available literature shows that there has been a lot of focus on material selection with respect to cost, but less on analysing environmental impact. Recent literature indicates that studies of the environmental impact mostly concerns with electric cars or metal-based components. Environmental effects are mainly analysed using EPIs or the LCA method. Process selection is shown to be of less importance compared to material selection; therefore a knowledge gap in the field of studying plastic components should be conducted based on analysing material and manufacturing processes.

3. THE OVERALL EVALUATION METHOD

The automotive industry is evolving to include more sustainable designs and products. This project focuses on an automotive component previously unexplored in literature. As most published works analyse electric cars and metal-based components, a singular plastic component has been chosen for this investigation. Ergonomics will also be explored in order to create an improved prototype of the component and a consumer preference survey will be undertaken to provide insight into customers' attitudes towards the product. The literature shows that to effectively analyse a product, the original and new improved design must be compared. In addition, customer opinion is the key to introduce a successful product. As a result, the steps of evaluating environmental impacts are shown in Figure 1. The proposed method utilised different software systems such as CAD and CES Edupack to aid environmental impacts evaluation from a design point of view. The overall approach is not limited to automotive components and it could be applicable to other mechanical products.

4. CASE STUDY EVALUATIONS

The case study was carried out at an automotive component manufacturer UNN UK Ltd. UNN manufactures interior trim for cars, including engine insulation and acoustic products. UNN strives to offset the environmental impact of its activities by enhancing their product design and development practices. The product under investigation is a handle that is part of the load floor. This is the removable floor in the boot of a car that can be taken out to increase boot space. The decision to use this component was taken based on a consultation with the manager and executives of UNN. The reasons behind the selection of the load floor handle were based on its high production rate, high quality level and the availability of data related to this product.

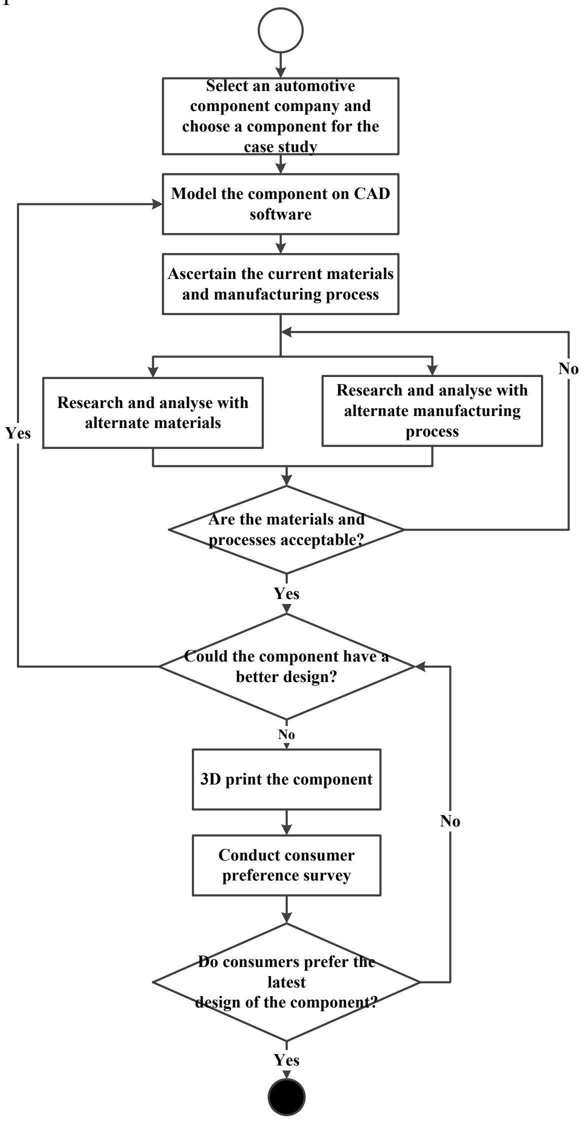

Figure 1. The proposed method

Figure 2. Boot compartment of the case study

4.1 Computer Aided Design, SolidWorks and CES Edupack

When designing a product, designers may start with idea sketches and concept drawings, then move onto schematic and measured drawings. CAD can be used to replace the measured drawings stage of design. CAD also allows for analysis of a design using simulations and can provide for rapid prototyping and computer aided manufacturing (CAM). SolidWorks was used in this investigation. The sustainability tool within Solidworks allows designers and engineers to simulate how a product affects the environment based on parameters such as location of use, location of manufacture, materials selection and manufacturing methods. It can used to compare results from different production models in order to ensure an environmentally friendly solution. This tool provides a way to evaluate a component's environmental impact through four different environmental stressors. The SolidWorks Sustainability tool is useful to help minimize the impact of each of the environmental stressors by helping select the material, manufacturing process, and region(s) of manufacture.

CES Edupack is software that includes a comprehensive database of materials and process information. It contains the properties of hundreds of materials as well as estimates for prices and energy usages. CES Edupack is crucial to the case study as its extensive database allows materials to be compared for their different attributes as well as for their sustainability.

4.2 Environmental Impact Measures

The aim of this study was to enable product designers to quickly evaluate the environmental impact of their products. Using SolidWorks Sustainability software, four well known environmental stressors were focussed on in order to reduce the environmental impact of the case study product. These environmental stressors were (i) carbon footprint, (ii) water eutrophication, (iii) air acidity and (iv) total energy usage.

4.3 Current Material and Manufacturing Process

The SolidWorks model of the current load floor handle design can be seen in Figure 3. The material composition of the present design is 99% impact modified polypropylene and 1% further unknown additives. The impact modified polypropylene is a low flow homopolymer, with higher strength, stiffness and melting temperature than other plastics. It has a high service temperature and is comparable to many engineering plastics such as ABS, PA and PE.

Adversely, it has poor UV resistance and it is highly flammable. Vinodh and Jayakrishna [20] proved that material choice has higher impact over the manufacturing process in reducing the environmental impact, therefore more emphasis was put upon material choice in the case study.

The manufacturing process used to create the current part is injection moulding. In the majority of cases, injection moulding is used for high volume production and multi-cavity moulds are often used. Tooling costs for the injection moulding process can be very high, so companies must have sufficient disposable income to accommodate this.

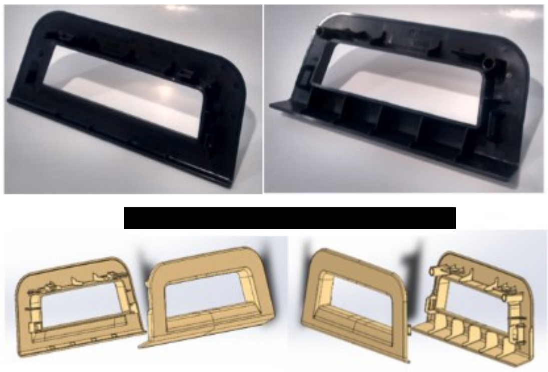

Figure 3. SolidWorks model of the original handle

The current design was analysed in SolidWorks Sustainability software as shown in Figures 4 and A1 (Appendix).

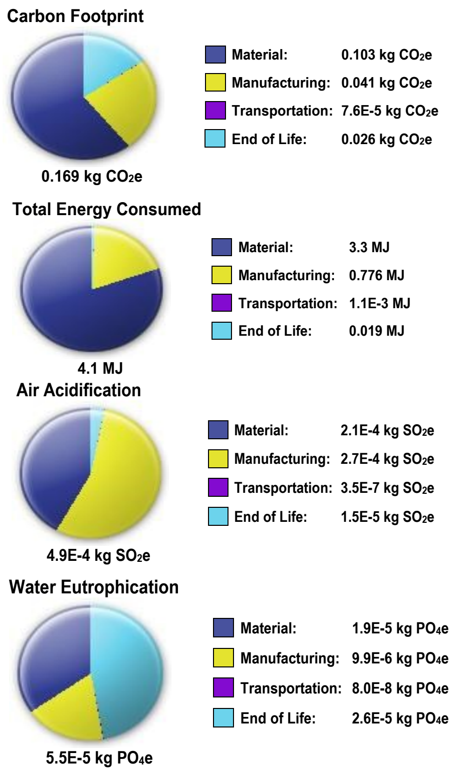

Figure 4. Handle Sustainability Analysis

To obtain these results, the material, manufacturing process, region of manufacture, region of use, type and length of transportation and end of life percentages were inputted. Data from the manufacturing company, UNN, was used in order to be as accurate as possible. The material was homopolymer polypropylene and the manufacturing process was injection moulding. The regions of manufacture and use were both from Europe and the transportation was 43km in a lorry. From the availability of data, the end of life percentages were estimated as 25% recycled, 24% incinerated and 51% landfill. Currently, the warranty on the car that contains this component is 3 years, therefore this value was used for the length of time the component is built to last and for the duration of use. Obviously, in the real world, cars would be expected to last for much longer than the warranty period but the manufacturer only has to replace products within the warranty period.

The sustainability analysis shows that in the cases of carbon footprint, total energy consumed and air acidification, material and manufacturing process choice is crucial. End of life is also significant to water eutrophication and carbon footprint, however this work aims to reduce the effect material and manufacturing process choice has on the environment. The pie charts also show that transportation is almost negligible as the distance from the supplier to the automotive company is very small. The values obtained in this analysis will be used as a baseline so that alternative materials and manufacturing processes can be compared to the current ones.

4.4 Handle Designs and Ergonomics

Handle design is an extensive part of ergonomic design as, despite new technologies, every day hundreds of items have to be picked up, moved or handled in some way. Often the contact between hand and equipment is awkward, inaccurate, or unsafe. In order for a handle to be ergonomic, it has to be tailored to different users and situations. There are 6 different types of hand grip that can be used to hold onto a handle. These are the power grip, pinch grip, internal precision grip, external precision grip, ulnar storage grip and other power grips.

The component under investigation was held using the power grip. When using a power grip, fingers are packed tightly together around an object and are overlapped by the thumb. The handle is thick enough to separate the fingertips from the palm. When using this grip, movements are carried out by the muscles in the forearm, upper arm and shoulder, rather than the smaller, more delicate muscles in the palm and fingers. This means that the movements are inaccurate and uncontrolled when using this grip.

When designing a handle, there are many things that must be considered, including size, shape, surface finish, security against slip, and surroundings. The size of a handle should be wider than the width of the palm and the thickness should allow for the thumb to just overlap with the fingertips. The current handle design is acceptable in this area as it is 130 mm wide, which is much larger than the average palm span of 84 mm for males and 74 mm for females. The thickness of the handle also allows for the thumb to comfortably overlap with the fingertips.

The shape of a handle for this application should prevent slipping and should be no sharp edges or high spots in the area of grip. These decrease comfort, strength, and security of grip to the extent that they may cause injury. The current handle design has a sloped edge, which could cause slipping and, due to the handle being made in two parts, the joint is on the inside of the handle, where it could rub against the user's fingers and cause irritation. The sharp edge is due to the injection moulding process. As injection mould was used to form the two parts, the plastic can seep into the gaps in the mould causing flash. Then, when the mould was removed, the flash was attached to the part as a sharp edge which then has to be removed. When the two parts of the handle were joined together this still leaves a reasonably sharp edge, which must be sanded down further before assembly in the UNN factory. Obviously, this adds another step into the assembly process and increases assembly time of the product.

The surface finish of a handle should consider replaceability and safety. The surface should be smooth if sliding is advantageous or if the handle will rotate within the hand. Skin damage such as blisters or cuts are a sign of bad design and some handles should be designed to offer protection against heat or electricity. The current handle design has a slightly rough surface finish to prevent slipping which is good for its application. The surface finish is designed to mimic the look of leather to make the component look expensive and classy. The process of adding this surface finish to a product is expensive as the injection moulds have to be carved to create the leather design.

For security against slip, material choice is important and also the handle could incorporate anti-slip devices such as a pommel, hilt or gentle finger grooves. The current handle is made of plastic which is not an anti-slip material. It also does not include any anti-slip devices, so it could be improved considerably in this category of handle design. Designing for the users surroundings include having adequate clearance around the handle for access and avoiding awkward posture. For the current handle, when using the power grip, there is not enough space for the knuckles to rotate around the handle. Instead, the hand rotates so far, then the knuckles hit the top of the handle. This is a bad design choice as it could cause injury to the user's hands. To improve the current handle design, the focus should be on developing the shape, surface finish and anti-slip devices. If improvements were made in these areas the handle would be more ergonomic and consumers should prefer it over the current design.

5. RESULTS AND DISCUSSION

5.1 Sustainability Analysis with Alternative Materials

SolidWorks Sustainability software was used to analyse how using different materials to make the chosen component would affect the environment. The current material of homopolymer polypropylene was used as a baseline and all of the other plastics in the SolidWorks database were compared, to see which materials were more environmentally friendlier. Homopolymer polypropylene is currently used as its properties are suitable for the application. Some of the materials that were found to be better for the environment, had different properties to polypropylene and may not be suitable. For this reason, materials with similar properties are included in the results even if their environmental results are lower than polypropylene.

5.1.1 High Density Polyethylene (HDPE)

A2 (Appendix) shows that changing the material to HDPE would improve the overall sustainability of the component in all areas of environmental stress. Although the material is more environmentally friendlier, a side product of this is that the manufacturing and end of life results are slightly higher. This is because it takes 2.3MJ/kg more energy to recycle 1kg of HDPE compared to homopolymer polypropylene. As a result of recycling 1kg of HDPE, 0.283kg/kg more greenhouse gases are released into the atmosphere. The analysis shows a 28% reduction in carbon footprint, a 12% reduction in air acidification, a 37% reduction in water eutrophication and a 10% reduction in total energy consumption.

5.1.2 Copolymer Polypropylene (CPP)

A3 (Appendix) shows that CPP is a more environmentally friendlier material than homopolymer polypropylene in all areas. Changing the material to CPP has the most effect on sustainability; however it also takes 1.5MJ/kg less energy to injection mould CPP compared to homopolymer polypropylene. This has a small effect on the manufacturing sustainability as can be seen in A3 (Appendix). The analysis shows a 30% reduction in carbon footprint, a 14% reduction in air acidification, a 40% reduction in water eutrophication and a 15% reduction in total energy consumption.

5.1.3 Analysis of Copolymer Polypropylene (ABS)

A4 (Appendix) illustrates that ABS has a negative effect on the environment, especially concerning air acidification and water eutrophication. This is because it takes 21.5 MJ/kg more energy to make 1kg of ABS compared to homopolymer polypropylene. It also creates 1.95kg/kg more greenhouse gases to process ABS. More energy and greenhouse gases were also used to injection mould ABS compared to homopolymer PP. The analysis shows a 15% increase in carbon footprint, a 25% increase in air acidification, a 20% increase in water eutrophication and a 10% increase in total energy consumption.

5.1.4 Low Density Polyethylene (LDPE)

A5 (Appendix) shows that LDPE is more sustainable in all areas, but the material change itself makes the biggest impact on the environment. It takes 3.3MJ/kg less energy to injection mould LDPE than homopolymer polypropylene. This is most likely because LDPE has a lower melting point than polypropylene so the injection moulding tool will not have to heat up as much to melt LDPE. The analysis shows a 22% reduction in carbon footprint, a 10% reduction in air acidification, a 37% reduction in water eutrophication and a 7% reduction in total energy consumption.

5.1.5 Polycarbonate

A6 (Appendix) depicts that polycarbonate is not an environmentally friendly material when compared with homopolymer PP. However, it is often used for the same applications as the properties are similar. Polycarbonate is a slightly more expensive material, but it is superior to polypropylene in strength, toughness and hardness. The analysis shows a 120% increase in carbon footprint, a 90% increase in air acidification, a 48% increase in water eutrophication and a 90% increase in total energy consumption.

5.2 Comparison of Materials

Of the materials investigated in the case study, some are more suitable than others for the application. Table 1 shows some of the different properties the materials possess and how they compare to the current material of homopolymer polypropylene.

As the component is in the interior of the car, it does not have to be as durable as if it was on the exterior, however it must still have good build quality as the warranty on the car is 3 years and it is expected to last longer than this. Out of the materials tested, ABS and polycarbonate can be discounted as they are less sustainable than the current material of homopolymer PP. They are often used in the automotive industry for applications that require more strength and toughness, such as for vehicle bumpers and grilles. Table 1 shows that ABS and polycarbonate outperform homopolymer PP in strength, stiffness, toughness and hardness. However, both plastics are more expensive because more energy is needed to create 1kg of the material than is needed to create 1kg of homopolymer PP. Also, less than 1% of polycarbonate and only 3-4% of ABS is recycled, compared with 5-6% of the current material, making them much less sustainable.

	Homopolymer Polypropylene	Copolymer Polypropylene	High Density Polyethylene	Low Density Polyethylene	ABS	Polycarbonate
Environmental Impact	-	✓	✓	✓	X	X
Yield Strength (MPa)	32 - 36	19 - 21	26 - 31	8 - 14	34 - 39	59 - 65
Young's Modulus (GPa)	1.4 - 1.6	0.8 - 1.0	1.1 - 1.2	0.2 - 0.3	2.1 - 2.8	2.3 - 2.4
Fracture Toughness (MPa.m^0.5)	1.66 - 1.75	1.25 - 1.32	1.52 - 1.82	1.21 - 3.45	1.46 - 4.29	2.15 - 2.36
Vicker's Hardness (HV)	10.1 - 10.6	7.47 - 7.85	7.9 - 9.9	2.7 - 4.4	10.4 - 14.9	17.7 - 19.6
Recycle Fraction in Current Supply (%)	5.26 - 5.81	5.26 - 5.81	8.02 - 8.86	8.02 - 8.86	3.8 - 4.2	0.672 - 0.742
Price	1.02 - 1.12	1.66 - 1.83	1.1 - 1.22	1.12 - 1.24	1.64 - 1.81	2.92 - 3.21

Table 1. Comparison table of materials

Copolymer polypropylene and low density polyethylene are both more environmentally friendly than the current material. However the properties of these materials differ from the specification of the component. As shown Table 1, copolymer polypropylene has approximately 10MPa lower yield strength than homopolymer polypropylene. This is because copolymer polypropylene has lower crystallinity due to the disorder created by the random insertion of a comonomer. This means that the atom structure in the material is less ordered, which reduces the strength and hardness of the material. It is imperative that the component has strength and hardness values in this region as, as the component is used in the boot, heavy items may be dropped on it so it must be able to resist blunt trauma and not chip or affect the finish of the product.

High density polyethylene is more sustainable overall than homopolymer polypropylene. Table 1 shows that the material change makes a dramatic difference to the sustainability of the component overall, even though the manufacturing and end of life are slightly less sustainable than the current material. It has very similar strength, stiffness and hardness to homopolymer polypropylene. This means that it fits the specification FIS set for the component properties. Compared to LDPE, high density polyethylene has little branching which strengthens the intermolecular forces between the atoms and increases the tensile strength of the material. HDPE has higher fracture toughness than homopolymer propylene as it has a more equal ratio of strength to ductility. Currently 8–9% of HDPE is recycled, compared to only 5-6% of polypropylene, which inherently increases its sustainability. HDPE is only marginally more expensive than homopolymer polypropylene, but given the increased sustainability, UNN would accept it as an alternative material choice to homopolymer polypropylene.

5.3 Sustainability Analysis with Alternative Manufacturing Process

SolidWorks Sustainability software was used to analyse how using a different manufacturing process to make the chosen component would affect the environment. The current manufacturing process is injection moulding and this was used as a baseline. Other plastic manufacturing processes include casting, blow moulding and thermoforming. These are unsuitable for this component as it is too complicated, not hollow and it is made in high volume. Because of the geometry of the component and its material, the only manufacturing processes that could be considered were injection moulding and extrusion. Extrusion can be used to reprocess waste plastic and fortunately it was the only other manufacturing process available in the SolidWorks database, so the injection moulding process was compared to this.

5.3.1 Injection Moulding

A7 (Appendix) shows that the manufacturing process of injection moulding is especially important in regards to air acidification and water eutrophication. The capital costs to set up an injection moulding machine can be anywhere in the region of £25,000 - £500,000 and injection moulders can produce components with a mass between 0.01 and 25kg. Injection moulding is a suitable manufacturing process for homopolymer polypropylene as the material only shrinks 1.57–2% between the mould and the finished cooled product. Although the melting temperature of homopolymer polypropylene is 161-170°C, the melting temperature required to achieve stable processing characteristics is 208-257°C. It also takes up to 155MPa of pressure applied to the screw in order for it to force the plastic into the mould. To achieve these high temperatures and pressures, a significant amount of energy is used. As in most manufacturing facilities energy is supplied from the national grid, this means that a significant amount of fossil fuels are burned in order to make the energy needed to heat the injection mould and power the screw. This increases the effect of the component on air acidification as air acidification is mainly due to the burning of fossil fuels. Concerning water eutrophication, this is affected by industrial waste water being disposed of and as injection moulding requires such high temperatures, a lot of water will be used for cooling purposes which will have an effect on water eutrophication.

5.3.2 Extrusion

The extrusion manufacturing process is very similar to the injection moulding process in that plastic pellets are melted, a screw moves them through a heated tube and they are forced into a mould. The main difference between injection moulding and extrusion is that extrusion is usually a continuous process. It is commonly used to reprocess recycled plastic waste into the pellets that can then be injection moulded. Extrusion requires the product to have a continuous profile, so it would not be suitable to make the case study component, however as mentioned before, it would be a useful way to recycle excess plastic so that it could be reused. Recycling and reusing excess plastic would make the component more sustainable overall as less waste would have to be incinerated or sent to landfill. A8 (Appendix) shows that extrusion is a more environmentally friendly manufacturing process than injection moulding. This is because it only takes approximately 6MJ/kg of energy to extrude a part, compared with 22MJ/kg of energy to injection mould one. Using extrusion rather than injection moulding also means 1.2kg/kg less carbon dioxide is released into the atmosphere. This reduces the amount of air acidification the component causes.

5.4 Comparison of Manufacturing Processes

Of the manufacturing processes investigated, the results show that extrusion would be a more sustainable way of creating a product than injection moulding. This is mainly because the SolidWorks Sustainability software only takes into account the one product it was analysed. In the real world, the production volume would have a huge impact on the sustainability results. As approximately 250,000 of the case study car are produced per year, and every car includes a load floor handle, this means that the production volume of the component is very high. Injection moulding is almost exclusively used in high volume production as components can be made in multi-cavity moulds and very little post production work is required as the ejected parts have a good surface finish. Injection moulding also enables very fast production rates due to the multi-cavity moulds, often with cycle times of 30 seconds or less. Bearing this in mind, it is very likely that when considering the high production volume, injection moulding will be the more sustainable manufacturing process. It is for this reason that it is recommended the component continues to be manufactured using the injection moulding method.

5.5 Improved Handle Design and Consumer Feedback

There are a number of improvements that could be made to the current handle design to improve its ergonomics. An improved handle design was created in SolidWorks which focussed on improving the handles shape, surface finish and anti-slip devices. In the improved handle, the shape has been improved by adding finger grooves which reduce slip and by increasing the clearance in the centre of the handle so that the knuckles no longer make contact with the handle when the hand rotates. The improved handle has been designed so that it has a very similar weight to the current handle. This is so that the sustainability analysis on the improved handle would be the same as on the current handle.

In order to gather feedback on the new handle design as shown in Figure 5, it was decided that the improved handle should be manufactured using rapid prototyping so that a consumer preference survey could be undertaken. A MakerBot Replicator 2 was used to 3D printed the improved handle design. The improved handle took 5 hours to print on the MakerBot, which confirms that rapid prototyping is not a suitable manufacturing process for high volume production, however for design purposes, it is useful to showcase any flaws a design has so that it can be changed before production begins.

A consumer preference survey was undertaken to compare the original handle design to the improved design. Volunteers were asked to comment on how comfortable they found the handles, how suitable they thought it would be for the application and which handle they would choose to have in their own car. All of the volunteers had some prior knowledge of design and ergonomics, making the survey more professional as many of the volunteers are experts in the field of design.

Figure 5. Original Handle Design compared with Improved Handle Design

The overall result of the survey was that 80% of the volunteers preferred the improved handle design. The consumers that preferred the improved handle commented on how the finger grooves improved grip and how the curvier design was more aesthetically pleasing and made the handle look more interesting. They also explained how the improved handle looked better quality and that the extra clearence stopped their knuckles from hitting the top of the handle. All of the volunteers agreed that both handles are functional for the application, although many mentioned that they would prefer to have the improved handle in their own cars.

A surprising result of the survey was that 90% of the customers reported that they preferred the surface finish on the prototype handle compared to the 'leather look' finish on the original part. Many mentioned that the 'leather look' finish looked cheaper as it was obvious that the component was made of plastic and not real leather. For this reason the surface finish on the improved handle should be slightly textured in a simple way to improve grip without looking inexpensive.

6. CONCLUSION AND FUTURE WORK

In this research, the impact an automotive component has on the environment was investigated. The literature review confirmed that most published works focus on material selection with respect to cost, but fewer reports analyse on environmental impact. As most literature that focuses on environmental impact concerns electric cars or metals, there was a gap in the research to evaluate a singular component. In most published works environmental effects are analysed using EPIs or the life cycle analysis method.

A solid CAD model was developed and a sustainability analysis was carried out. The sustainability analysis measured the environmental impact over the life cycle of the handle in terms of carbon footprint, air acidification, water eutrophication and total energy consumption. The research found that by changing the material to high density polyethylene there would be approximately a 30% reduction in carbon footprint, a 24% reduction in air acidification, a 26% reduction in water eutrophication and a 15% reduction in total energy consumption, which altogether would drastically alter the environmental impact of the component. It was found that injection moulding should continue to be the manufacturing process and it was observed that material change has a greater influence over environmental impact than changing the manufacturing process.

This study highlights the importance of selecting materials of low environmental impact for the new products. Design engineers should focus on selecting the proper material for new components in the product design and development stage, which will help decide the manufacturing process and other factors influencing the reduction of environmental impact [20, 21]. By reducing the environmental impact of a component during the early stages of product development implies the product will have superior end of life impact over the environment [22]. An in-depth cost analysis could be undertaken to find out if making the component more sustainable as well as financially viable.

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ABOUT THE AUTHORS

Alex Gallimore is a Test and Development Engineer at Cummins..

Wai M Cheung is a senior lecturer with expertise and research interests in sustainable product development, life cycle engineering, information and communication technology and cost modelling.

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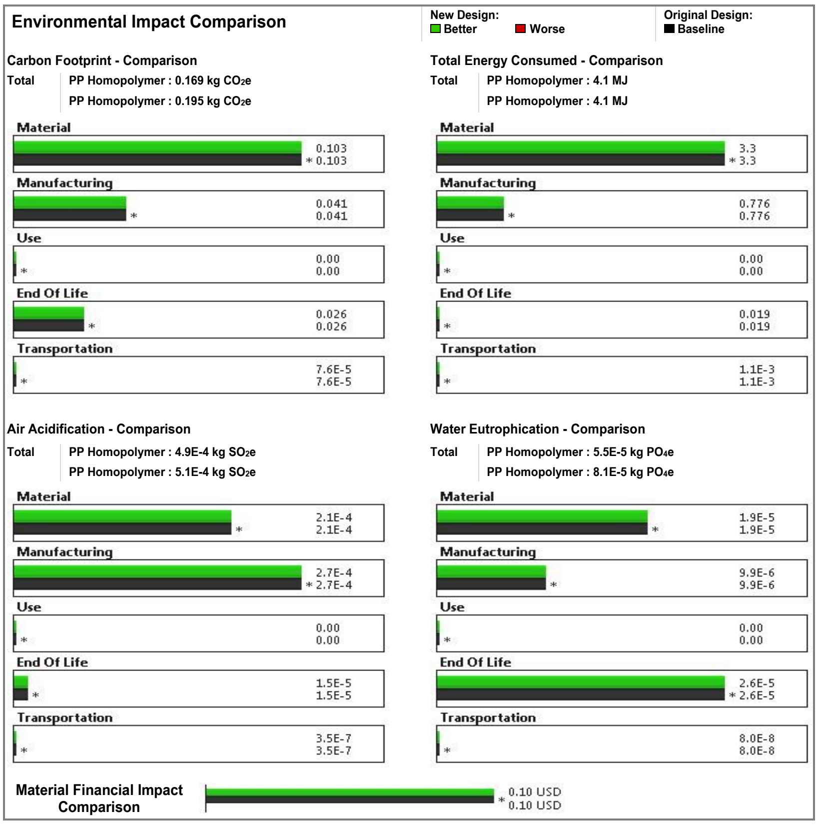
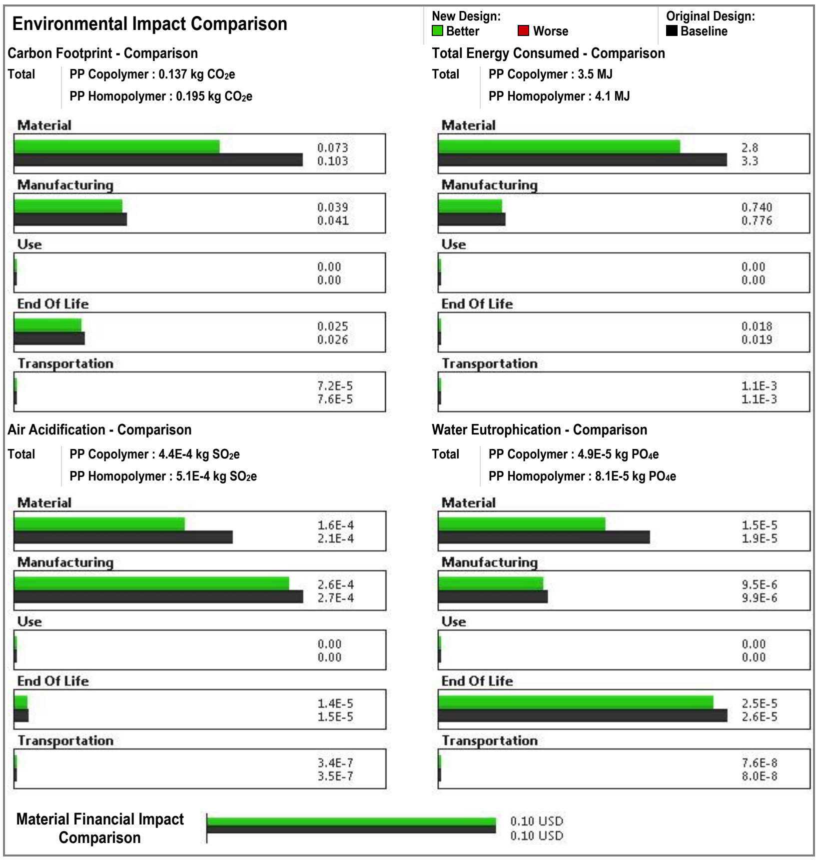
Appendix

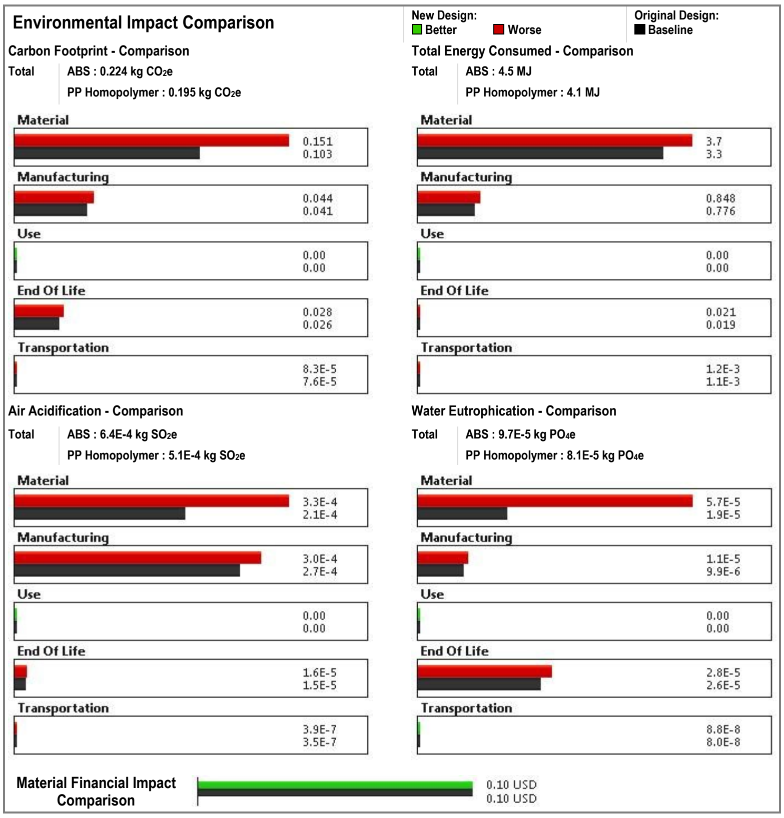


A1. Handle sustainability analysis baseline

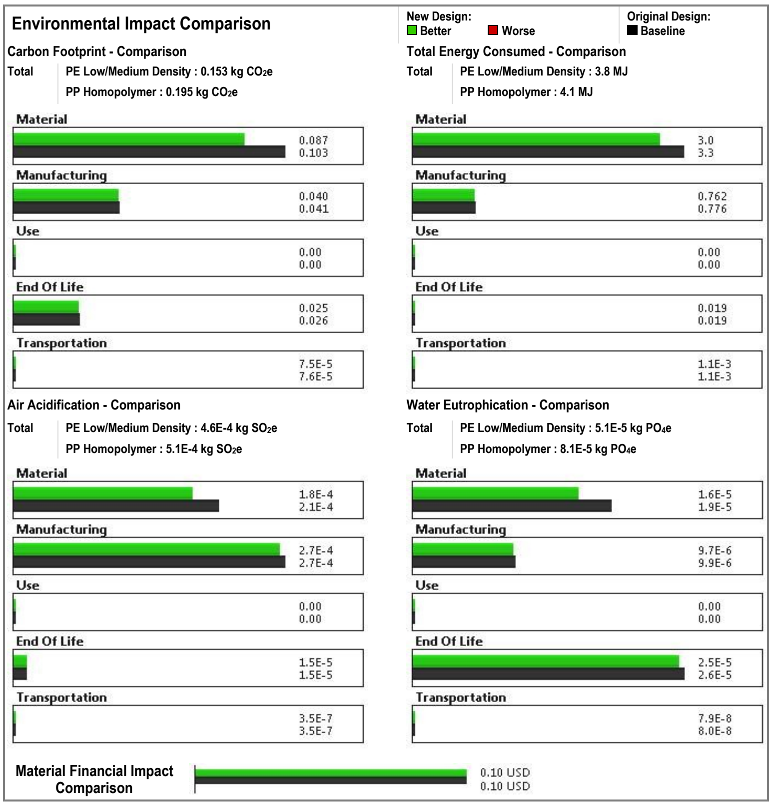
A2. Analysis of HDPE



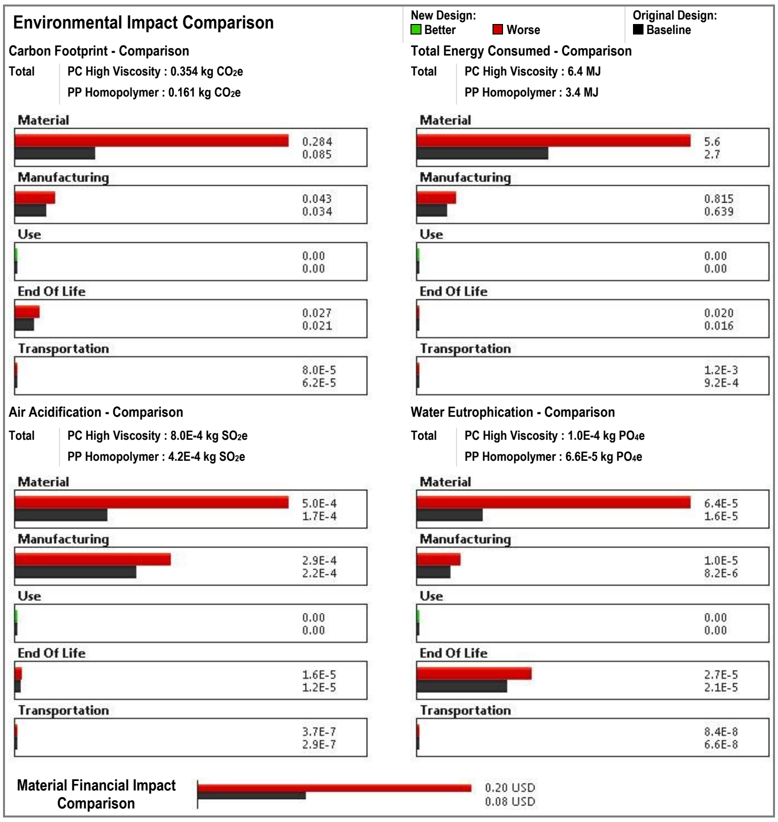
A3. Analysis of Copolymer Polypropylene



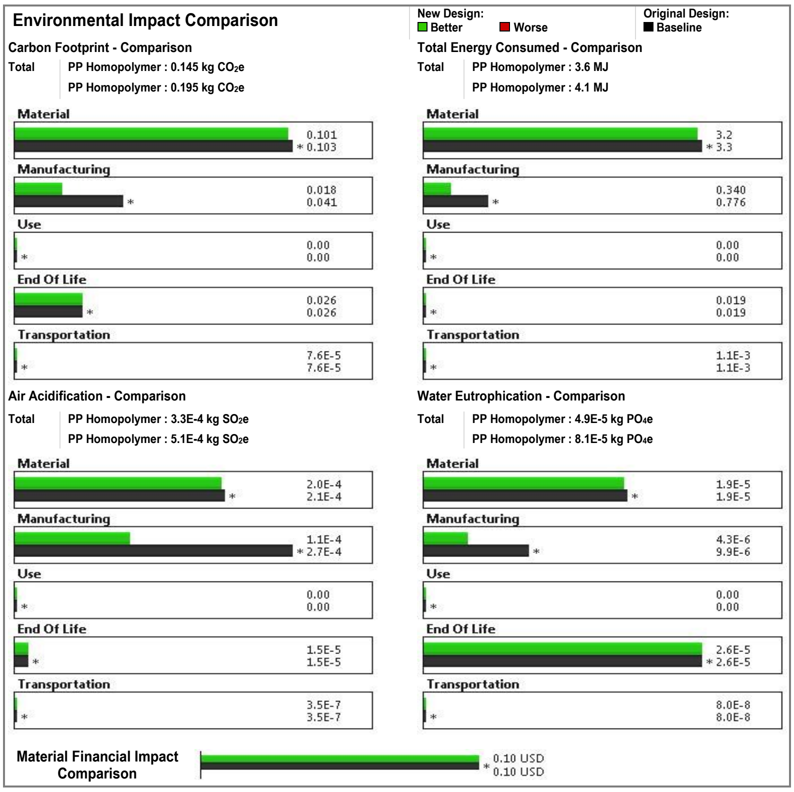
A4. Analysis of ABS



A5. Analysis of LDPE



A6. Analysis of Polycarbonate



A7. Sustainability Analysis of Injection Moulding

A8. Analysis of Extrusion