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Guest Editorial

Aspects of sustainable design and manufacture

1. Introduction

Concerns for the environment are currently dominated by global warming and climate change, caused primarily by the consumption of fossil fuels. A significant factor is the consumption of energy by manufactured products during their use phase. The production of these products is also a focus of attention because of the inefficient way that Society in general and industry in particular manages resources. A responsible approach to design and manufacture of products should embrace efficient resource use by reducing the consumption of non-renewable resources throughout a product's life-cycle. This provides tremendous opportunities for practicing a whole raft of concepts and practices that embrace, for example: design for environment, environmentally benign/conscious manufacture, waste minimization, dematerialization and product service systems, energy conservation and management, green/sustainable supply chain management, product end-of-life management and reverse logistics.

The concerns for the environment are intrinsic to the concept of sustainable development but this concept also embraces the economic and social context within which concern for the environment is exercised. Whilst the broad concept of sustainable development is commonly accepted, it is the emphasis on resource use and conservation that most strongly permeate legislation. Governments have recognized their responsibility to the environment and exercised their authority through legislation that directly affects manufacturing businesses. Such legislation requires that businesses reduce their consumption of resources, especially energy, minimize their waste and accept responsibility for their products when they reach the end of their working life. It is within this context that the proposal for a special issue was generated.

2. The special issue

The current decade has witnessed a dramatic growth on an international scale of research to understand and improve the management of sustainable production and products. This research focuses on the many different factors that can influence the various life-cycle stages of a product. Whilst each of the stages is important, it is often the use and disposal phases that can have the greatest impacts and for this reason there is an inevitable focus on the importance of design. This has become

more apparent through the introduction of EU Directives that address specific industrial sectors, for example the End-of-Life Vehicles (ELV) and Waste Electrical & Electronic Equipment (WEEE) Directives.

The call for papers attracted almost 50 submissions and, following an extensive review and revision process, 30 papers were selected for publication in this 'special issue'. The papers have a wide range of themes with strong emphasis on 'Design for Environment (DfE)', 'End-of-Life (EoL) Management' and 'Supply Chain Management'.

2.1 *Design for environment*

The design of a product influences each and every stage of the life-cycle, from material production to end-of-life recovery. How effective are eco-design strategies and tools? Are such tools able to reduce environmental effects throughout the life-cycle of a product or are they really only targeting specific life-cycle phases? These are some of the themes addressed by authors.

Unrealistic expectations for DfE are the concern of Boks and Stevels who contend that DfE 'principles' are without value unless considered within a specific context. They emphasize this view with examples from the electronic manufacturing industry with relatively complex products that affect all life cycle stages. They advocate communications with specific industries rather than the development of generic tools. Surmounting organizational barriers between environmental specialists and product designers is the concern of Johansson *et al.* The paper focuses on mechanisms to overcome such barriers choosing electronics industry case studies to demonstrate how technological and organizational mechanisms can be used to facilitate Eco-design practice.

Bovea and Wang posit that it is likely a product designed to provide superior environmental performance will be more expensive than the original product. Under such circumstances, the authors ask if there is a level of 'environmental premium' that customers would be willing to pay. Their approach focuses on the establishment of a relationship between QFD, LCA, LCC and contingent valuation and the customers' willingness to pay. The combination of LCA and DfE to evaluate the break-even benefits (environment and economic) for both an existing and new design of distribution boards is the subject of the paper by Bevilacqua *et al.* The objective of their research was the provision of a software tool that would aid designers without an expert knowledge of LCA. The authors claim that their approach is transferable and they highlight problems that must be resolved to create an integrated methodology. The EU Directive on 'Eco-Design of Energy-using Products' is the subject of the paper by Grote *et al.* The authors describe 'work-in-progress' to develop an improved DfE tool that integrates economic and environmental considerations. They demonstrate the process using a case study and highlight the benefits of environmental consideration during rather than after the design process.

Xu *et al.* explore the ways by which modular design can contribute to improved design and use efficiency of products. In their case study for a product family of cellular phones they demonstrate how Information Content Assessment (ICA) can provide a useful method for performance evaluation. This enables them to advocate Product Family Design Reuse (PFDR) as an effective management tool for achieving cost and performance advantages. Sakao proposes the integration of

QFDE, LCA and TRIZ to propose a methodology for environmentally-conscious product design that overcomes the limitations of using any one of these methods in isolation. The author demonstrates the benefits of this approach by considering the case study of a hair dryer. Cost-efficient product disassembly is one of the necessary measures required to improve the economic viability of EoL product recovery and reuse. Willems *et al.* report research to develop 'active' fasteners that can be easily disengaged to simplify disassembly. They describe materials, applications and designs that can be used to significantly improve disassembly efficiency.

2.2 Environmental management

The paper by Singh *et al.* addresses the need to introduce an environmental dimension in product and process planning. The authors start with the precept that there is an absence of an environmental dimension in Advanced Product Quality Planning and no links to an Environmental Management System. The paper uses automotive component manufacturers to demonstrate an integrated environmental process planning procedure that reduces the environmental impacts of manufacturing, reduces costs and maintains quality. Geldermann *et al.* have adopted 'Pinch Analysis' and applied it to a multi-problem (combinatorial) task, specifically the optimization of energy use, water use and pollution control. They use a bicycle frame coating process for their case study and conclude that whilst real environmental benefits do accrue, there may be economic costs. They extend their discussion beyond a single company to consider how benefits can be optimized in an industrial park.

Evans *et al.* evaluate 'product-service solutions' from the perspective of ready-meal production and delivery. The paper uses case studies to demonstrate how close cooperation between the producer and other actors can deliver environmental performance improvements that simply could not be achieved by changes in production arrangements alone.

2.3 Energy and waste management

As a major resource input and a cause of global warming it is perhaps surprising that there is only one energy-related paper in the special issue. That paper, by Mouzon *et al.* reports research conducted to minimize the energy used by manufacturing equipment, concentrating specifically on under-utilized equipment. The authors present results from a multi-objective mathematical programming model that enables a production manager to determine the most efficient production sequence that will minimize the total energy consumption whilst optimizing the total completion time.

Although waste is an intrinsic feature of EoL processing and thus features extensively in papers that deal with EoL issues, very few papers dealt with process waste and of these only one met the reviewers' approval. The complex problem faced by supermarket convenience food manufacturers when dealing with uncertain production schedules is addressed by Darlington and Rahimifard. The problem is particularly acute for very short shelf-life products that are subject to considerable volatility in demand, in particular ready-meals. Over-production and the concomitant waste is an endemic problem and the authors demonstrate the benefits of a hybrid, two-stage planning technique for the effective reduction of such waste.

2.4 Supply chain management

No business can be environmentally responsible in isolation because most businesses are dependent on the performance of their suppliers, transporters and users, each of which can adversely affect their environmental credentials. However, the reverse supply chain is equally important because it influences both the economic and environmental values of recovering and returning EoL products. In this respect, the influences of transportation and packaging become important because of the associated economic and environmental cost.

Serrato *et al.* have used a Markov Decision Model to deal with the complexity of a returns processing problem. The authors explore the hypothesis that outsourcing reverse logistics is more suitable when returns are more variable. A principle outcome is the identification of sufficient conditions on the cost parameters and the return fraction to guarantee the existence of an optimal threshold policy for outsourcing. Wu *et al.* has combined a Analytical Hierarchy Process with a Fuzzy Logic Process to produce a methodology to support decision-making for green supply chain management. The authors present an efficient approach to enable managers to evaluate competing projects and determine the most environmentally benign alternative.

With its emphasis on Chinese industries, the paper by Zhu and Sarkis seeks to correlate environmental performance with economic performance. The authors used a moderated hierarchical regression analysis of data provided by 341 manufacturing companies to investigate the extent of green supply chain practices. They conclude that there is positive evidence to suggest a beneficial correlation between the operation of green supply chain practice and environmental performance but that this is driven primarily by competitive pressures rather than institutional pressures.

Vachon's paper focuses on the package printing industry in Canada and the United States and evaluates the link between supply chain practices and the selection of environmental technologies. The paper considers pollution prevention, pollution control and management systems. Of particular interest is the positive links that exist between the industry and its suppliers and the minor impact that the industry's customers have on environmental investment decisions. Industrial packaging is the focus of the paper by Verghese and Lewis. Whilst such packaging has been a focus for logistics management it has received less interest from an environmental perspective. The paper quotes examples from several successful Australian case studies and provides useful guidelines for initiating a packaging review project.

2.5 Product end-of-life management

When there has been an economic incentive, there has always been an active recycling industry. The current emphasis on end-of-life disposal seeks to optimize the reuse of products rather than material recycling but how realistic is this, especially in the face of technological obsolescence? Would research be better directed at maximizing the recovery of materials and value by designing effective shredding and sorting processes?

Deciding the best way to deal with waste, especially when faced with producer-responsibility legislation, is of increasing concern to those manufacturers directly engaged in consumer products. Staikos and Rahimifard have developed a decision making model for the footwear industry which identifies the most appropriate recovery, reuse and recycling option for post-consumer shoes and present a case

study to demonstrate the practicality of their model. The paper by Morana and Seuring contains a cautionary tale about the problems of establishing a closed-loop supply chain to recover long-lived EoL products from customers. Despite the technical opportunity and support from the manufacturer, the scheme failed because it was a voluntary system with no apparent incentive for the customer to return products. The implications of using recycled versus virgin materials for supply chain structure and supplier relationships and their broader effects on operations strategy are reported by Field and Sroufe. The authors concentrate specifically on the corrugated cardboard industry where vertical integration is common, and non-integrated firms are both customers and competitors of integrated firms. A principle finding was that benefits accrue primarily to the non-integrated firms.

Kim *et al.* have provided a review of the literature pertaining to disassembly scheduling and proposed directions for future research. In particular they have focused on the divergence property, with respect to the zero inventory property, indispensable surplus inventory and mathematical representation. The disassembly line balancing problem is described in the paper by McGovern and Gupta. The problem is defined mathematically and shown to belong to the unary NP-complete class of problems. The authors have developed known-optimal instances of the problem and then subjected disassembly line versions to several algorithms and/or heuristics.

In the paper by Ijomah *et al.* the authors address the need for robust design for remanufacturing guidelines to aid effective product recovery. Using case studies they highlighted opportunities for improving competitiveness and profitability through redesign to accommodate remanufacture. The use of genetic programming to support strategic decision-making at the design stage for disassembly and recycling is the focus of the paper by Shimizu *et al.* Based on available information at the design stage, the prototype system automatically decides the optimal disassembly sequence and quantitatively evaluates the disassembly plan.

The concept of product value in the manufacturing, use and EoL phases is considered by Kumar *et al.* The authors propose a model to characterize the value flow during the product's life-cycle and investigate the role of product attributes and product usage history. They present an example to demonstrate the use of the model in selecting the best product recovery option. Jun *et al.* used a multi-objective evolutionary algorithm to evaluate alternative options for the EoL product recovery selection problem. Using the example of an automotive turbocharger product they proffer a solution for the competing options of: disposal/replacement; reuse; recondition; and remanufacture, and apply the criteria of recovery cost and recovery quality.

The case for a strategic sustainability methodology, using reverse logistics as the case study, is proposed by Presley *et al.* The authors demonstrate the use of an activity-based management methodological framework to frame decisions using corporate sustainability. The case study demonstrates how this methodology can be applied to the selection of alternative, competing reverse logistics providers. Independent product recovery facilities can play a vital role in recovering EoL product and in the promotion of reuse and recycling. However, such facilities must be economically viable and this requires that they efficiently manage product recovery costs and inventory control. The paper by Vadde *et al.* presents an optimal

pricing model as an effective strategy to control inventory applied to several scenarios.

3. Concluding remarks

The papers included in this special issue provide an interesting insight into the rapidly expanding range of research activities in support of a sustainable approach for the design and manufacture of products. It therefore should not be surprising to note a shared conclusion among all contributing authors that there is an urgent and imperative need for further research in every phase of a product's life-cycle.

The achievement of the underlining principles of sustainable development, defined as part of a global vision for 'Our Common Future', is a journey that many experts argue has just begun. The recent meteorological events and the resulting major disasters linked to the impact of climate change and global warming have created an unsurpassed interest and support throughout the international community, and perhaps more importantly by businesses and Governments. The Editors believe that this has generated tremendous challenges, expectations and opportunities for the scientific community to investigate and realise the methods, technologies and tools which can transform the achievement of such principles from a conceptual vision to a common reality.

4. The scope for a new journal

The strong support for this special issue by the research community has encouraged the Editors to propose that Taylor & Francis consider the introduction of a new journal. Engineering and sustainable development are intrinsically linked. Many aspects of sustainable development depend directly and significantly on appropriate and timely actions by engineers. Engineering is an extended process of analysis, synthesis, evaluation and execution and therefore it is argued that engineers must be involved from the outset of any proposal to develop sustainable solutions. Engineering embraces many disciplines and truly sustainable solutions are often inter-disciplinary in nature. The proposal for the new International Journal of Sustainable Engineering (IJSE) is predicated on the need for engineers to have access to a source of information and an opportunity to share, through publication, new ideas and solutions for sustainable development. A 'call for papers' for the inaugural issue of the IJSE is included at the end of this special issue.

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