

Integrated Environmental Process Planning for the Design & Manufacture of Automotive Components

Satnam Singh*¹, Dr. Jane Goodyer² and Professor Keith Popplewell¹.

*Corresponding Author.

¹Faculty of Engineering & Computing, Engineering Manufacturing & Management
Department, Coventry University, Priory Street, Coventry, CV1 5FB, UK.

Telephone: +44(0)24-7688-7017, Fax: +44-(0)2476-88-8272

Email:singhs7@coventry.ac.uk, k.popplewell@coventry.ac.uk

²Institute of Technology & Engineering, Massey University, Palmerston North, NZ.

Email:j.goodyer@massey.ac.nz

Abstract

Advanced Product Quality Planning (APQP) logic is widely used by manufacturers for the design and manufacture of automotive components. Manufacturers are increasingly finding difficulties to incorporate environmental considerations in the broad range of products that they manufacture. Therefore, there is a need for a systematic method for environmental process planning to evaluate product configurations and their associated environmental impact. The framework and models discussed in this paper can deal with a variety of product characteristics and environmental impacts through a selection of Environmental Performance Indicators (EPIs) for a final product configuration. The framework and models have been applied in a real-life application and have proven that changes in product design or process selection can reduce the product's environmental impact and increase process efficiency. Hence, manufacturers can use the framework

and models during the Advanced Product Quality Planning (APQP) process to benchmark each product variation that they manufacture in a standardised manner and realise cost saving opportunities.

Keywords: Environmental Process Planning, Environmental Performance Indicators (EPIs), Environmental Performance, APQP Process, Product Design & Manufacture.

1. Introduction

This research is targeted at fast moving, high volume automotive component manufacturers that are governed by ISO 9001 and ISO/TS 16949 and have Advanced Product Quality Planning (APQP) systems in place. These types of manufacturers produce a wide range of product variety. Product variety is the number of different versions of a product offered by an organisation at a single point of time and this version of product normally complements the manufacturer's existing product portfolios (Singh *et al.* 2006). Variety within the product arises by varying the values of attributes from one product to another such as material, dimensional, aesthetic and performance attributes. Such attributes are driven by customer specifications (Jayachandran *et al.* 2006a)

There are many environmental impacts that can arise from the increase in the manufacture of a variety of products. One such impact is the increase of scrap that is disposed to landfill. As a product reaches the end of its lifecycle, it may be superseded by a new improved variety and therefore obsolete products will have to be disposed. Furthermore, new product variants may have additional environmental impacts associated with them and this can include increase in energy usage or increase in emissions to manufacture the products.

Currently automotive component manufacturers have to follow certain processes when suggesting the design and manufacture of a new product variant that will meet an Original Equipment Manufacturer's (OEM) specification. The Advanced Product Quality Planning (APQP) is such a process that is widely used to evaluate the design and manufacture of a range of products in an organisation. The APQP process is a structured method of defining and establishing all the steps necessary to assure that a product satisfies the customer requirements (Bobrek *et al.* 2005). However, from an environmental perspective, there are no written descriptions of the system for controlling the environmental impacts of products during the design and manufacturing phases in the APQP process.

Therefore, in order to address this gap, this paper proposes a framework that can address environmental issues in any future new products whilst meeting the requirements of the APQP process. To build the foundation, section 2 of this paper describes the literature review on previous work integrating environmental performance with various production management issues, which also includes product design and manufacture. Section 3 describes in detail the APQP process and how the framework or models in this paper can help in streamlining environmental decisions. Section 4 describes the research methodology applied and section 5 explains the environmentally based process planning models. Section 6 validates the framework and models through a case study and finally, sections 7 and 8 of this paper discuss and conclude the findings from the case studies. As it is difficult to find a common method of quotation and supply in literature, the case study has helped to build an environmentally based process planning framework for the design and manufacture of automotive components. This framework can deal with a variety of product characteristics and their associated environmental impacts.

2. Literature review

Process planning is concerned with the generation of a plan conducted on an off-line manufacturing engineering basis limited to the product design, market potential and available resources (Bhaskaran 1990). Process planning is also the act of preparing detailed operating instructions for turning an engineering design into an end product i.e. translating the design specifications of products into manufacturing instructions (Ciurana *et al.* 2003). Careful selection of process plans is essential as process planning is concerned with transforming raw material to its finished form governed by its design specifications and sharing of constrained resources. A great deal of data is collected for the process planning activity and this includes the identification of machines, tools, parameter selection for machining, operations, etc.

Recent studies that have received continuous investigation and research are the use of computers to aid product design and process planning (Rogers *et al.* 1994). Computers are used in process planning due to the complexity of the process planning task and the lack of an effective mapping between design features and specific production processes. Once the product has been modelled on the computer, a sequence of process planning steps is needed to enable an efficient and accurate manufacture of the part (Kulkarni *et al.* 2000). It has been envisaged that process planning is a function in a manufacturing facility that assigns a sequence of manufacturing processes to a design and in an automated process planning environment; a process planner generates a process plan for a design without any human involvement (Chang and Wysk, 1986). Other work on computerising the process planning activity deals with making the process planning more efficient (Dong *et al.* 1996, Paris and Brissaud 2000, Kang *et al.* 2003, Park 2003). Currently, computerised process planning does not cover environmental issues.

Effective process planning is an important element when a new variety of product is subjected to the APQP process. The APQP process has been sanctioned by the three automotive giants Chrysler, Ford and General Motors in 1994 (Ottoson 2004). A further characteristic of the APQP process is described in Section 3, however, in general, the aim of the APQP process is to improve the product quality during the design and manufacturing phases to satisfy customer requirements. A study has linked the importance of product quality planning such as the use of APQP to environmental quality (Madu *et al.* 1995). The study stresses that the buying patterns of consumers are significantly shifting from an emphasis of direct product quality to also include environmental quality. Environmental performance is a measure of to what extent an organisation contributes towards maintaining or improving the environment. Integrating environmental considerations into process planning is a difficult challenge and often, conflicting environmental trade-offs are involved (Richards 1994). Furthermore, manufacturing companies do very little to include environmental considerations in evaluating their product portfolios during design and manufacturing stages (Tang and Yam 1996, Jayachandran *et al.* 2006b)

Limited publications exist that addresses environmental issues during product quality and process planning. Usually studies address issues with scrap, defects, by-products waste etc. (Munoz and Sheng, 1995), and the reduction of waste streams at the source through choice of alternative processes, parameters and catalysts (Srinivasan and Sheng, 1999). Srinivasan & Sheng (1999) argued that process planning in environmentally conscious machining involves a multi objective analysis of manufacturing dimensions that include production rate, quality, process energy and mass of waste stream generated by the process. They further stressed that usually the issues that limits the

environmental analysis is the material and geometric complexity of engineered components.

Process planning essentially translates the engineering drawing and specifications into manufacturing instructions. Typical composition of these instructions are tools and machines, jigs and fixtures, material and process selection, machining parameters, cost and time estimates, as well as machining codes (Chang and Wysk, 1983; Corti and Staudacher, 2004). Overall, process planning is conducted to conform to specific objectives such as shortest time and/or the minimum cost. Currently, process planning is widely used in businesses in a variety of forms, for example, computerised or as dictated in the APQP process. Once the product has been designed, the environmental issues such as reduction in emissions or reduction in material waste to landfill is governed the company's Environmental Management System (EMS). Therefore, analysing environmental impacts of selected processes based on the process planning activity is often neglected. This is because the process plan forms the basis for cost accounting, detailed production schedules, data collection or monitoring, equipment engineering, facilities design and other performance evaluations practises. Therefore, this paper describes a suitable framework that can supplement the process planning activity from an environmental viewpoint within the APQP process, as it has been iterated that currently the APQP process only aims to improve the product quality during the design and manufacturing phases.

3. Research framework and models in the context of the APQP process

The major aims of ISO/TS16949 is to develop a fundamental quality system that provides for continuous improvement, emphasises on defect prevention and the

reduction of variation and waste in the supply chain. It also aims to be simpler, consistent and more flexible than the older requirements, and to simplify record keeping, while reducing costs and waste. Within the ISO/TS 16949 standard, APQP is a process for planning quality into the product or service from its conceptual stage, right through design, development, manufacturing and distribution (Figure 1). Within the APQP process, there is a requirement to conduct a Production Part Approval Process (PPAP) and Initial Sampling Inspection Report (ISIR). PPAP requires that whenever a production run of a new product (or a new variety) is being made, that the first-off samples from the production run are approved by the customer, before the rest of the production quantity is approved for manufacture. ISIR is a documented procedure by which the supplier of a part or sub-system gives evidence to the customer that they are able to satisfy the requirements of delivery date, quality, process capability and production rate.

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The goal of the APQP process is to facilitate communication with everyone involved so that all steps are performed in advance to ensure the production of a quality product. As outlined in Figure 1, the customer initially conducts a pre-sourcing activity to select a suitable supplier by raising Request for Quotation (RFQ) documentation. During the second stage (Plan & Define), suppliers use a variety of methods (e.g. business plans, product reliability studies, etc) to determine their customer needs in order to plan and define a quality program. In stage three, Product Design and Development, the product quality planning team focuses on designing quality into the product. This stage also includes a prototype manufactured to verify that the product meets the customer's

requirements. Stage four, Process Design and Development, is concerned with the development of a manufacturing system and the associated control plans needed to ensure production of quality products. Validation of the manufacturing process is the main focus in stage five (Product and Process Validation). This stage normally includes the evaluation of a production trial run during which the product quality planning team validates the process flow chart and control plan.

It is evident that the APQP process does not facilitate the suppliers to analyse or document any environmental issues while building quality into the range of products that they manufacture. This is because the APQP process does not require it as it is designed only to focus on product quality. Therefore, the research framework and models in this paper are devised to supplement stage three (Product Design & Development), stage four (Process Design & Development) and stage five (Product & Process Validation) of the APQP process to include environmental considerations. From the description of the APQP process, it has been shown that it is heavily dependent on quality characteristics of a product and on the use of a wide range of quality toolkits. It is envisaged that the framework and models shown in this paper would help manufacturers to also look into a product's environmental quality while satisfying customer needs. Just as a control plan governs the quality characteristics of a product, the framework and models in this paper would enable manufacturers to benchmark their product characteristics to the environmental elements.

4. Research methodology applied

The research was conducted by interviewing five companies namely; Company A, B, C, D & E through a series of case studies in the United Kingdom. Apart from conducting

structured interviews, other research techniques such as observation, document analysis and focus groups were also applied to the case studies. The five case studies were conducted in this manner to maximise the validity of the research through triangulation (use of many sources and research methods). Thorough analysis of the case studies has helped to attain the most accurate picture of events. The feedback received from these organisations was cross-analysed with each other and further development work was conducted to establish a suitable environmental process planning framework and models. The framework and models were then validated in Company A.

The companies were selected based on the criteria that they must have a well-established product management programme and ideally be supplying to the automotive industry. Companies that supply to the automotive industry must have the ISO/TS 16949 accreditation as minimum requirements and have a product management programme approved by the customers. Following meetings with senior managers for several companies, five manufacturing companies were identified that would be ideal for this research. A decision was made to select companies that supplied products directly to Original Equipment Manufacturers (OEMs) and Tier 1 suppliers in order to maximise the variety in detail of the company's products and environmental management activities. This also meant that the results would have increased reliability and validity. Further characteristics of these companies include:

- Company A is a large multinational automotive component manufacturing company. It supplies components directly to Tier 1 suppliers and OEMs. It manufactures various components for the powertrain systems.
- Company B is an automotive bodywork sealing components supplier that supplies plastic and rubber components directly to OEMs.

- Company C designs and produces exhaust pipes and fuel tanks. It supplies fully assembled parts directly to OEMs.
- Company D supplies various transport equipment and general engineered components to the automotive industry.
- Company E supplies shims, gaskets, washers and light pressed components for the automotive industry. These components are manufactured in various materials including metal, plastic and alloys.

The main aims of the case studies were:

- To map current decision making processes deployed within the APQP logic during process planning for the management of new product variety,
- To gauge how much environmental assessment was conducted coupled with associated practices,
- To identify and design an integrated environmental process planning framework with supporting models that can be used in conjunction with the APQP process.

The findings from the case studies include:

- The case studies confirmed that all the organisations had an Environmental Management System (EMS) in accordance to ISO 14000 standards but however, the approach to environmental management was reactive and compliance based. This did not include the environmental performance to assess products during the design and manufacturing phases within the APQP logic during process planning.
- The main element that hindered this process was the APQP process itself as it did not require products to be rigorously subjected to an environmental analysis. The main environmental issues considered during the APQP process were the materials, substances and emissions governed by legislations.

- It was also evident from the case studies that no form of environmental assessment was conducted to compare product variety during the design and manufacturing phases (which includes process selection) as the components were benchmarked against the quality, cost and delivery (including health & safety) criteria only.
- Management also expressed that currently there are no tools within the APQP logic than can prompt people to look into the environmental issues during process planning.
- Different departments within these organisations had different focus towards product variety and environmental considerations for process planning via the APQP process. Throughout the case studies, the departmental decision routes showed that environmental issues seemed to be the least important aspect as the APQP process did not require it.
- It has been acknowledged by these organisations that with the increase in variety of automotive components, environmental assessments of products during the process planning stage within the APQP process is essential to realise cost saving opportunities. Cost savings can be realised during the product design and manufacturing phases by highlighting the alternative design, material or processes that can be applied to produce the components.
- The overall environmental strategy within the APQP context is to subject the component to a design and process study that prevents the generation of defective products that would otherwise be disposed to landfill. Manufacturers used Material Data Sheets (MDS) within the APQP logic to declare the raw materials used to manufacture the products. From the legislation viewpoint, manufacturers are only concerned about the reduction in emission limits to satisfy regulations.

In conclusion, by environmentally assessing automotive components during the APQP process can help to demonstrate that a company's environmental management programme is achieving some kind of success. There should be a procedure to identify, collect and analyse data in a coherent manner to assess product variety during the design and manufacturing phases within the APQP context. Environmental standards within these organisations are adopted as a proof that the companies are committed to protect the environment from its production activities, but the case studies revealed that products are not subjected to any form of direct environmental analysis during the process planning stage via the APQP process.

5. Environmentally based process planning framework and models

A systematic method of creating an environmental process planning system to evaluate product configurations and their associated environmental impacts is shown in Figure 2. The environmentally based process planning system framework in Figure 2 consists of two sections. The vertical path deals directly with the product's characteristics (e.g. size, shape and features such as holes, chamfers, etc.) and the horizontal part deals only with the product's environmental impacts. Both paths meet at the Environmental Performance Indicators (EPI) selection. Each and every product may either differ from its design characteristics or the manufacturing processes it goes through during production. Therefore, it is essential to list all of the product's configurations and select those characteristics that are most relevant for benchmarking. It is also essential to select all the necessary environmental inputs and outputs that are relevant to the product either during design or production phases. The following steps as outlined in Figure 2 can be deployed:

- Step 1 - List all the product configurations: This is the attributes or characteristics the product has such as width, thickness, overall diameter or length. The manufacturer must make a database of all the characteristics their products encompass to enable them to select the correct environmental performance indicators. For example, for the product characteristic width, the component may be subjected to a grinding operation but for the characteristic length, the component may be subjected to a Computer Numerical Control (CNC) turning centre. Both of these processes would have different environmental impacts; for example, a CNC turning centre may consume high levels of energy as opposed to a grinding machine or vice versa.
- Step 2 - Utilise the Product Environmental Performance Indicators (PEPI) model: As shown in Figure 3, each process has an input and an output. For example, for a CNC turning centre, the main inputs would be energy (e.g. electricity), water (as coolant) and materials (e.g. tooling). Once the component has been machined, there would be several outputs. This can include waste water (e.g. used coolant) and product waste (e.g. swarf). Details of the PEPI model is described later in this paper.
- Step 3 - Select the appropriate EPIs: At this stage it is essential to select all the relevant EPIs from the PEPI model for benchmarking. For example, from the manufacturing process waste from a grinding machine, measuring the grinding slurry is more appropriate as opposed to measuring wear on the tools. Measuring the tool wear would be more appropriate for a CNC turning centre.
- Step 4 - Analyse the selected EPIs: At this stage, the selected EPIs must be benchmarked between product variations. Each change in a product or process characteristic can have either a positive or a negative environmental impact and should be addressed accordingly.

- Step 5 - Evaluate and score the product variations: Finally, the product variation is scored based on the manufacturing trials conducted. This can include items such as percentage of waste reduction due to the changes in product design or process change. It is also essential to convert this scoring in monetary values to gain an overall feel for the change. For example, by deploying the framework and models on benchmarking coolant use within the grinding machine and ultimately by changing the product or process characteristics, it may be possible that the water usage has been reduced from 2 litres per minute to 1 litre per minute, then this can be a cost saving for the company (calculated based on the cost of fresh water per litre).

'[Inset figure 2 about here]'

The case studies have helped in developing the PEPI model within the organisations (Figure 3). The PEPI-inputs and PEPI-outputs are governed by an internal production boundary. The internal boundary encompasses all the product ranges that are designed and manufactured within the factory. Before implementing the PEPI model, a clear understanding of the manufacturing processes, its products and related activities have to be developed. Organisations that were interviewed have decided that PEPI inputs can be mapped during the PPAP stage and PEPI outputs can be mapped during the ISIR stage. For companies that only have ISO 9000 series accreditation, PEPI inputs can be mapped during the product design (prototype) stage and PEPI outputs can be mapped during production trials.

'[Inset figure 3 about here]'

The main elements of PEPI inputs were identified as energy, water and materials usage. PEPI outputs have approximately three times more elements identified as shown in Figure 3. Each element of a PEPI Input and Output can be further sub-categorised to enable product scoring. For example, a PEPI Input - Energy; can consist of biomass, renewable resources, natural gas usage, electricity consumption and fuel consumption including petrol, diesel or kerosene. Another example for a PEPI Output - Packaging Waste; can consist of biodegradability, reusability and scrap rates. The list is not exhaustive and typical sub-categories identified from the case studies are illustrated in Figures 4 & 5. Each organisation would need to define which environmental criteria that has to be met and which of these criteria is most relevant to the industry as a whole. For example, in an automotive design focused company, they may only be concerned with very few PEPI outputs but a process-based company may have all the indicators mapped. Any company that wishes to adopt the PEPI model are free to manipulate and include any other indicators as they wish to suit their industry. However, the organisations interviewed have indicated that the environmental elements shown in Figures 4 & 5 are the major source of contributors to their environmental performance during product design and manufacture.

'[Inset figure 4 about here]'

'[Inset figure 5 about here]'

PEPI inputs and outputs can be utilised to measure the environmental performances for each product range. The PEPI model can be utilised to benchmark the first prototype

(first product variation) against its varieties by using an agreed (standardised) value. An example of a benchmarking chart i.e. PEPI Scoring and Comparison Chart (PSCC) is shown in Figure 6. The environmental characteristics for PEPI inputs and outputs are listed on the left of the chart and a column would then show the standard range or value that is acceptable by the company or it is within the limits governed by relevant regulations. The first product variant can then be measured in terms of its environmental impacts and then subsequent product variations can also be mapped. This can be done by measuring the environmental elements such as waste materials (e.g. in grams), energy usage (e.g. in Kilowatts) or waste water usage (e.g. in litres). The case studies pointed out that this is a useful method as sometimes, one additional design or process change can have a major impact on the product's overall environmental performance.

'[Inset figure 6 about here]'

6. Application of the integrated environmental process planning system.

Company A is the main collaborating organisation for this research and was selected to conduct the validation of the framework as this company utilises powder sintering technology to produce various ranges of automotive components. The main advantage of powder sintering is that components can be pressed to near net shape, thus reducing the amount of waste generated from machining operations. Company A also utilises many processes to produce a final component for the customer. As the list of the PEPI elements are exhaustive, only one element at inputs and outputs (i.e. raw materials & material waste) and at one process (i.e. pressing) was selected for benchmarking

utilising the integrated environmental process planning system. Product 'X' was selected in this instance and it has just been subjected to the APQP (both PPAP & ISIR) process for a new type of engine.

Product 'X' is first pressed using a blend of powder materials and then sintered at high temperatures. The pressing process produces the component at a specific width, outer diameter and a profiled shape in bore diameter (annular or shaped blank). The component is then subjected to a side face grinding operation (to control width) and then centreless grinding operation (to control the outer diameter). A profile is then machined using a Computer Numerical Control (CNC) machine and then the finished component is packed for shipping. Throughout these processes the component reduces in weight as by-product material is generated. During the pressing operation, material weight is lost as powder waste for each component. During the sintering process, material weight is lost due to evaporation (i.e. wax in the powder blend). Grinding and CNC machining operations reduces the component weight through the formation of swarf and grinding slurry. This study was conducted using the steps described in section 5 of this paper and as outlined in Figure 2. This can be shown below:

- Step 1 - List all the product configurations:

Utilising the environmentally based process planning system framework (see figure 2), the product configurations were first listed for each process the product goes through. For the pressing operation in this instance, the product configurations were width, outer diameter and profiled shape. For example, if CNC machining was subjected for this study, the product configurations would have been the bore diameter and profiled shape.

- Step 2 - Utilise the Product Environmental Performance Indicators (PEPI) model:

The next stage was to select elements from PEPI model (see Figures 3, 4 & 5) for benchmarking. In this instance, the list selected for PEPI inputs and comprised of electricity consumption, fresh water use, raw materials, material composition, product rejects, waste water, material waste, packaging waste, etc.

- Step 3 - Select the appropriate EPIs:

For brevity, not all data can be presented, therefore, the raw material usage and material waste at the packing stage was benchmarked as shown in Figure 7. This also had the biggest environmental impact due to the cost to dispose the sintered material waste. The company advised that the material waste during the processes should be within 20% of the material weight. This meant that that a 100 gram component can only have 20 grams of material waste as scrap resulting from the manufacturing processes.

'[Inset figure 7 about here]'

- Step 4 - Analyse the selected EPIs:

During the PPAP stage, the initial variant (variation 1) pressed was an annular blank with a width of 12.20 mm, outer diameter of 45.70 mm and with no profiled shape as it was an annular blank. The weight at pressing was measured at 83.461 grams and after being subjected to the machining operations, the final weight was 37.503 grams (as required by the customer with a tolerance of +/- 0.5 grams (i.e. the final weight is fixed). This constitutes that the component lost 45.958 grams (55.07% of weight) as scrap through the manufacturing processes when measured at the packing stage. This data was inserted into the PSCC as shown in Figure 7.

This component was produced with additional material, as the sintering behaviour was not known at this stage. It was agreed that if the component had very high material waste, then it would be scored as 1 i.e. bad. On the other hand, if the material had very low material waste then it would be scored as 5 i.e. good. During the ISIR stage, the next variation (variation 2) of this product was manufactured by reducing the pressing width and with a profiled shape whilst maintaining the final customer's requirements weight and profile specifications. This product was pressed with a profiled shaped (near net shape) blank with a width of 11.95 mm and with the same outer diameter of 45.70 mm. It was immediately noticeable that there would be less material removal during the machining processes due to the smaller width and the near net shape of the component. The weight at pressing was measured at 58.615 grams and after being subjected to the machining operations, the final weight was 37.503 grams. This variation of the component constituted that the component now lost 21.112 grams (36% of weight) as scrap when measured at the packing stage. A score of 3 was given for this product. Although this was an improvement, it was not near enough to the 20% material waste target set earlier in the PSCC as illustrated in Figure 7.

From the discussions with the shop floor operators, the outer diameter was ground with 5 passes, i.e. the same component had to go through the centreless grinding machine 5 times to achieve final sizes. Company A envisaged that product 'X' should only go through the centreless grinding machine twice which was rough grinding and then finish grinding. The final variation (variation 3) of this product was then pressed. This time the previous press tooling was modified to press a profiled shape (near net shape) to a width of 11.70 mm and outer diameter of 42.00 mm. In this instance, the weight at pressing was measured at 47.017 grams and after being subjected to the machining operations, the final weight was 37.503 grams. This final variation of the component

constituted that the component now only lost 9.514 grams (20.25% of weight) as scrap when measured at the packing stage. This was near enough to the target set earlier. A score of 5 was given to this product. This study showed that by utilising the framework and scoring chart, the material waste (measured in grams) was reduced from 55.07% to 36% with the first variation and then to 20.25% with the final variation.

- Step 5 - Evaluate and score the product variations:

Company 'A' advised that the cost of powder for this blend is £5.15 per kg. This component was on the company's order books for 100 000 components per year. The material waste for the first variant which amounted to 45.958 grams per component was reduced to 9.514 grams with the final variation thus, saving 36.444 grams of material waste per component (0.0364 kg per component). With sales volumes of 100 000 parts per year, the material waste saved amounts to approximately 3640 kg which cost £18 746 per year. The product scoring has shown that the final product (variation 3) had the least material wastage compared to the other two products.

This case study has shown that by utilising the integrated environmental process planning framework, Company 'A' was able to realise cost saving opportunities by redesigning their products and processes. Company 'A' envisaged that if it had followed the APQP process strictly to build quality in product 'X' then the material wastes would have not been identified during the product design phase. It was likely that Company 'A' would continuously produce annular blanks to machine product 'X' and supply to the customers as long as product 'X' met the customer requirements. Therefore, without an early application of environmentally based process planning framework, the 3640 kg of material waste from the manufacturing processes would have been disposed of as landfill waste. This would not only entail a negative environmental impact but extra disposal costs. Furthermore, it would have been difficult to recycle the waste material

as the powder blend consisted of different alloying elements. If the framework and analysis was subjected to the entire spectrum of product 'X's design and manufacture, there was a potential that the company could realise much more cost saving opportunities.

7. Discussion

The initial work of setting up the environmentally based process planning system framework within an organisation may be difficult and time-consuming. This is because it would need certain expertise to list and evaluate all types of product configurations input. This also includes the identification and selection of all the environmental indicators that are most relevant to the range of products that the organisation produces. To overcome this difficulty, the organisations interviewed in the case studies envisaged that it would be useful to design and set-up a simple database system that can list all types of configuration inputs and environmental indicators with a list of standard values for each indicator. Once this database system has been created and validated, future environmental impact, based on product variety characteristics, can be studied easily (e.g. from a drop-down list of product characteristics vs. associated environmental impacts).

There is currently a need to conduct further research on identifying an acceptable range of values for the Product Scoring and Comparison Chart (PSCC) as outlined earlier. Further work would include reviewing all current environmental regulations that have indicated maximum permissible environmental impact values or further discussions with organisations involved in determining these values. Indeed over time, the automotive component suppliers that use this methodology and scoring charts would

need to reduce the agreed values to improve their environmental performance. This also includes the processes that the products go through within the facility.

The future research work for this study includes the addition of a trade-off analysis between the environmental impact and cost/performance characteristics. As stated earlier, the organisation are currently heavily depended on quality, cost and delivery (including health & safety) criteria during the APQP process. It may be possible that during the PEPI evaluation of products, conflicting environmental trade-offs may surface during the use of the framework and models. Trade-offs must be made when one option offers improved environmental performance in one aspect while being environmentally less desirable in another. One of the organisations interviewed in the case study gave an example of the use of paraffin in their machine that was replaced with organic cutting fluid. Although the organic cutting fluid was environmentally friendly, it had increased the start-up time of the machine as high viscosity of the cutting fluid takes time to be absorbed by the machine. It is clear that integrating environmental considerations that has a complex mix of factors into the process planning is a difficult challenge.

By utilising the PEPI model, suppliers can improve their environmental performance by reducing the environmental impacts of their products during design and manufacturing phases. Products can be benchmarked against a standard value and improvement in product performance can include reduction in energy use, packaging materials, waste generation and transportation distances. In some instances, careful consideration of product design and manufacture using this framework can reduce a product's environmental impact not only during design and manufacturing phases, but also during product use and disposal. The choice of indicators is important in addressing the

product's environmental performance criteria. The indicators must be integrated with the company's operational control systems such as production efficiency and waste measurement systems.

By utilising the methodology outlined in this paper, organisations can have several bottom-line benefits of improved product and process environmental performance. This includes reduced material and energy input costs, reduced waste disposal costs, improvements in process efficiency, streamlined product design, reduced cost of transportation and improvements in revenues due to product performance and entry into new markets. Furthermore, by benchmarking the products to the environment, companies may be able to enhance product brand image. Companies can use this methodology to launch new products as a standard and cohesive management tool. Ultimately, this methodology can assist in optimised manufacturing decision-making whilst PEPI tools can be used to benchmark and to identify cost saving opportunities such as potential improvements in energy efficiency, reduction in consumables, materials, labour & tool costs. The framework and models can also be used as a tool to encourage innovation within the organisation. Furthermore, it may also be useful for companies to publish production based environmental performances in annual reports and therefore can improve a company's reputation by demonstrating commitment to the environment.

8. Conclusion

The outcome of this research enables automotive component suppliers to modify their product design (or product configurations) and to change their manufacturing techniques to be more environmentally based while maintaining the production of good

quality parts. Currently there is lack of guidance on how to integrate environmental factors in process planning. Without the availability of a suitable environmentally based process planning framework, manufacturers tend to be highly reliant on Quality Management Systems (QMS) for the manufacture of various products. This includes the use of Advanced Product Quality Planning (APQP) tools such as Production Part Approval Process (PPAP) and Initial Sampling & Inspection Reports (ISIR). From the environmental perspective, manufacturers use Environmental Management Systems (EMS) such as ISO 14000 to satisfy regulatory requirements in order to control emissions and release of hazardous substances to the environment. As a consequence of focusing on the APQP process, there is limited capability for environmentally based process planning in the design and manufacture of a range of products to meet with increasing number of environmental regulations and at the same time realising cost saving opportunities. All five organisations used in this case study have helped in identifying and designing the integrated environmental process planning framework incorporating Environmental Performance Indicators (EPIs). This also includes the introduction of Product Environmental Performance Indicators (PEPI) framework to help manufacturers select relevant environmental elements and benchmark these elements using the PEPI Scoring & Comparison Chart (PSCC). As product ranges increase (causing increased variety), it is essential that the process is focused on the environment. Application of the framework and models in a real life application has proven the effectiveness of the system in reducing environmental impacts whilst maintaining product quality.

Word Count: 6466 without references below.

9. References

Bhaskaran K. Process Plan Selection. *Int. J. of Production Research*, 1990, **28**, 1527-1539.

- Bobrek M, Sokovic M. Implementation of APQP-concept in design of QMS. *J. of Materials Processing Technology*, 2005, **162**, 718-724.
- Chang T, Wysk R. CAD/Generative Process Planning with TIPPS, *J. of Manufacturing Systems*, 1983, **2**, 127-135.
- Chang T, Wysk R. *An Introduction to Automated Process Planning Systems*, Prentice-Hall, Englewood, Cliffs, New Jersey, 1986.
- Ciurana J, Romeu MLG. Optimising process planning using groups of precedence between operations based on machined volumes. *Engineering Computations*, 2003, **20**, 67-81.
- Corti D, Staudacher A.P. A concurrent engineering approach to selective implementation of alternative processes, *Robotics and Computer-Integrated Manufacturing*, 2004, **20**, 265-280.
- Dong J, Parsaei HR, Leep HR. Manufacturing Process Planning In A Concurrent Design and Manufacturing Environment. *Computers Ind. Engineering*, 1996, **30**, 83-93.
- Jayachandran R, Singh S, Goodyer J, Popplewell K. The design of a sustainable manufacturing system: A case study of its importance to product variety manufacturing, in 2nd Virtual International Conference on Intelligent Production Machines and Systems, Online at <http://conference.iproms.org/>, 2006a, Cardiff, UK.
- Jayachandran R, Singh S, Goodyer J, Popplewell K. A systematic way of identifying environmental aspects and development of environmental management programs, in 8th International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises, 2006b, pp. 102-109.
- Kang M, Han J, Moon JG. An approach for interlinking design and process planning. *J. of Materials Processing Technology*, 2003, **139**, 589-595.

- Kulkarni P, Marsan A, Dutta D. A review of process planning techniques in layered manufacturing. *Rapid Prototyping Journal*, 2000, **6**, 18-35.
- Madu CN, Kuei C, Winokur D, Environmental Quality Planning: A Strategic Total Quality Management (STQM) Approach. *Futures*, 1995, **27**, 839-856.
- Munoz AA, Sheng, P. An analytical approach for determining the environmental impact of machining processes, *J. of Materials Processing Technology*, 1995, **53**, 736 - 758.
- Ottosson S, Dynamic Product Development - DPD. *Technovation*, 2004, **24**, 207-217.
- Paris H, Brissaud D. Modelling for process planning: the link between process planning entities. *Robotics and Computer Integrated Manufacturing*, 2000, **16**, 259-266.
- Park SC. Knowledge capturing methodology in process planning. *Computer-Aided Design*, 2003, **35**, 1109-1117.
- Richards DJ. Environmentally Conscious Manufacturing. *World class Design to Manufacture*, 1994, **1**, 15-22.
- Rogers JS, Farrington PA, Schroer BJ, Hubbard RG. Automated Process Planning System for Turned Parts. *Integrated Manufacturing Systems*, 1994, **5**, 41-47.
- Singh S, Goodyer J, Popplewell K. Pre-requisites for managing the integration of environmental performance into product variety manufacture: A case study approach, in 8th International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises, 2006, pp. 118-125.
- Srinivasan M, Sheng, P. Feature-based process planning for environmentally conscious machining – Part 1: Microplanning, *Robotics and Computer-Integrated Manufacturing*, 1999, **15**, 257-270.
- Tang E, Yam R. Product Variety Strategy – An Environmental Perspective. *Integrated Manufacturing Systems*, 1996, **7**, 24-29.

FIGURES

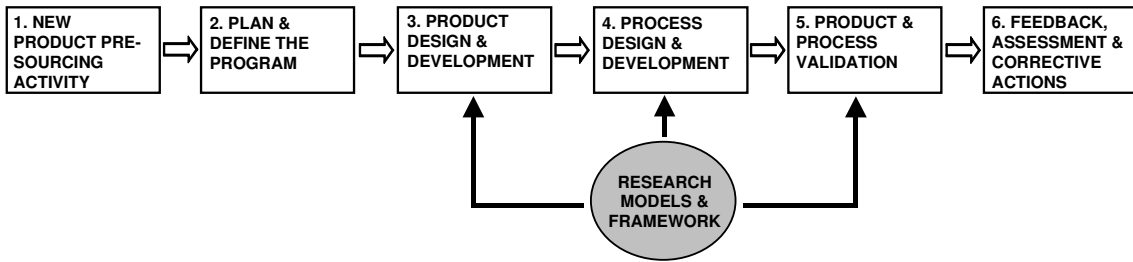


Figure. 1 Research models & framework within the APQP process

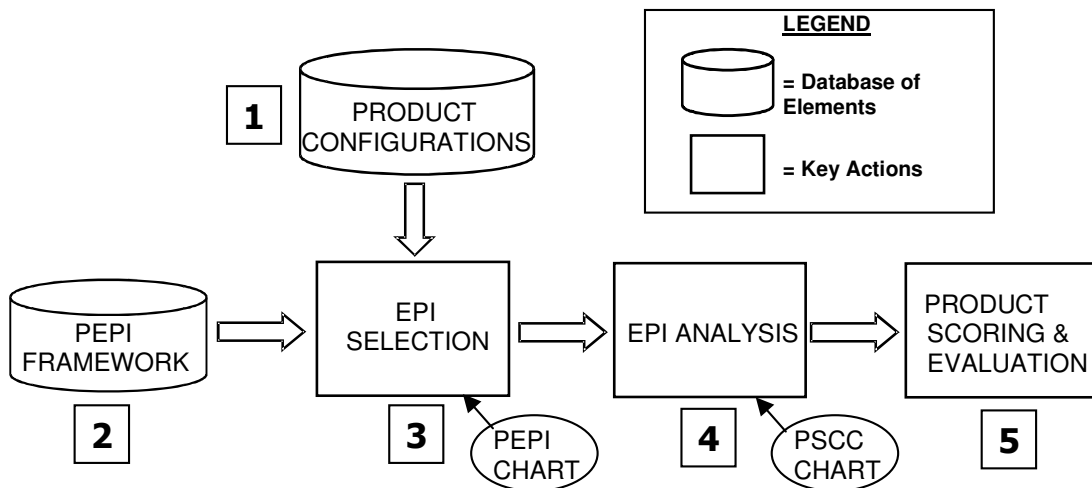


Figure. 2 Environmentally based process planning system framework

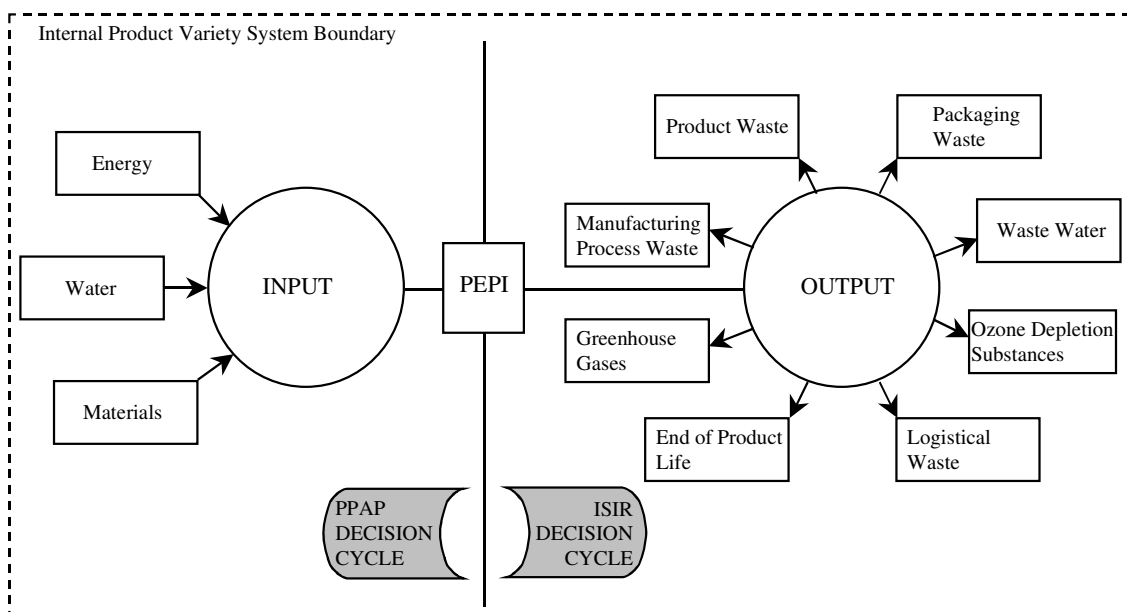


Figure. 3 Product Environmental Performance Indicators (PEPI) model

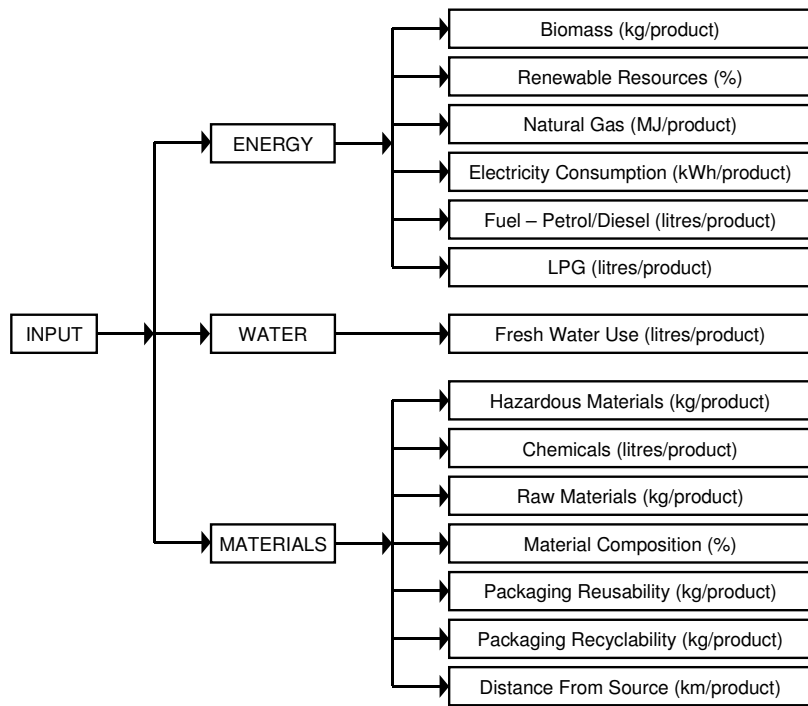


Figure. 4 Mapping Elements of PEPI Inputs

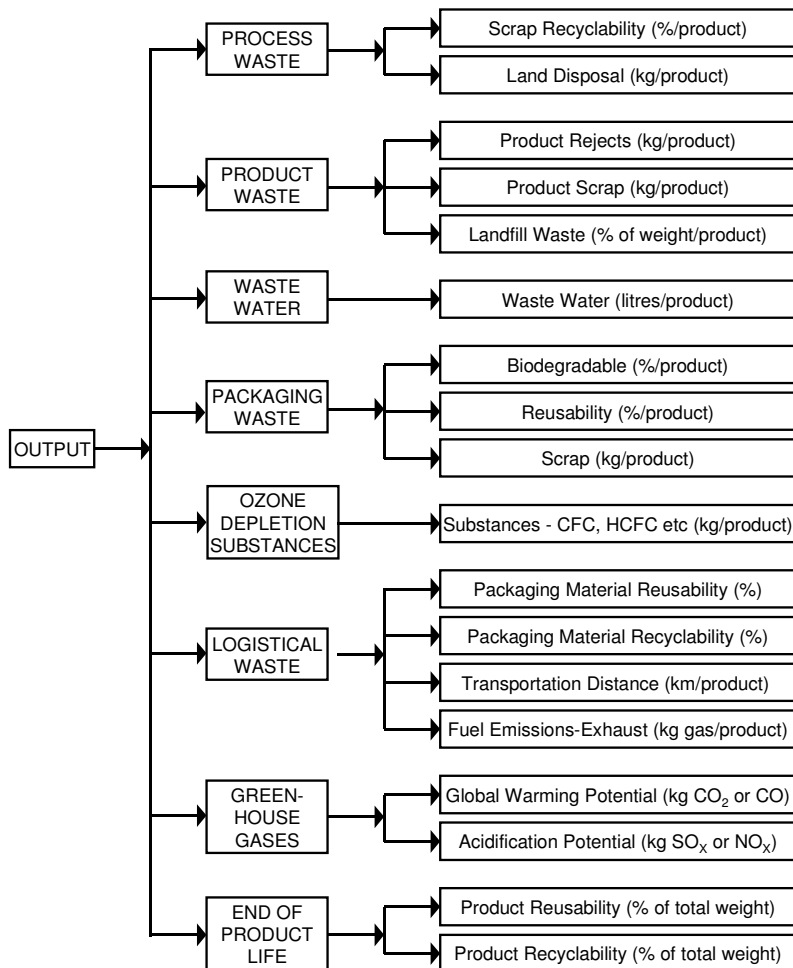


Figure. 5 Mapping Elements of PEPI Outputs

Integrated environmental process planning for the design and manufacture of automotive components

Singh S

2007