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Investigating the Potential of a Three Dimensional Concurrent Engineering Based Approach to Environmental New Product Development

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INVESTIGATING THE POTENTIAL OF A THREE DIMENSIONAL CONCURRENT ENGINEERING BASED APPROACH TO ENVIRONMENTAL NEW PRODUCT DEVELOPMENT

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Executive Summary

The increasing importance of environmental issues in new product development heightens the significance of the three dimensional concurrent engineering (3DCE) concept as a platform that allows for the assimilation of environmental considerations into the new product development process. While environmental concerns can be integrated without 3DCE, the added element of early supply chain consideration that is inherent in 3DCE is critical to the successful environmental new product development (ENPD) efforts as the environmental performance of a product is the consolidation of its environmental impact through all the stages of its lifecycle; making it dependent on the supply chain. This study aimed to explore and investigate the potential role and utilisation of the supply chain, through a 3DCE-based approach, during ENPD. It took the form of a mixed method study composed of a multi-case study, exploring supply chain management and the new product development process, and controlled experiments, exploring the impact of early supply chain design during environmental new product development. It was found that having the procurement function manage supply-side interactions and the design function practice preliminary supplier selection enables ENPD through early supply chain design. The key is the availability of supplier-specific information (supplying company and product information) and the effective use of the information. The information is made available through supply chain information sharing, a process that is hampered by the willingness to share and information availability. Using technology, mapping the supply chain for visibility and consolidating industry efforts were found to aid the information sharing. The findings and outputs of this study simultaneously expand the knowledge surrounding the utilisation of the supply chain during the integration of environmental considerations into the product development process, improve industry understanding of various organisational issues that surround the ENPD activity and offer new pragmatic mechanisms to support organisational ENPD efforts.

DEDICATIONS

To my wonderful family, Clara and Martin Mombeshora, for their unwavering support and continuous encouragement since day one.

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Thank you.

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NOMENCLATURE

This section explicitly outlines the assumed definitions for important terms that have been used throughout this work; where necessary, the definitions are further elaborated in the report.

TERM	DEFINITION
CHANNEL MEMBERS	Organisations involved in getting a company's products customers (e.g. resellers, distributors etc.)
COMPETITIVE ADVANTAGE	The strategic advantage a business entity has over its rival entities within its industry.
DOWNSTREAM	Flow from the organisation to customers
EARLY SUPPLY CHAIN DESIGN	Supply chain design during the early phases of the product development process
ECO-DESIGN	An approach to the design of a product with a special consideration for the environmental impacts of the product during its whole lifecycle.
ENVIRONMENTAL NEW PRODUCT DEVELOPMENT	New product development into which environmental issues are explicitly integrated in order to create a product with reduced environmental impacts.
ENVIRONMENTALLY RESPONSIBLE MANUFACTURING	An approach to manufacturing which focuses on the efficient and productive use of raw materials and natural resources, and minimizes the adverse impacts on workers and the natural environment.
FIRST MOVER ADVANTAGE	The advantage gained by the initial ("first-moving") significant occupant of a market segment.
FRUIT FLY INDUSTRIES	Industry with a rapid evolutionary cycle or a fast industry clockspeed.
GREEN SUPPLY CHAIN MANAGEMENT	Management mode that considers the environmental effects and resource utilisation efficiency in the whole supply chain.
GREY LITERATURE	Published and unpublished material that cannot be identified through the usual bibliographic methods e.g. websites, academic theses and dissertations, and company white papers.
INDUSTRY CLOCKSPEED	A measure of the evolutionary life cycle of new products, which captures the dynamic nature of the industry.
LONG-TERM COMPETITIVE ADVANTAGE	A strategic advantage a firm has attained and maintains over rival firms in its competitive industry.
NEW PRODUCT DEVELOPMENT	The complete process of bringing a new product to market.
PROCUREMENT	Deals with the sourcing activities, negotiation and strategic selection of goods and services that are usually of importance to an organisation.
PURCHASING	The process of ordering and receiving goods and services. It is a subset of the wider procurement process.
SOURCING	The component of the procurement process that deals with supplier selection and management.
SUPPLY CHAIN	The entire chain or network of organisations, technologies, and capabilities that provide some good or service to a final customer.
SUPPLY CHAIN ARCHITECTURE	Configuration of a product's supply chain.
SUPPLY CHAIN DESIGN	Determination of the configuration of a product's supply chain.
SUSTAINABLE DEVELOPMENT	Development at a societal or business level that meets the needs of the present without compromising the ability of future generations to meet their own needs.
SUPPLY CHAIN MANAGEMENT	The oversight of materials, information, and finances as they move in a process from suppliers to manufacturers to wholesalers to retailers to consumers, involves coordinating and integrating these flows both within and among all companies.
SUPPLIER-SPECIFIC INFORMATION	Typical product information (such as that relating to performance, cost and materials) augmented with information specific to the supplier of the product (such as location, manufacturing and waste management).
SYSTEM LOGISTICS	Part of supply chain management that plans, implements, and

	controls the flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customer's requirements.
SYSTEMS THINKING	Understanding of a system by examining the linkages and interactions between the components that comprise the entirety of that defined system.
THREE DIMENSIONAL CONCURRENT ENGINEERING	Simultaneous design of the product, the manufacturing process and the supply chain.
UPSTREAM	Flow from raw materials into the organisation.
VALUE CHAIN MIGRATION	The shifting of the value-creating force in a products supply chain.
VERTICAL INTEGRATION	An arrangement in which the upstream supply chain of a company is owned by that company.

Acronyms and Abbreviations

Acronyms and abbreviations used throughout this report are defined in this section.

Abbrev.	**Definition**
3-DCE	Three Dimensional Concurrent Engineering
BOM	Bill of Materials
CAD	Computer Aided Design
E-3DCE	Environmental Three Dimensional Concurrent Engineering
EBOM	Engineering Bill of Materials
EI	Environmental Information
EMAS	Environmental Management and Audit System
EMS	Environment Management System
ESCD	Early Supply Chain Design
ESI	Early Supplier Involvement
DfE	Design for Environment
DfM	Design for Manufacturing
ENPD	Environmental New Product Development
ERS	Engineering Requirements Specification
GSCD	Green Supply Chain Design
GSCM	Green Supply Chain Management
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
MRS	Marketing Requirements Specification
NPD	New Product Development
PDP	Product Development Process
PEP	Product Environmental Performance
PLM	Product Lifecycle Management
SCG	Supply Chain Greenness
SCM	Supply Chain Management
SCNPD	Supplier Collaboration in New Product Development
S-LCA	Simplified Life Cycle Analysis
SSI	Supplier-Specific Information
TIM	Technology and Innovation Management

Disclaimer:

The company pseudonyms used within this thesis are fictional. Resemblance to any real life company, product or service is purely coincidental.

1. INTRODUCTION

With organisations experiencing increased social and regulatory demands to behave in an environmentally conscious manner on a global scale, environmental impact is increasingly becoming a factor considered alongside cost, functionality and value during the product development process. Against this back drop, some organisations are enhancing their competitiveness by improving their environmental performance through the mitigation of the environmental impact of their production and service activities (Bacallan, 2000). However, these new requirements are often viewed as mandates or burdens that slow development while ramping up cost, detracting from the main business of the company. As a result, environmental aspects are often considered an afterthought, resulting in delays and added costs as changes are made after the late addition of environmental requirements into the development process (Handfield *et al.*, 2001; Ellram *et al.*, 2008). This research sets out to tackle this problem. With its roots in concurrent engineering; three-dimensional concurrent engineering (3DCE) holds great promise for the early integration environmental considerations into the product development process through its emphasis on the early consideration of supply chain design. 3DCE is the notion that the simultaneous design of product, process and supply chain, through links between internal functions and participation with external partners, leads to improved operating performance (Fine, 1998).

In addition to its original focus of reducing product development time, the 3DCE concept appears to be a platform that allows for the marrying of environmental considerations and new product development (Ellram *et al.*, 2008). ENPD is defined here as product development into which environmental issues are explicitly integrated in order to create a product with minimised environmental impacts. This also includes the redesign of existing products to reduce their environmental impact in terms of materials, manufacture, use, or disposal. As the environmental performance of a product is the amalgamation of its environmental impact through all the stages of its lifecycle, from the extraction of raw materials to its end of life, it is dependent on the totality of the supply chain in both upstream and downstream directions throughout its lifecycle. With ENPD practices such as eco-design and environmentally responsible manufacturing (ERM) requiring the co-operation of the entire supply chain, the importance of the early consideration of supply chain aspects increases. Through early supply chain design, specific information pertaining to the product's supply chain and characteristics of components and materials from the supply base is available during the design phase. It is this availability of information that can allow for various environmental assessments to be carried out, these assessments can be more accurate if they are based on real/specific supply chain information as they will be based on supply chain specific information. Additionally, effects of making alterations to the product's supply chain can be seen in real time as the product is being designed. The availability of this information not only allows for certain environmental considerations and assessments to be made during the product's development and - not after product design has been completed - but also has the potential to facilitate supply chain design during the product development process. Designing the supply chain early during the NPD process has been shown to deliver commercial benefits (Fine, 1998); through the combined competitiveness potential that better environmental performance and early supply chain design can offer, it is hypothesised that the 3DCE can significantly improve the practice of ENPD.

1.1 Rediscovering The Missing Link

In his 1998 book *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*, drawing inspiration from the Noble Prize winning work concerning the genetic control of early embryonic development by Lewis, Nüsslein-Volhard and Wieschaus (*Nobelprize.org*, 2013), Charles Fine presented to the world his theory of business genetics. As in the natural world where species must evolve to survive, Fine stated that businesses must also do the same. Following that, he coined the term *clockspeed* to refer to the lifecycle of an industry.

> *"In the natural world, species evolve - that is they change to meet new challenges - or they die. The same genetic imperative operates in business"* – Charles Fine (1998)

1.1.1 *Fruit Flies and Clockspeeds*

To gain a deep understanding of successive generations in a short period of time, Fine focused on observing fruit fly industries - defined as industries with rapid evolutionary cycles e.g. the computer industry - under the premise that fruit flies could be examined for information that would benefit businesses of all kinds. Through the observation of industrial fruit flies, patterns in industry dynamics can be discerned; additionally, by studying dynamic processes in the evolution of industry structures, firms can also develop insights into how an industry's future may unfold.

According to Fine, industry evolves in accordance with the effects of three types of clockspeed; namely, product, process and organisational. *Product* clockspeed contrasts the fast telecommunications industry with the slow nuclear power plant industry, while *process* clockspeed can be exemplified by the rapid evolution of animation and special effects technology in the film-making industry and *organisational* clockspeed may be illustrated by alliances and mergers that typify some industries e.g. technology and biotechnology.

Although the idea that the evolution of industries is naturally speeding up - i.e. industry clockspeeds are getting faster - is not a new one, the notion that slow-clockspeed industries can use the experiences of fruit flies to guide them as their industry's clockspeed increases is a fresh perspective. Analysis of fruit flies enables managers and business leaders to see with greater accuracy and clarity the technology and market forces that will affect future needs. It is the understanding of these needs that makes it more likely that one can design superior quality supply chains.

Fine urges that firms must not just focus on individual capabilities but rather on strategic thinking of the whole value chain. In fast clockspeed industries, individual capabilities can lose value overnight due to the activities of competitors or evolving technologies; while some technological advance can dramatically change some industries, such an advantage is often temporary as the innovation is diffused among other producers.

> *"Lasting success will not go to the firm that manages great business opportunities, or the firm that develops the best proprietary technology, but rather to the firm that can anticipate, time after time, which capabilities are worth investing in and which should be outsourced; which should be cultivated and which should be discarded; which will be the levers of value control and which will be controlled by others."* – Charles Fine (1998)

1.1.2 *The Nature of Competitive Advantage*

Whether rooted in market position, business models, processes or competences of organisations, it has always been a core tenet of the strategy field that long-term competitive advantage is attainable. The concept of long-term competitive advantage suggests that it is possible for a firm to not only attain but maintain a strategic advantage over rival firms in its competitive industry through the acquisition or development of an attribute or a combination of attributes that allows it to outperform its competitors (Porter, 1985). In Clockspeed, Charles Fine proposed that all competitive advantage is temporary. History offers numerous examples of the transient nature of competitive advantage: from personal computers displacing word processing companies such as Wang (Ziegler, 1992); to Amazon.com displacing numerous small and independent bookstores all over the world (Carmody, 2013); and the disruptive nature of digital technology to the previously film-based consumer camera industry (DiSalvo, 2011). Since Fine introduced the notion of temporary advantage, it has been a topic of debate within the strategy field. In addition to the works of O'Shannassy (2008), and McGrath and Gourlay (2013), in 2008 it resulted in a call for papers for a special issue of the Strategic Management Journal entitled The Age of Temporary Advantage (Organizations and Markets, 2008).

Based on locking in your advantages and locking out the competition, long-term advantage can be viewed as a slow clockspeed industry construct; while temporary advantage can be viewed as a concept related to fast clockspeed industries. It is imperative that companies focus on exploiting their current capabilities and competitive advantage while also consciously and purposefully building new capabilities for the inevitable moment when the old ones no longer provide an advantage. As a result, the strategic planning process should consist of trying to think through the company's series of temporary advantages. In this climate, the only long-term competitive advantage is the firm's ability to transition from one temporary advantage to the next.

1.1.3 Sustainability: The Next Source of Advantage.

For both prosperity and maintaining economic growth firms are increasingly aware of the importance of being ahead of the next so-called 'waves' of innovation. Being able to accurately predict and prepare for the next wave of innovation gives firms the opportunity to become competitive through the attainment of the first mover advantage (Lieberman and Montgomery, 1988). For a wave of innovation to occur, a combination of a significant array of relatively new and emerging technologies and a recognised genuine need in the market that is leading to a market expansion is required. Today, there is a critical mass of enabling technologies that make integrated approaches to sustainable development economically viable. Added to increased regulation through, for instance, the ratification of the Kyoto Protocol, the formation of the EU Emissions Trading Scheme, and the EU directives on waste and hazardous substances, this suggests that the next wave of innovation will be in sustainable development (Hawken *et al.*, 1999; Hargroves and Smith, 2005). Figure 1 shows previous and predicted future waves of innovation. With the next industrial revolution predicted to driven by the emerging need for simultaneous productivity improvement while significantly reducing impacts on the environment, firms that work to address sustainable development can position themselves to be at the forefront of the next wave of innovation. In their 2005 book 'The Natural Advantage of Nations', Hargroves and Smith consolidate the work of over thirty world leaders in sustainability and collect evidence from around the globe to show that the drive for a sustainable world is both an environmental imperative and a practical and potentially profitable necessity, which is already underway and not always in conflict with economics and business practice.

Consequently, some organisations are enhancing their competitiveness through ENPD, which allows for the improvement of their environmental performance through the mitigation of the environmental impact of their production and service activities. Many still consider trade-offs between social, environmental and economic goals as inevitable during ENPD however, this research investigates whether 3DCE provides an integrated approach that allows for 'win-win-win' opportunities to arise.

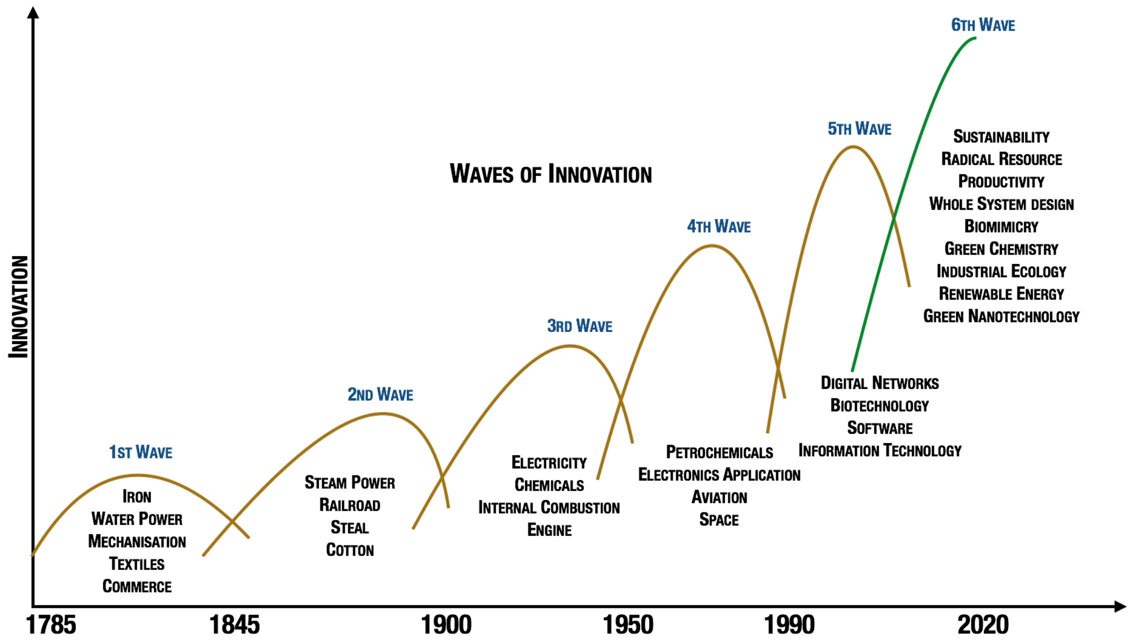


FIGURE 1: WAVES OF INNOVATION (FROM HARGROVES AND SMITH (2005))

Regardless of a company's motivations to produce environmentally competitive products, whether it lies in corporate or customer value proposition, by its nature, the advantage that can be offered by creating environmentally competitive products is fleeting. This can be illustrated using the Kano model of customer satisfaction (Ullman, 1997); the model is shown in Figure 2. The Kano model classifies product attributes based on how they are perceived by customers and their effect on customer satisfaction. A competitive product meets basic attributes, maximises performance attributes and includes as many excitement attributes as possible at a cost the market can bear. Basic attributes are those that are expected, whose absence would cause dissatisfaction. Performance attributes are those for which more is better, and a better performance attribute will improve customer satisfaction. Lastly, excitement attributes are unspoken and unexpected by customers but can result in high levels of customer satisfaction, however, their absence does not lead to dissatisfaction.

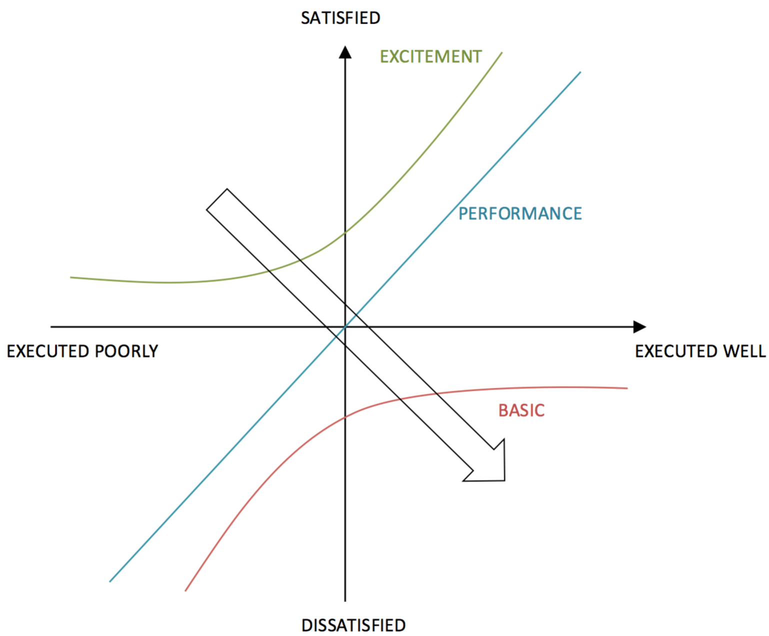


FIGURE 2: KANO MODEL FOR CUSTOMER SATISFACTION (FROM ULLMAN (1997))

In a competitive marketplace where manufacturers' products provide similar performance, providing excitement attributes that address latent needs can provide a competitive advantage. When environmental performance attributes are classed as excitement attribute, they become attributes that are incorporated into products that are not necessarily at the forefront of customer considerations when they are looking to buy their products. One of the most challenging aspects of the Kano model is that it predicts that all features will migrate from excitement to basic attributes. The drift is driven by customer expectations and by the level of performance from competing products. The absence of that attribute would now be a frustration, meaning new excitement features need to be discovered. Today, environmental attributes can be distinguished as excitement features, tomorrow they will become known features and the day after that they will become used throughout the market. Regardless of their classification, environmental attributes are set to be a constant product feature and by adopting ENPD early companies can reap the rewards of the competitive advantage that can be gained by offering them as excitement features before that advantage is eroded as they become basic attributes.

1.1.4 Three Dimensional Concurrent Engineering

Whilst Japanese manufacturing methods rose to prominence and proved superior to those of their western counterparts, in the 1980s western manufacturers worked relentlessly to benchmark companies such as Sony and Toyota. By the early 1990s, many had achieved breakthroughs in their understanding of competitive advantage through manufacturing. A significant portion of this learning came under the heading of concurrent engineering or design for manufacturing (DfM) (Fleischer and Liker, 1997; Nevins and Whitney, 1989; Ulrich and Eppinger, 1994). Managers came to the realisation that, in order to achieve improved manufacturing performance, they had to stop focusing solely or primarily on the factory but rather shift to concurrently designing the product and the manufacturing process – that is, designing the product for manufacturability. 3DCE is an extension of this concept, augmenting the concurrent design and development of product and manufacturing process with that of supply chains. Figure 3 is a graphical representation of a comparison between concurrent engineering and 3DCE and Figure 4 illustrates the impact of 3DCE on product development time.

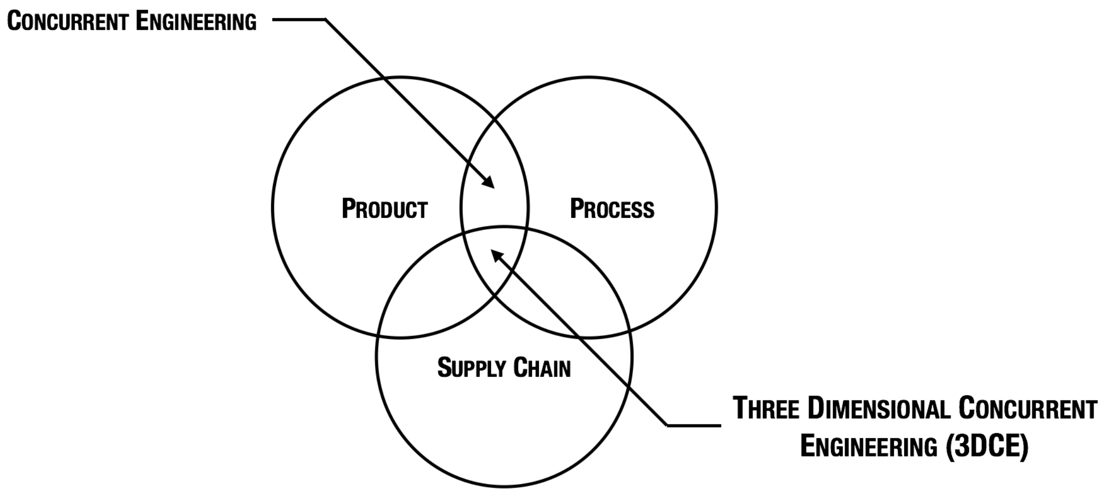


FIGURE 3: THREE DIMENSIONAL CONCURRENT ENGINEERING MODEL (MODIFIED FROM FINE (1998))

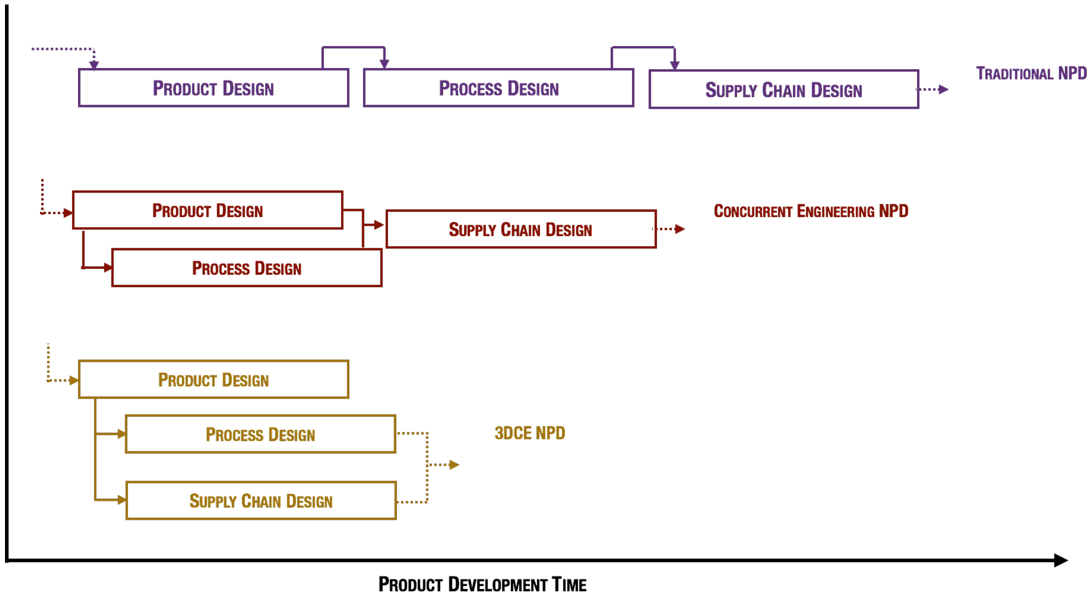


FIGURE 4: DEVELOPMENT TIME OF TRADITIONAL NPD VS CONCURRENT ENGINEERING VS 3DCE

3DCE can be viewed as the integration of core competences of a manufacturing firm to achieve competitive advantage; its three aspects must be treated as a single, fully integrated capability and managed concurrently rather than as separate functions. It is almost such that the strategic nature of supply chain design advocates for its integration with product and process development (Fine, 2000).

> *You may think of your company as a solitary, stand-alone entity which is served by subsidiary organisations... that view, however, vastly underestimates the importance of the supply chain as a whole and fails to capture its true essence* – Charles Fine (1998)

Under increasingly globally competitive conditions, as firms sought to attain long-term growth and profitability through the rapid introduction of new products, the product development process, an inherently collaborative activity between internal groups - such as engineering, marketing, manufacturing, sales and service - increased in complexity due to the addition of external partners - such as subcontractors, customers, technology suppliers and co-development partners) (Rufat-Latre *et al.*, 2010; Wagner and Hoegl, 2006). This decrease in vertical integration, combined with increasing globalisation and outsourcing, resulted in the growth of supply chain management (SCM) which places great emphasis on the management of relationships within the supply chain; viewing the supply chain as more than just a logistic network comprising of interrelated companies built around delivering a specific product or service to the customer (Saeed *et al.*, 2005). Through cooperation and information sharing, SCM coordinates different parties within the network and establishes business partnerships with the aim of achieving overall and long-term benefits for all involved parties. While product innovations can be matched by competitors, due to its more tacit nature, superior SCM is often able to offer a long-term advantage (Fine, 1998; Christensen, 2001). It can be seen as a dynamic capability that enables the continuous strategic innovation that is necessary for the retention of competitive advantage in disruptive environments, as long as the executing firm does not get exhausted by continuous transformation and innovation or get complacent by success.

> *Supply chain design is too important to leave to chance as proactive chain design will shortcut and forever make obsolete the slow, incremental process of industrial evolution* – Charles Fine (1998)

Being over fifteen years old, it is easy to discard Fine's work in favour of more recent incarnations of the ideas he discussed that can be found in works such as *Open Innovation* (Chesbrough, 2003) and *Wikinomics* (Tapscott and Williams, 2008). However, it is still an important fact that supply chains need to be continually re-engineered with an eye on financial analytics, and not just musically, and artistically orchestrated (Goldratt and Cox, 1984; Davenport and Harris, 2007; Ribbonfarm Consulting, 2007). Since its inception, 3DCE has been credited with many potential benefits, including reduced costs, reduced time to market, improved supplier integration and improved quality (Fine, 1998; Klassen and Angell, 1998; Balasubramanian, 2001), which are generally NPD goals.

1.2 The Project Overview

Supported by concurrent engineering, 3DCE is a simple yet powerful model of NPD in which the traditional focus on an appropriate match between product and process is augmented by an additional consideration of supply chain configuration. With concurrent engineering becoming commonplace enough to no longer provide a source of competitive advantage, 3DCE promises to offer organisations the next level of breakthrough in improving performance. The nature and state of 3DCE research and industry implementation is such that, to increase its adoptability it is necessary to add to the existing 3DCE theoretical framework. With ENPD being traditional product development with the added dimension of integrated environmental considerations, it can be seen as the next step in the evolution of the product development process. These two drivers focused this research on exploring the potential role and utilisation of a 3DCE-based approach for ENPD.

1.2.1 The Research Problem

As the main aim of ENPD is to reduce environmental impacts throughout all the stages of a product's lifecycle; to achieve this, it is paramount to determine where those impacts occur. When these impacts occur in the supply chain's operations or in use and disposal by end users (as opposed to the internal manufacturing phase), supply chain management (SCM) becomes one of the key tasks in the implementation and management of ENPD. This especially holds true for organisations at the end of the supply chain, organisations that do not typically have product design functions or carry out design only in relation to planning and design of facilities and operations. Typically, they 'buy in' rather than manufacture the products and materials that they require. Subsequently, most of the environmental impacts of their activities reside in their supply chains. For such companies, undertaking ENPD can be managed through SCM, with ENPD principles and methods applied to specification and purchasing rather than directly in the product design activities. For manufacturing companies with a product design function, SCM becomes an important element or outcome of ENPD as there is a need to reduce the 'bought-in' environmental impacts of input materials and components. As they increasingly 'contract-out' or 'buy-in' components and subassemblies, design activities and product impacts are shifting to earlier points in the supply chain. Not only is SCM becoming an increasingly important business issue, it plays a vital role in the attainment of ENPD goals; therefore, it is important to investigate it in the ENPD context.

1.2.2 The Research Aim and Contribution

By viewing 3DCE holistically, as a complex adaptive system and with a particular emphasis on ENPD, the main aim of this project is to simultaneously enhance 3DCE research and its practical implementation and to encourage SCM during the environmental new product development process. This will be achieved through the accomplishment of the following aim:

> *Explore and investigate the potential role and utilisation of the supply chain, through a 3DCE-based approach, during the integration of environmental considerations into the new product development process.*

Progressing from concurrent engineering, by supplementing it with supply chain considerations, the outcomes from this research project ultimately aim to aid organisations aiming to attain the label of 'green and competitive' through their NPD efforts.

1.3 Research Process Overview

Figure 5 is a map of the thesis document, it illustrates the flow of the thesis and how the different chapters relate to each other and Figure 6 presents an idealised model of the research process that was undertaken, in reality, the complexities of researching in the real world means that research did not progress from identification of the research focus right through to the presentation of findings in a nice sequence of steps, but rather it was necessary to revisit previous stages in the research process. Created as a comprehensive documentation of the work that was undertaken during the 36-month long research project, this thesis has been divided into parts that coordinate with the adopted process and express, not necessarily in linear form, a coherent argument or investigation. It aims to be a holistic demonstration of the skills, intellectual capabilities and scholarship of the research student and to show the structures of reasoning on which the research is based, not just a record of research done. Hence the research content presented in this thesis is based on existing knowledge and developing that knowledge using reasoned argument, sound evidence and critical and reflective stance.

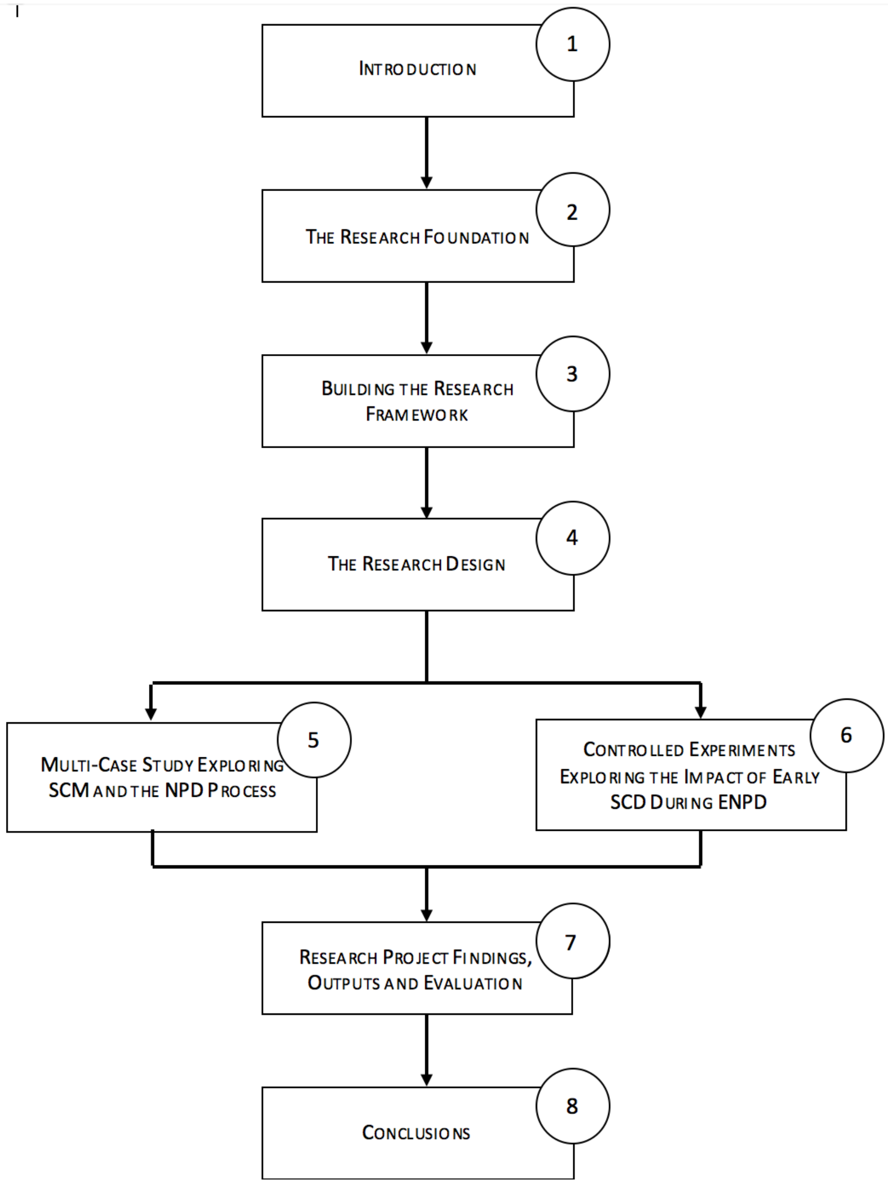


FIGURE 5: THESIS DOCUMENT MAP

Stage	Activity	Thesis: Chapter	Thesis: Section
Investigating Stage	**Identify Research Area**	1: Introduction	Introduction and Background
	Review Literature and Theories	2: Research Foundation	Literature Reviews
	Select Topic	2: Research Foundation	Deficiencies in Literature
Planning Stage	**Formulate Objectives and Questions**	3: Research framework	Conceptual Framework and Research Objectives
	Outline Research Approach	4: Research Design	Layers of Research Design
	Formulate Research Plan	4: Research Design	Mapping Activities to Objectives
Operational Stage	**Collect Data**	5: Multi-Case Study 6: Controlled Experiments	Experiments and Interviews
	Analyse Data	5: Multi-Case Study 6: Controlled Experiments	Quantitative and Qualitative Analysis
Concluding Stage	**Present Findings**	5: Multi-Case Study 6: Controlled Experiments 7: Research Findings and Outputs	Outputs and Inferences
	Summarise Study	7: Evaluation 8: Conclusion	Evaluation and Conclusions

FIGURE 6: LINKING ADOPTED RESEARCH PROCESS TO THESIS CONTENTS

2. The Research Foundation

Chapter Overview

This chapter contains a comprehensive and systematic review of literature focused on the research aim, identifying, appraising, selecting and synthesizing all relevant, high quality research evidence and arguments. It aims to provide context for the study and to situate it within the body of literature.

Highlighted Contents

	Section
Context Setting	2.1.1, 2.1.2
Synthesising New Perspective	2.1.3
Identifying, Exploring and Relating Theory to Practice	2.2
Key Literature	2.3.1
Deficiencies in Literature	2.3.2
Linking Literature to Project Aims	2.3.2

A literature review is a necessary step in structuring a research field and forms an integral part of any research conducted (Easterby-Smith *et al.*, 2002); it helps in the identification of conceptual content of the field (Meredith, 1993) and guides towards theory development. Through it, the researcher's critical awareness of the relevant knowledge in the field is demonstrated. Given the relatively immature level of 3DCE research to date, this literature review section aims to create theoretical corroboration for 3DCE by drawing on literature in product design, process design and supply chain design. In addition to that, the connection between SCM and ENPD theory and practice will be explored.

The information that formed the basis of this literature review was acquired, analysed and synthesised using the 'touring and camping' method suggested by Hart (2001), presented in Figure 7. The set of skills outlined in Table 1, were utilised throughout the review process, as they ensure critical engagement with the literature.

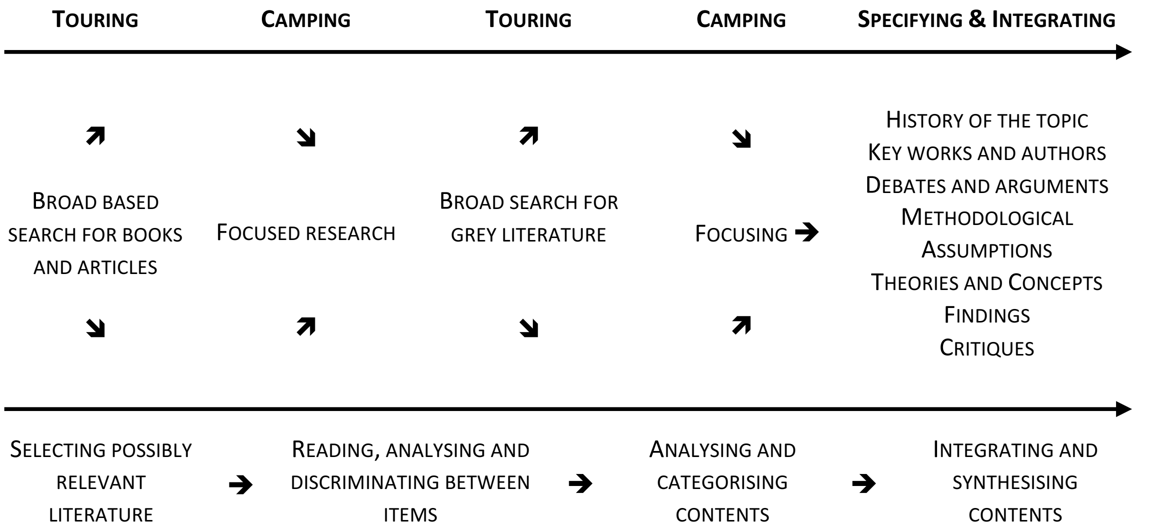


FIGURE 7: TOURING AND CAMPING TO ACQUIRE, ANALYSE AND SYNTHESIZE INFORMATION (FROM HART (2001))

TABLE 1: SKILLS FOR CRITICAL ENGAGEMENT WITH THE LITERATURE (FROM GRAY (2006))

SKILL	**ACTIONS**	**DESCRIPTION**
ANALYSIS	SELECT, DIFFERENTIATE, BREAK UP	Dissecting data into their constitute parts to determine the relationship between them.
SYNTHESIS	INTEGRATE, COMBINE, FORMULATE, REORGANISE	Rearranging the elements derived from analysis to identify relationships.
COMPREHENSION	UNDERSTAND, DISTINGUISH, EXPLAIN	Interpreting and distinguishing between different types of data, theory and argument to describe the substance of an idea.
KNOWLEDGE	DEFINE, CLASSIFY, DESCRIBE, NAME	Describing the principles, uses and function of rules, methods and events.

Forming the foundation of the research project, the literature review presented here can be viewed as being comprised of three parts. The first is concerned with building an understanding of subject matter (Section 2.1) while the second related theory to real life practice (Section 2.2). In addition, the research study is placed in a historical context within the literature.

2.1 Understanding the Subject

This section starts off by looking at how environmental issues and competitiveness relate to each other, moves on to exploring how NPD transitions into ENPD, before delving deeper into the structure of 3DCE.

2.1.1 Green and Competitive

Environmental concerns appeared on the agenda of manufacturers in the second half of the last century and, since then, academics and practitioners have contributed to understanding managing sustainability in businesses, from both environmental and social perspectives. Twenty years ago, the challenge of responding appropriately to environmental concerns was becoming a part of purchasing, marketing, and corporate strategy, changing the way businesses operate (Menon, 1997; Hart, 1995b). Where environmental responsiveness was once viewed as involving trade-offs with other corporate goals, compliance, and expense, some were starting to portray it as an opportunity (Porter and van der Linde, 1995) others disputed this (Walley and Whitehead, 1994). Porter and van der Linde (1995) argued that there was an underlying logic linking the environment, innovation, resource productivity, and competitiveness; while, Menon (1997) claimed that there was an emerging consensus among business leaders that the goals of social good and business success were no longer an either/or proposition but are being increasingly interwoven into an ''eco-preneuring'' paradigm. They were urging that the effective development of new, environmentally improved (or greener) products would clearly be crucial in creating successful environmental strategies, and in helping to move companies and economies towards environmental sustainability.

Over the decades, interest in managing the sustainability of their operations, supply chain, and products has grown amongst manufacturing firms as pressure from government and society to deal with factors contributing to global warming, the scarcity of raw materials, and the deterioration of human rights continues to rise (Seuring, 2004; Porritt, 2007). External incentives and pressures, such as environmental laws and regulations, customer demand for sustainable goods and services, and pressure from environmental interest groups, seem to compel organizations to take appropriate actions and manage their sustainability; and the literature suggests these are the primary determinants of manufacturers increasingly managing sustainability (Alblas *et al.*, 2014).

Literature offers a multitude of theories and studies on the management of sustainability, varying from high-level general management strategies (Baumgartner and Ebner, 2010; Epstein, 2008; Waage, 2007b) to more detailed methods for addressing specific problems. The latter category includes methods for the design for environment (DfE) concept (Srivastava, 2007b), design-oriented work for green operations and green supply chain management (Sarkis, 2001b; Sarkis *et al.*, 2011; Seuring and Mueller, 2008), and tools and metrics that can be used to make design decisions more sustainable (Robert *et al.*, 2002; Waage *et al.*, 2005).

Despite all this research, companies still face great difficulties in managing sustainability. While this problem is acknowledged in the literature (Sroufe *et al.*, 2000b; Seuring and Mueller, 2008; Dangelico and Pujari, 2010; Driessen *et al.*, 2013), existing contributions provide limited overviews of general difficulties and challenges in managing sustainability, such as cost implications, inadequate knowledge and skills, ambiguous laws and regulations, and the complexity of communication and coordination efforts in supply chains (Handfield *et al.*, 2001; Collins *et al.*, 2007; Seuring and Mueller, 2008).

The most recent study by Przychodzen and Przychodzen (2015) sought to explore the implications of environmental innovation on financial performance. The results indicated that eco-innovators were generally characterised by higher returns on assets and equity and lower earnings retention, suggesting that strong asset and financial capabilities are relevant pre-conditions for the development of eco-innovativeness and that there is a need for environmental policy to create clear incentives for organisations to increase activities in that area.

Even as firms are being increasingly urged to develop green products, industry remains slow to act upon such initiatives. Richey *et al.* (2014) investigated the impact of green initiatives on firm performance and how the related commitment of resources impacts the effectiveness of those initiatives. Using multi-source data, their findings suggest that the commitment of proper resources is critical to the success of any green initiative and also supports the notion that being the first firm in an industry to initiate a green program provides few tangible benefits. But perhaps more importantly, even firms with an environmental focus neglect to realise superior performance unless the specific strategy is matched with consistent support from top management.

The debate regarding the potential for firms to be "green and competitive' by examining the relationship between ENPD activities and market and eco-performance for environmental new products, Pujari *et al.* (2003) went beyond the anecdotal evidence in the extant literature, to empirically research ENPD activities and their impacts and were able to show that, contrary to the popular perception, there is more synergy than conflict between the conventional and environmental product development paradigms.

Looking at market conditions, out of 1000 consumers surveyed in Europe and the United States, a study by McKinsey found that over 70% were willing to pay an additional 5% for a green product if it met the same performance standards as a non-green alternative. However, as the premium increased the willingness to pay diminished, less than 10% of the customers said they would choose green products if the premium rose to 25 percent (Miremadi *et al.*, 2012). In a different study, Nielsen found that 66% of consumers were willing to pay extra for products and services that come from companies who are committed to positive social and environmental impact; a sizable jump from the two previous years at 55% and 50%, respectively (Nielsen, 2015). However, Unhur (2011) argues that 'willingness to pay' is an illusion as consumers will consistently tell surveys that they are willing to pay more for socially and environmentally superior products, but when the time comes they rarely commit to buying greener products. Consumers and the public instead expect sustainability as a baseline condition of business. They don't expect to pay for it. They are, however, more than willing to punish if it's not there. Regardless of whether or not consumers and markets are unwilling to pay more for sustainability, companies that can produce products that are sustainable, but also cost and function the same as non-green competitors are likely to find overwhelming market acceptance.

2.1.2 From NPD to ENPD

Coupled with the emerging need for simultaneous productivity improvement while significantly reducing impacts on the environment, new product development can be viewed as a critical process to improving a company's competitiveness. As environmental impacts generated throughout the product lifecycle are significantly determined during the early phase of its development, NPD plays a crucial role in enhancing the environmental performance of new products. The logic within its approach means that ENPD is not a radically different process to conventional NPD, but involves adding a further level of complexity into the NPD process. This process must continue to deliver core benefits to customers, while also addressing stakeholder needs for improved eco-performance, and manage any necessary trade-offs with existing core or auxiliary product benefits. Addressing eco-performance within product development decisions does imply some of the key differences between ENPD and conventional NPD which are detailed in Table 2.

TABLE 2: KEY DIFFERENCES BETWEEN NPD AND ENPD

DIFFERENCE	IMPACT	CONTRIBUTING AUTHORS
FOCUS ON DESIGN FOR POST-USE APPLICATIONS	Attention is given to the fate of products post-use, particularly design for the ''Five R's'' of repair, reconditioning, reuse, recycling, and remanufacture.	(Wheeler, 1992)
BROADER CUSTOMER SATISFACTION CONSIDERATION	Environmental concerns lead to customer requirements beyond functionality, cost, and quality; requirements relating to how products are made, how long they last and, how they can be disposed of.	(Peattie, 1999)
FOCUS ON PHYSICAL PRODUCT LIFECYCLES	Reflecting a physical ''cradle-to-grave'' product life cycle perspective, physical consequences of production and consumption become considerations; such as where raw materials going into products come from, and what happens to products post-use.	(Sharfman *et al.*, 1997)
AUGMENTED SUPPLY CHAIN PERSPECTIVE	Suppliers have an important role in determining all aspects of product quality including eco-performance. ENPD requires a detailed understanding of the socio-environmental impacts of the whole supply chain, down to the simplest ingredient, which may previously have been perceived as standardized and unlikely to pose quality problems. Concern for the environmental impacts of suppliers can be seen in the introduction of the ISO 14000 series of environmental management systems (EMS) and quality standards to complement the ISO 9000 series. It can also be seen in the requirement of many businesses that their suppliers undergo environmental audits.	(Simon *et al.*, 2000; Sinding, 2000)

2.1.3 UNDERSTANDING 3DCE

Fundamentally, the concept of 3DCE is the consolidation of product design, process design and supply chain design. To attain a solid understanding of it, the definitions of its founding concepts are outlined in Table 3. Various links exist between and among these three base concepts; acting as an expansion of Figure 3 *(see Section 1.1.4)*, Figure 8 tries to capture visually the many ideas of 3DCE and show in more detail the interface points and key issues in the simultaneous design and development of product, process and supply chain.

TABLE 3: DEFINING THE CORE CONCEPTS OF 3DCE

3DCE CONCEPT	DEFINITION	CONTRIBUTING AUTHORS
PRODUCT DESIGN	Product design focuses the products specifications and can include activities of architectural choices and detailed design choices.	(Koufteros *et al.*, 2005; Brown and Eisenhardt, 1995; Safizadeh *et al.*, 1996)
PROCESS DESIGN	Process design deals with methods that will be used to manufacture the product and can include the development of unit processes and manufacturing system development.	(Ulrich and Eppinger, 1994; Fleischer and Liker, 1997; Nevins and Whitney, 1989)
SUPPLY CHAIN DESIGN	Supply chain design can be divided into supply chain architecture decisions and logistics systems decisions. It considers in-sourcing and outsourcing, logistical channels, customers, suppliers and the types of relationships an organisation has with members of its supply chain.	(Parker and Anderson, 2002; Liker and Choi, 2004; Choi *et al.*, 2001; Handfield *et al.*, 1999; Webster, 1992; Howard and Squire, 2007)

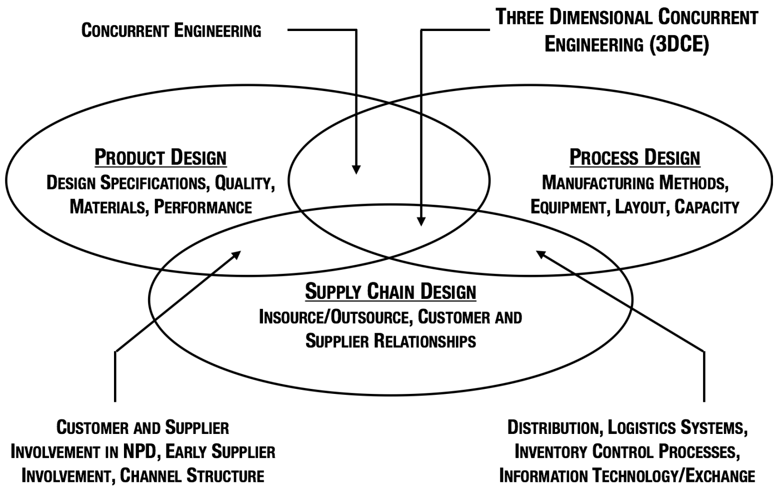


FIGURE 8: INTEGRATING 3DCE LITERATURE (FROM ELLRAM ET AL. (2007))

3DCE has its roots in concurrent engineering, which supposes that products and processes should be designed simultaneously, involving multi-functional teams early on in the process, which may include customers and suppliers (Birou and Fawcett, 1994; Blackburn *et al.*, 1996; Swink, 1998; Koufteros *et al.*, 2002). Due to the many of its benefits being demonstrated, the adoption of concurrent engineering techniques has become commonplace enough that it no longer provides a source of competitive advantage (Fine, 1998). Resultantly, organisations are looking for the next level of breakthrough in improving performance. Moving past concurrent engineering, 3DCE is defined as: "… the simultaneous development of products, processes and supply chains" (Fine, 1998), including: "… the concurrent design and development of capabilities chains."

In his study on determining the right supply chain for your product, Fisher (1997) found that increased costs and adversarial supply chain relationships could result from the improper integration of product, process and supply chain design. In his research he established that it was necessary to match the supply chain design (responsive or efficient) to the type of product (functional or innovative) and the process and manufacturer's ability to meet customer requirements. This marks the first time that an example of - what was to be later known as 3DCE - became available in literature. It wasn't until the following year that the term 3DCE was formally coined and explicitly introduced. Although studies that explicitly incorporate supply chain design with product design and production planning, thus creating 3DCE, have been limited, their number has been steadily increasing with time.

In their work, Feng et al. (2001) developed a stochastic programming model to determine the tolerances of product design and selection of suppliers, simultaneously, based on quality loss. Focusing on technological incompatibility, Signhal and Singhal (2002) linked product design to process and supply chain through a component compatibility matrix. Through their investigation into the effect of the supplier integration process on cost, quality and new product development time, Ragatz et al. (2002) showed that that integrating suppliers into the NPD process has direct implications for process design decisions and for supply chain configuration decisions. In addition, they developed a conceptual model to integrate suppliers under technological uncertainty conditions. In their research - building on the work of Fisher - Wang et al. (2004) described the relation between specifications of a product and the type of supply chain strategy. Then went on to develop and integrated Analytic Hierarchy Process (AHP) and Pre-emptive Goal Programming (PGP) methodology for considering both qualitative and quantitative factors in supplier selection.

Using survey data, Petersen et al. (2005) provided evidence that linking supply chain design, via ESI, to product and process improves overall design and financial performance. This provides preliminary evidence that a competitive advantage can be attained through the decisions regarding the product-process-supply chain integration. In a similar study, Huang et al. (2005) integrated platform product decisions, manufacturing process decisions, and supply sourcing decisions. Using a mathematical model to quantify the relationships among various design decisions, their study cumulated in the development of a qualitative model and a proposed Genetic Algorithm (GA) method for solving it. Much like (Singhal and Singhal, 2002) , Frixon (2005) developed an analytical to link component compatibility with product, process and supply chain design. Fixon developed a multi-dimensional framework as a coordination mechanism that builds on existing product characteristics such as component commonality, product platforms, and product modularity.

As highlighted above, initially, the 3DCE studies focused heavily on providing qualitative insights in to the problem. In 2005 Fine et al., for the first time in the field, conducted the first quantitative 3DCE study. They proposed a goal-programming model to address 3DCE and studied relationships between product structure (modular and integral) and supply chain structures (modular and integral). Using a short network approach, by considering decisions concerning product design and the manufacturing process and the impact of such decisions on the supply chain, Blackhurst et al. (2005) were able to develop a Product Chain Decision Model (PCDM). Thomas, McKay, and Pennington (2006) reported information requirements that need to be met by using tools and techniques to support the execution of 3DCE processes.

Ellram and Stanley (2008) explored the integration of strategic cost management with a 3DCE environment and concluded that this integration can result in higher levels of company performance and competitiveness. In another investigation, they used the 3DCE approach to integrate ERM and NPD and investigated positive effects of this integration (Ellram *et al.*, 2008). Through an extended house of quality, Tchidi and He (2010) introduced an expended quality function deployment process in a 3DCE environment that transforms customer requirements into product design, process design and supply chain design. In more recent works, Shidpour et al. (2013) use a Multi-Objective Linear Programming (MOLP) model integrated to the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method in order to determine the best configuration product design, assembly process and suppliers of components and Rudrajeet (2015) adopts a 3DCE perspective when exploring the antecedents of value creation in second-hand clothing value chains in Sweden.

The review of literature above highlights that there is some modelling, conceptual and empirical basis for exploring the importance and relevance of 3DCE in industry.

Complementary 3DCE Literature

Exploring the linkages between the base concepts that make up 3DCE offers a good way of augmenting the limited 3DCE literature. The linkages are product/process, supply chain/product and process/supply chain; literature within these also supports the model for 3DCE.

Product/Process

In the 3DCE model, the product/process overlap is concerned with technology, specifications and the process technology and equipment to be used during design and manufacturing. A close connection between the two results in better overall operating performance on several measures (Ettlie, 1995; Safizadeh *et al.*, 1996), including cash flow (Kim *et al.*, 1992). The product/process link represents concurrent engineering, a practice that is well established both in literature and in practice. Distinguishable from other approaches to NPD through its presumption that products and processes should be designed simultaneously and reliance on the early involvement of multi-functional teams, sometimes including suppliers (Swink, 1998; Koufteros *et al.*, 2002); concurrent engineering has been seen to yield many benefits. Its well-executed adoption supports a product innovation or quality focus (O'Leary-Kelly and Flores, 2002) and results in operational benefits such as reduced time to market, cost reduction, risk reduction, quality improvement and customer satisfaction that may lead to the ability to exact higher profits (Balasubramanian, 2001; Koufteros *et al.*, 2002). Arguably, it can also speed up the product development process, leading to a competitive advantage through higher profits, improved market share, and an increase in return on equity (Stevenson, 2002; Smith, 1997). Table 4 summaries product/process literature and highlights its links to 3DCE.

TABLE 4: COMPLEMENTARY PRODUCT/PROCESS LITERATURE (MODIFIED FROM ELLRAM ET AL. (2007))

Literature Stream	Contribution to 3DCE	Benefits	Contributing Authors
Product and Process	A close relationship exists between the best type of manufacturing process, the products volume and the nature of the product. Effectively linking these has been shown empirically to improve cost, quality, time, flexibility, delivery and customer service.	- Improved cash flow - Improved operating performance - Improved market share	(Safizadeh *et al.*, 1996; Ettlie, 1995; Kim *et al.*, 1992; Hayes and Wheelwright, 1979; Stevenson, 2002)
Concurrent Engineering	Links the process of product development, technology, organisational structure and communication channels to superior product development performance in the areas of time to market, development and product costs, quality and overall product performance.	- Supports product innovation and quality focus - Time to market reduction - Cost reduction - Improved customer satisfaction - Higher profits - Cost reduction	(Swink *et al.*, 2006; Balasubramanian, 2001; Koufteros *et al.*, 2002; O'Leary-Kelly and Flores, 2002; Fleischer and Liker, 1997)

Supply Chain/Product

In the 3DCE model, the supply chain/product overlap relates to product architecture and the make/buy decision. This can be seen to relate to integrating the following into the design process: early supplier involvement (ESI), listening to the voice of the customer and distribution channel design. Table 5 summarises supply chain/product literature and highlights its links to 3DCE.

The key to business success is to continually deliver products that satisfy customers through the design and management of supply chains (Christopher and Towill, 2001, 2002; Griffiths *et al.*, 2000). Through listening to customer voice, customer requirements can be turned into NPD goals that unify the entire NPD team across its cross functional boundaries (Swink, 1998). Literature, as suggested by the 3DCE model, reinforces the potential benefits of using the voice of the customer to integrate the downstream supply chain into the product development process.

Of the various new product development collaboration strategies a firm can adopt (e.g. competitor, customer, suppler, university), supplier collaborations - if properly executed - have the highest long term positive impact on product innovation (Un *et al.*, 2010). This is due to the narrow knowledge base provided. ESI focuses on the participation of suppliers in the early stages of the development process, such as idea and concept generation and product design phases. ESI has a positive impact on flexibility (Imai *et al.*, 1985; Clark and Fujimoto, 1991; Nishiguchi and Ikeda, 1996) and has been reported to be beneficial with regards to product effectiveness (product quality and cost), project efficiency (product development time and project cost) (Johnsen, 2009; Fujimoto *et al.*, 1996; Dyer and Singh, 1998) and is seen as a source of competitive advantage (Oh and Rhee, 2010; Birou and Fawcett, 1994; Clark, 1989) that leads to profitability (Birou and Fawcett, 1994), improved market adaptability (Song and Parry, 1997) and the development of new concepts and technologies (Langner and Seidel, 2009). Due to the important role that suppliers play, supplier selection is of the upmost importance and suppliers should be selected based on their technical superiority and cooperativeness with the aim of creating close working relationships (Hakanson, 1993).

Fine advocates that there is a definitive fit between product characteristics and supply chain structure; both downstream and upstream members play an important role. Marketing channels research has examined the fit between product characteristics and supply chain structure

(Bowersox, 1969; Anderson and Schmittlein, 1984; Williamson, 1975; John and Weitz, 1988; Klein *et al.*, 1990) and the fit between product characteristics and the design of the downstream channel, or supply chain including the presence of various intermediaries, has long been addressed (Coase, 1937; Williamson, 1975).

TABLE 5: COMPLEMENTARY SUPPLY CHAIN/PRODUCT LITERATURE (MODIFIED FROM ELLRAM ET AL. (2007))

LITERATURE STREAM	CONTRIBUTION TO 3DCE	BENEFITS	CONTRIBUTING AUTHORS
VOICE OF CUSTOMER	The customer is the ultimate judge of quality and product performance. Research supports that understanding and incorporating customer needs into NPD process decreases time to market and improved quality, as well as ensures the project's overall market success.	- Improved commercial success - Decreased time to market	(Morash *et al.*, 1996; Ettlie, 1997; Burchill and Fine, 1997; Swink, 1998; Keller, 1999; Christopher and Towill, 2001, 2002; Griffiths *et al.*, 2000; O'Leary-Kelly and Flores, 2002)
EARLY SUPPLIER INVOLVEMENT	Focuses on supplier participation in the initial stages of design and development which can lead to improved manufacturability, increased flexibility, decreased time to market, reduced relationship risk and improved product success.	- Reduced development costs - Reduced lead time - Improved design for manufacturability - Reduced relationship risk - Overall improvement in NPD success - Improved product innovation - Improved market adaptability	(Birou and Fawcett, 1994; Asmus and Griffin, 1993; Clark, 1989; Dyer, 1996; Hartley *et al.*, 1997; Culley *et al.*, 1999; Gadde and Snehota, 2000; Petersen *et al.*, 2005; Wagner and Hoegl, 2006; Johnsen, 2009; Schiele, 2010; Oh and Rhee, 2010; Un *et al.*, 2010; Langner and Seidel, 2009; Fujimoto *et al.*, 1996)
CHANNEL STRUCTURE/ DESIGN	The design and structure of the channel is important to overall product success. Current supply chain literature indicates that organisations competing as integrated network entities versus channel members have better performance.	- Higher profits for channel members - Lower prices for customers	(Anderson and Schmittlein, 1984; Coase, 1937; Bowersox, 1969; Williamson, 1985; John and Weitz, 1988; Johne and Snelson, 1988; Rao and McLaughlin, 1989; Klein *et al.*, 1990)

Process/Supply Chain

The process/supply chain overlap in the 3DCE model relates to the manufacturing system and the make-or-buy decision and execution. This link has been explored in literature relating to inventory control processes, with regards to the quantity of inventory that will be kept throughout the supply chain and where it will be stored (Evers and Beier, 1998); logistics systems, such as types of transportation and their impact on the supply chain (Carter and Ferrin, 1995); information exchange and information technology (Fine, 1998; Kopczak and Johnson, 2003); and manufacturing processes that convert raw materials into components and finished products (Childerhouse and Aitkey, 2000; Lee, 2002). Through the proper integration of manufacturing, inventory, logistics and information processes in the supply chain, inventory levels can be minimised, accuracy of information increased, channels of distribution and supplier and customer relationships improved and opportunities for revenue enhancement created. It has been found that agility in information, logistics and inventory systems within the supply chain play a crucial role in ensuring a rapid and effective response to customer demand (Cavinato, 2005; Krajewski and Wei, 2001; Moinzadeh, 2002; Sauvage, 2003; Smaros *et al.*, 2003; Simatupang and Sridharan, 2005). With low production costs being a mere order qualifier, agility or responsiveness in process and supply chain become an advantage (Christopher and Towill, 2001, 2002). Table 6 summaries process/ supply chain literature and highlights its links to 3DCE.

TABLE 6: COMPLEMENTARY PROCESS/SUPPLY CHAIN LITERATURE (MODIFIED FROM ELLRAM ET AL. (2007))

LITERATURE STREAM	CONTRIBUTION TO 3DCE	BENEFITS	CONTRIBUTING AUTHORS
LOGISTICS, INVENTORY, MANUFACTURING AND INFORMATION	Incorporates the bi-directional (customer-supplier) importance of information exchange, integration of process and inventory control in multi-echelon supply chains.	- Minimised inventory - Reduction in overall supply chain costs - Revenue enhancement - Increased accuracy of information - Improved channels of distribution - Improved supplier/customer relationships	(Simatupang and Sridharan, 2005; Sauvage, 2003; Smaros *et al.*, 2003; Davis, 1993; Carter and Ferrin, 1995; Evers and Beier, 1998; Fine, 1998; Jain *et al.*, 1991; Krajewski and Wei, 2001; Christopher and Towill, 2001, 2002; Childerhouse and Aitkey, 2000; Lee, 2002; Moinzadeh, 2002; Kopczak and Johnson, 2003)

2.1.4 ENVIRONMENTAL 3DCE

Fine (1998) pointed out that product development time can be reduced through 3DCE based practices, while still attaining competitiveness in cost, quality and features. In addition to supporting traditional product development goals, 3DCE has the potential to support organisational goals of creating more environmentally responsible products, processes and supply chains - which this research project investigates further. As is currently common eco-design practice, environmental considerations can be integrated in the product development process without the use of the 3DCE approach; however, this will likely result in the neglect of developing the advantages that can be attained from good supply chain design. Failure to explicitly integrate supply chain design as part of ENPD will likely result in increased costs and reduced performance (Ellram *et al.*, 2008).

Just as 3DCE can be broken down into its three foundation concepts (product-process-supply chain), environmental three dimensional concurrent engineering (E-3DCE), which is 3DCE with the added element of environmental considerations, can also be broken down into three founding concepts as shown in Figure 9. E-3DCE can be seen as being made up of eco-design, environmentally responsible manufacturing (ERM) and green supply chain design (GSCD); Figure 10 illustrates this through a version of the 3DCE model that has been adapted to show E-3DCE and its many ideas.

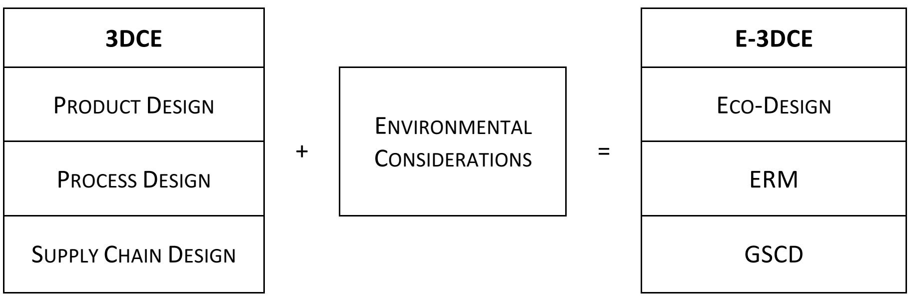


FIGURE 9: TRANSITION FROM 3DCE TO E-3DCE

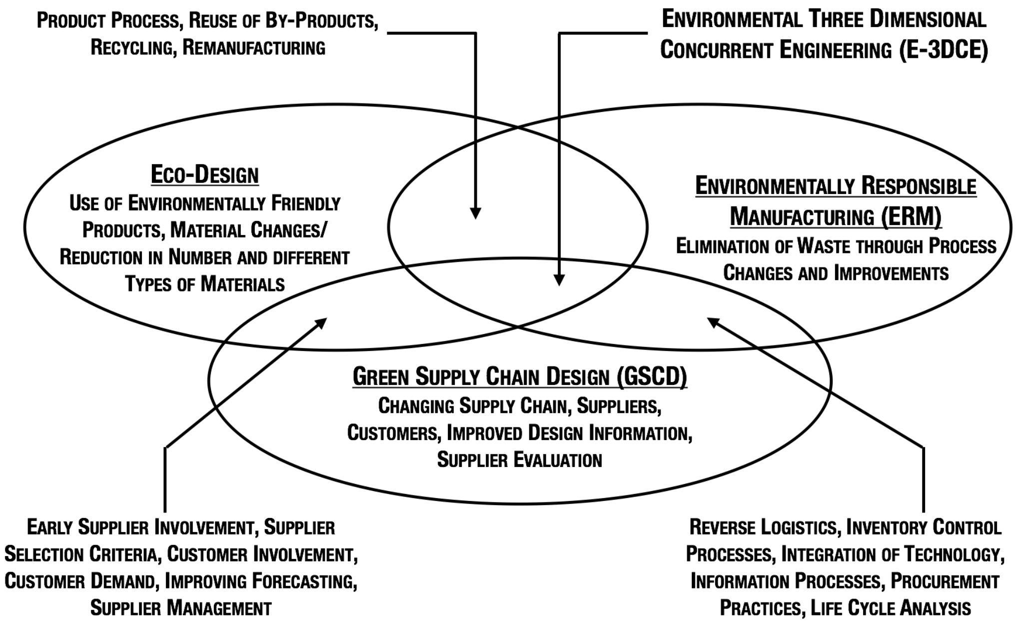


FIGURE 10: MODEL OF E3DCE (MODIFIED FROM ELLRAM ET AL. (2008))

It is also important to have an understanding of what happens when the 3DCE founding concepts (product, process and supply chain design) transition to the environmentally focused E-3DCE founding concepts (eco-design, ERM and GSCD).

Product Design vs. Eco-Design

While product design in the traditional product development process focuses on issues such as quality, design specification and performance (Koufteros *et al.*, 2002; Sroufe *et al.*, 2000a), in ENPD product design applies this focus to improving the environmental performance of a product through actions such as the use of fewer and more sustainable materials, reduction in through life environmental impacts and ease of disassembly and recycling (Sarkis and Rasheed, 1995; De Ron, 1998). Practicing eco-design can result in safer and less costly final products, which have higher, more consistent quality and greater scrap value (Porter and van der Linde, 1995). Eco-design takes a life cycle view, focusing improvement efforts on the areas of greatest environmental impact over the product's life cycle (Shrivastava, 1995; Sabatini, 2000; Starik and Rands, 1995; Nielsen and Wenzel, 2002a).

Process Design vs. Green Process Design (GPD)

While mainstream process development focuses on manufacturing methods, equipment, layout and capacity (Handfield *et al.*, 2001; Rao and Holt, 2005), ERM initiatives (which encompass GPD) also have to focus on processes that reduce waste. In this case, waste is defined as any activity that creates additional costs for the organization or consumes any type of resources without an offsetting benefit (Carter and Ellram, 2003; Safizadeh *et al.*, 1996) and its reduction can be accomplished through production process changes, operational improvements that reduce waste, and improved inventory management (Angell and Klassen, 1994; Sarkis and Rasheed, 1995; Starik and Rands, 1995; Sabatini, 2000). Adopting ERM can lead to improved process consistency, reduced downtime, and lower costs (Porter and van der Linde, 1995) while recyclable products can lower the user's disposal costs and lead to designs that allow companies to more readily recover valuable materials (Ellram *et al.*, 2008).

Supply Chain Design vs. Green Supply Chain Design

In addition to the traditional supply chain design focuses that mainly revolve around the make-or-buy decision, green supply chain design has extra initiatives that focus on the firm's activities outside the firm's boundaries. The main objective of green supply chain design is to extend the firms environmentally conscious practices to its supply chain in both up and downstream directions (Min and Galle, 1997; Walton *et al.*, 1998; Carter and Narasimhan, 2000a, b). This includes aspects such as the nature of supplier and customer relationships, delivery mechanisms and, in some cases, direct involvement by external stakeholders in order to gain the perspective of those outside of the firm's boundaries.

Applying 3DCE to ENPD

Moving on from there, it is paramount to gain an understanding of how these founding concepts, individually and collated (as E-3DCE) relate to 3DCE. A summary linking ENPD literature to product, process, design and 3DCE is provided in Table 7.

TABLE 7: COMPLEMENTARY 3DCE AND ENPD LITERATURE (MODIFIED FROM ELLRAM ET AL. (2008))

Environmental Lit. Stream	Relationship to 3DCE	Contributing Authors
Eco-Design	Eco-design takes a lifecycle view and focuses on making a product that uses environmentally friendly materials, fewer materials and mixes fewer materials together.	(O'Brien, 1999; Waage, 2007a; Shrivastava, 1995; Porter and van der Linde, 1995; Sarkis and Rasheed, 1995; De Ron, 1998; Starik and Rands, 1995; Sabatini, 2000; Nielsen and Wenzel, 2002a)
Green Process Design	Involves the reduction of the source of waste through production process and operational process changes including improved inventory management, procurement, and transportation. A sustainable process focus may result in improved process consistency and quality, reduced downtime, lower costs and lower waste.	(Sarkis and Rasheed, 1995; Starik and Rands, 1995; Sabatini, 2000; Angell and Klassen, 1994; Porter and van der Linde, 1995; Walton *et al.*, 1998; Pil and Rothenberg, 2003; Pohlen and Farris, 1992; Dault, 2002; Gungor and Gupta, 1999a)
Green Supply Chain Design	Focus on the impact of the firm's activities outside of the firm's boundaries including supplier involvement, evaluation, and audit, customer demands and concerns, stakeholder perspectives, ESI, and improved demand information. Consider the impact of incoming components as well as outgoing products.	(Klassen and McLaughlin, 1993; Min and Galle, 1997; Sarkis, 2003; Rao and Holt, 2005; Walton *et al.*, 1998; Carter and Narasimhan, 2000a, b; Handfield *et al.*, 2002; Carter and Carter, 1998; Hervani *et al.*, 2005; Chen, 2001)
Integration of Eco-Design, GPD and GSCD	Sustainable products and processes are designed simultaneously with supply chain member participation while giving consideration to the entire product lifecycle, from birth to regeneration. Conceptual benefits of integrating 3DCE and sustainability include reduced operating costs, competitive advantage, differentiation, improved image, reduced risks, and reduced compliance costs.	(Starik and Rands, 1995; Shrivastava, 1995; Sarkis, 2003; Hart, 1995a; Maxwell and van der Vorst, 2003; Manzini and Vezzoli, 2003)

The 3DCE-ENPD Link

Through the comparison of literature related to 3DCE concepts in the mainstream operations literature and in environmental literature, Ellram et al. (2008) noticed that despite the two streams developing with many parallels, there have been limited overlaps. Literature supporting 3DCE concepts focuses on traditional NPD performance improvements such as cost reduction, cycle time reduction, and inventory reduction while literature focused on the base components within E-3DCE focuses on reduction of environmental impacts and improvement of environmental performance. Where environmental impacts and traditional manufacturing goals such as quality have been studied together and applied in practice, it has been demonstrated that an environmental focus contributes to improved quality (Pil and Rothenberg, 2003).

The extensive overlap in approaches used to facilitate NPD and environmental considerations within the supply chain suggests that there is great potential for synergy from simultaneously considering traditional performance issues and environmental performance issues and in embracing 3DCE concepts. Initially, most organisations viewed, treated and managed environmental goals and traditional product environment goals separately (Handfield *et al.*, 2001; Handfield *et al.*, 2002), resulting in redundancy in the system and the duplication of efforts. However, this changed as organisations adopted a view that was more in accordance with ISO1400 – the view that ENPD involves the introduction and integration of environmental criteria within an existing system (ISO, 2011). Thus ENPD is viewed as both process-based, as environmental considerations are incorporated within the decision making process, and product-based, as physical adaptations are made to a product to reduce its environmental impacts (Ammenberg and Sundin, 2005). Duetz et al. (2013) reviewed eco-design in the UK manufacturing industry and found that the product development process is dependent on the product and organisation making it; while White et al (2008) in their study on approaches to sustainable design came to the conclusion that the integration of environmental aspects must be achieved across the multi-disciplinary product development process. The literature shows that there is a growing interest in more integrated approaches, making E3DCE worth investigating.

2.2 Theory and Practice

Broadly speaking, this research project aims to investigate the relative effects of supply chain design and supply chain information sharing within ENPD. Resultantly, following on from the understanding attained in the previous section, this section delves into the context in which product development and eco-design are practiced and the relationship between supply chain management and environmental new product development. Additionally, it explores supply chain information sharing, environmental information in the product development process and supply chain design as critical aspects of the ENPD process and relates ideas and theory to practice.

2.2.1 Product Development in Context

Multiple definitions of the product development process exist, based on modifications to definition proposed by Ulrich and Eppinger (1994), the following rounded definition is put forward:

> "A systematic series of steps or stages, composed of activities or tasks and supported by tools and techniques, for converting ideas into products of perceived value; typically beginning with the identification of a market opportunity and ending in the fulfilment of the market opportunity through the production and sale of a product."

The development of a product is a process within the internal processes of a company, which in turn are embedded in a product chain - the other actors have some role in producing, consuming, recycling, and disposing of the product - (Baumann *et al.*, 2002). This context within which product development occurs can be divided into three different levels. The first level deals with the product design and development phase of the product development process and its tools. The second level deals with the product development process as a whole, it is concerned with the company context and relates to the business strategy, management, marketing etc. The last level, the third level, deals with the product development process from a product chain perspective and includes interactions with suppliers, customers, waste handlers etc.

In its practice, much like most other business processes, there is no single way of characterising the product development process; its beginning and end are not always clear and its steps are not always discrete and distinct. To satisfy customer needs, the development of a product can be initiated, executed and concluded in numerous ways. A product development process is comprised of several distinct phases, with each phase accomplishing an important objective toward the end goal of commercial success. A generic product development process is illustrated in Figure 11; the presented process is based on some cited best-known methods (Belliveau *et al.*, 2002; Kahn *et al.*, 2005; Rafinejad, 2007). In this process, knowledge generation and integration proceed through a series of phases (each with a distinct purpose) until the product design and the process are qualified as satisfying the target market needs and as meeting business objectives.

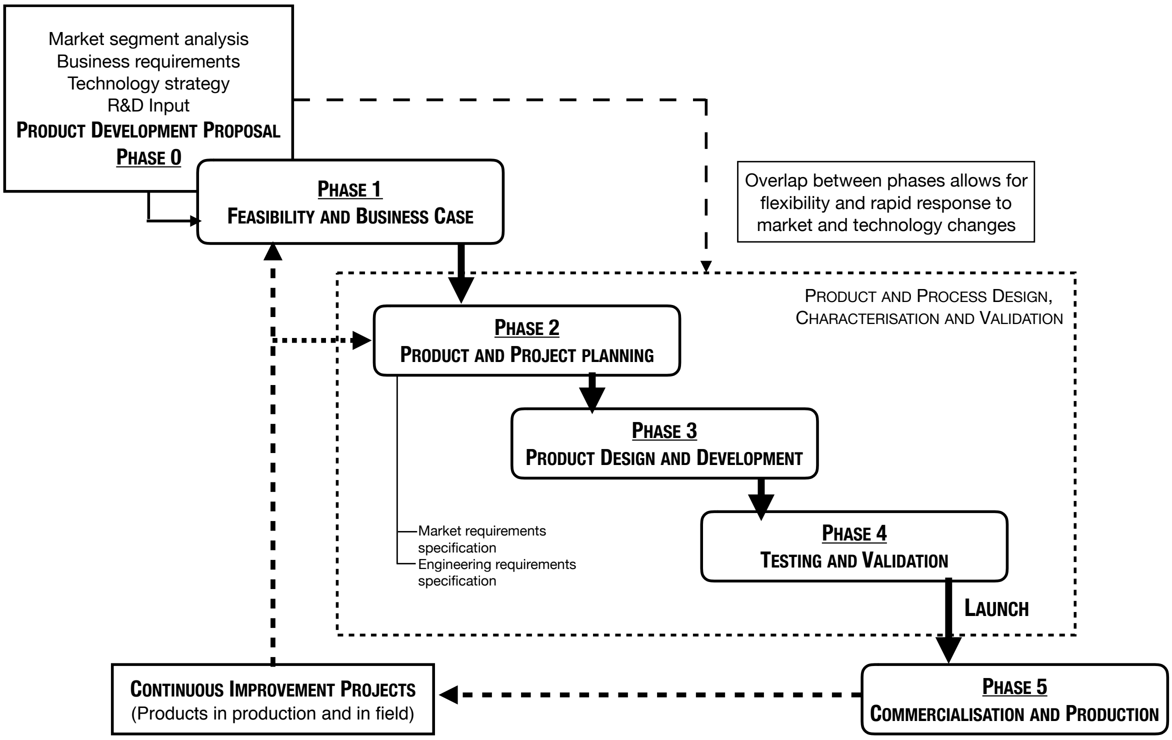


FIGURE 11: PRODUCT DEVELOPMENT PROCESS (MODIFIED FROM RAFINEJAD (2007))

Table 8 outlines the role that key organisational functions adopt during development process, and the general activities that they undertake. However, the contributions of the different key players change during each of the phases. To this effect, Table 9 outlines in detail the cross-functional tasks and responsibilities of the members associated with the organisational functions, during the different phases of the development process.

TABLE 8: KEY ORGANISATIONAL FUNCTIONS AND THEIR ROLE (MODIFIED FROM RAFINEJAD (2007))

	MARKET	DEVELOP	MAKE	SELL/SUPPORT
	MARKETING AND SALES	DESIGN AND ENGINEERING	PRODUCTION (MANUFACTURING AND SUPPLY CHAIN MANAGEMENT)	MARKETING AND SALES
ROLE AND RESPONSIBILITY	Strategic marketing (perceive opportunity and set direction)	Research and development; Innovation and technology development; Product design and development	Materials management; Manufacturing; Supply chain management	Commercialisation (introducing product into commerce)
GENERAL ACTIVITIES	Providing information on the market (during pre-development, development and post-development periods)	Definitions on the product and process design, and preparations for production; identifying new technologies, developing product; and process design technologies.	Preparing prototypes and pilot production; initiating full-scale commercial production; interacting with suppliers and supply development; and improving process capabilities and cost reductions in product process.	Marketing and selling the product; managing customer relations and distribution channels; managing product (including lifecycle management); and customer post-sale support
	OPERATING INFRASTRUCTURE (MANAGEMENT, HUMAN RESOURCES, HEALTH AND SAFETY, FINANCE)			

TABLE 9: PRODUCT DEVELOPMENT TASK LIST AND RESPONSIBILITIES (BASED ON FROM RAFINEJAD (2007))

NPD Phase		Organisational Function: Management	Marketing and Sales	Design and Engineering	Production
Feasibility and Business Case		Create preliminary project plan; Assign phase managers; Allocate resources; Approve phase exit and authorise next phase	Articulate market opportunity; Define market segments; Determine commercial viability; Develop preliminary MRS	Determine phase tasks and deliverables; Create preliminary ERS; Define product architecture ; Assess new technologies; Conduct phase review	Identify production constraints; Assess production feasibility; Create supply chain strategy
Exploration and Feasibility Review					
Project and Product Planning		Monitor progress; Create product project plan; Manage project communications; Allocate resources; Approve phase exit and authorise next phase	Finalise MRS; Develop product business plan; Collect customer needs; Identify competitive products; Develop co-development and beta customer plans	Determine tasks and deliverables of subsequent phases; Finalise ERS	Prepare manufacturing plan for product development and production roadmap; Prepare materials and supplier sourcing plans
Planning Review					
Product Design and Development	Concept Development	Monitor progress; Manage project communications; Allocate resources	Update product business plan; Develop product release and launch strategy	Update phase tasks and deliverables; Develop product concepts; Investigate feasibility of concepts; Perform modelling, simulation and trade off studies; Design, build and test bench prototypes; Prepare product cost breakdown; Perform risk analysis; Conduct product concept review	Support bench prototype builds as required; Identify suppliers for key components; Estimate manufacturing cost
	Concept Review				
	High Level Design	Monitor progress; Manage project communications; Allocate resources	Develop plans for product options and extended family; Set target sale price point(s)	Generate alternative product architectures; Define major subsystems and interfaces; Refine design; Prepare preliminary test plan and exit criteria	Design for manufacturability input; Define final assembly scheme; Establish global ramp-up plan; Perform make-buy analysis; Set target costs; Develop supplier management strategy
	Detail Design	Monitor progress; Manage project communications; Allocate resources; Approve phase exit and authorise next phase	Select beta-customers and prepare agreement	Define part geometry; Choose materials; Assign tolerances; Prepare detailed design documentation; Conduct critical design review; Finalise test plan and exit criteria; Characterise design and prototypes vs ERS; Update design documents and finalise bill of materials; Create preliminary spare parts list; Conduct phase review	Define piece-part production process; Define quality assurance processes; Develop manufacturing facilities and tools; Begin procurement of long-lead tooling; Verify supplier's design and performance; Assess product manufacturability; Prepare product should-cost estimates with Design and Engineering; Supplier sourcing; Preliminary supplier selection; Develop suppliers and negotiate contracts; Finalise packaging, assembly sequence and flow layout; Update manufacturing and sourcing plans; Prepare detailed manufacturing documentation
Design Maturity Review					
Testing and Validation		Monitor progress; Allocate resources; Manage project communications; Approve manufacturing and supplier plan, including build plan; Approve phase exit and authorise next phase	Develop promotion and launch materials; Define product baseline configuration, models, and options; Publish product specifications; Prepare launch project plan; Develop sales plan; Facilitate field testing	Update phase tasks and deliverables; Prepare product configuration tree; Reliability, life and performance testing; Obtain regulatory approvals; Identify and implement design changes; Release product documentation to Production; Conduct phase review	Refine fabrication and assembly processes; Train workforce; Refine quality assurance processes; Finalise supplier selection; Facilitate supplier ramp-up; Build and test beta units ; Perform build verification; Finalise manufacturing and sourcing plans and contracts; Finalise product should-cost estimates
Ready to Launch Review					
Commercialisation and Production		Manage project communications; Monitor progress; Allocate resources; Approve product life cycle roadmap; Run overall post-mortem	Launch product; Manage product cost, cost of ownership, profit margin, and market penetration; Validate probability and market share targets	Update phase tasks and deliverables; Support Marketing, Customer Support, Production, and Materials teams as required; Evaluate early production output	Map materials resources planning; Manage pilot production run; Execute manufacturing plan; Execute sourcing plan; Issue purchase orders; Goods reception; Begin operation of entire production system; Validate cycle time, quality, and cost targets to materials resource specification; Maintain customer support; Supplier evaluation
Project Review					

2.2.2 *Eco-Design in Context*

Although traditionally, the design process itself consumes few resources, about 15% of manufacturing costs, it is responsible for committing the remaining 85%; in a wider context, product design might be considered responsible for most, if not all, environmental impacts (Knight and Jenkins, 2009). Resultantly, sustainable product design is considered one of the most important practices for achieving sustainability (Chen *et al.*, 2012; Lindahl, 2006; Lewis and Gertsakis, 2001; BSI, 2002). In the specific case of the design process, this involves the adoption of 'eco-design' or 'design for environment' techniques. Through eco-design, environmental considerations can be introduced early in the product design process, allowing for the reduction of environmental impacts (Cerdan, 2009). Eco-design can be defined as ''the systematic integration of environmental considerations into product and process design'' (Knight and Jenkins, 2009). Eco-design adopts a product lifecycle perspective where the product being designed is evaluated from the cradle (raw material extraction) to the grave (disposal of product at end-of-life). Eco-design differs from 'design for the environment' in that it represents a shift from waste management and end-of-pipe solutions to a focus on the products themselves throughout their entire lifecycle (Lewis and Gertsakis, 2001), this lifecycle perspective is presented in Figure 12.

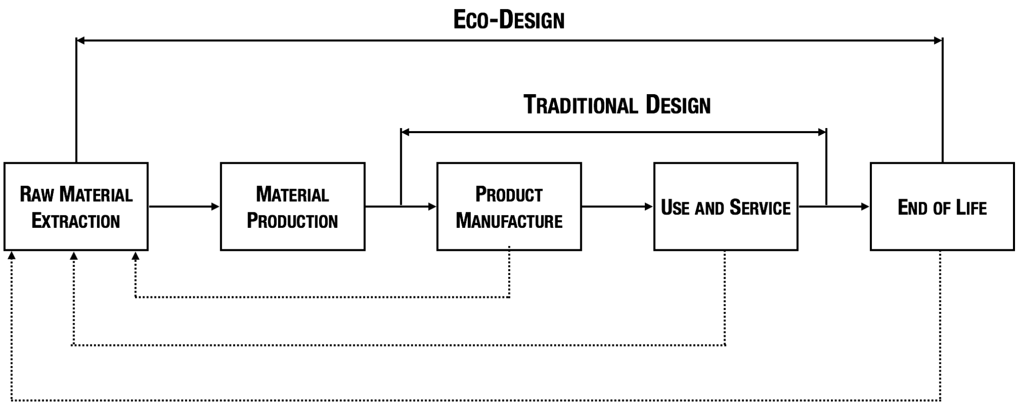


FIGURE 12: PRODUCT LIFECYCLE PERSPECTIVE ADOPTED DURING ECO-DESIGN COMPARED TO TRADITIONAL DESIGN (MODIFIED FROM LEWIS AND GERTSASKI (2001))

While eco-design aims to minimise the "adverse environmental impacts of products throughout their entire life cycles'' (ISO/TR14062, clause 4), it should be noted that it only adds environmental considerations to product design and stops short of full sustainable design; sustainable design incorporates social and ethical aspects (Maxwell *et al.*, 2006). Understanding of what eco-design actually is in practice has now developed to the point where it has recently been described as ''not a specific method or tool'' but rather a ''way of thinking and analysing.'' (Lindahl, 2006). In practice, this way of thinking and analysing takes various eco-design methods, as might be appropriate, and applies them to each of the different levels of the design process shown in Table 10.

TABLE 10: LEVELS OF PRODUCT DESIGN (FROM FERRENDIER AND MATHIEUX (2002))

	LEVEL	DEFINITION
LEVEL 1	Product Improvement	Progressive and incremental improvement of the product, e.g. through re-styling using fewer materials
LEVEL 2	Product Redesign	A new product design, on the basis of an existing product
LEVEL 3	New Product Concept Definition	An innovation 'rupture' (as technical functions to fulfil product functionality are different)
LEVEL 4	New Production System Definition	Occurs when innovation in the production system is necessary

Eco-Design Methods and Tools

From an environmental point of view, a company's conventional product design process can be improved upon by applying appropriate eco-design methods and tools, the scope of which depends to a large extent on the specific objectives of the company (Cerdan, 2009; Knight and Jenkins, 2009). Within the field of eco-design research the terms "tool" and "methods" are often used interchangeably and are typically used to describe any systematic means to deal with environmental issues during the product development process (Baumann *et al.*, 2002; Byggeth and Hochschorner, 2006; Pigosso *et al.*, 2010); they include design strategies, methodologies and techniques. In order to be effective, the chosen methods need to be based on a sound foundation in design and engineering ''that is also integrated with the environmental sciences'' (Karlsson and Luttropp, 2006).

Since the early 1990s, various methods and tools have been developed to evaluate the environmental impact of products and to improve the development process and environmental performance of products. There is a large body of scientific literature devoted to discussing the different viable methods and tools for eco-design. Comprehensive reviews of these tools are available in literature, most notably in Baumann et al. (2002), Knight and Jenkins (2009) and Pigosso (2012). For example, Pigosso (2012) and Baumann et al. (2002) identified and examined over 100 and 150 methods, respectively.

Table 11 presents an overview of existing eco-design tools and methods, categorised by type.

TABLE 11: OVERVIEW OF ECO-DESIGN TOOLS AND METHODS

CATEGORY	DESCRIPTION	EXAMPLES
FRAMEWORKS	General ideas about what should guide the environmental considerations in the product development process. Frameworks often come with a 'toolkit' or guidelines and strategies.	Design for Disassembly –designing a product so that at the end of its life it can be easily, cost-effectively and rapidly taken apart (Boothroyd and G. Alting, 1992).
		Design for Remanufacturing – designing a product so that at the end of its life it can be easily, cost-effectively and rapidly taken apart and its components used in new products (Zwolinski *et al.*, 2006).
		Design for Recycling – designing a product so that at the end of its life it can be easily, cost-effectively and rapidly taken apart and its components recycled (Gaustad and G.Olivetti, 2010).
CHECKLISTS AND GUIDELINES	Qualitative tools that list issues to consider during the product development process; they are used to check whether requirements are fulfilled or not.	Ten Golden Rules – ten of the most common issues that must be addressed in eco-design (Luttropp and Lagerstedt, 2006).
		Smart Eco-Design: Eco-Design Checklist – a list of eco-design must-does (Clark and Adams, 2002).
RANKING AND RATING TOOLS	Relatively simple quantitative tools that provide a pre-specified scale for assessment.	Eco-Compass – a comparative tool to evaluate one existing product with another, or to compare a current product with new development options (Fussler and James, 1996).
		Sustainability Radar (STAR*) – combines metrics that describe the three dimensions of sustainability: eco-efficiency, social productivity and sufficiency (Hockerts, 1999).
ANALYTICAL TOOLS	Comprehensive quantitative tools for evaluating and measuring the environmental performance of products.	Lifecycle Assessment (LCA) – process to analyse the environmental burdens associated with the entire life cycle of a product or service, 'from the cradle to the grave' (Tischner, 2000; Hauschild *et al.*, 2005; Donnelly *et al.*, 2006).
		Material, Energy and Toxicity (MET) Matrix – a tool which can be used to summarise the environmental impact at each stage of a product's lifecycle (van Berkel *et al.*, 1997).
SOFTWARE AND EXPERT SYSTEMS	Tools that can handle large amounts of environmental information while being as quick to use as some of the simpler tools; developed as a way of avoiding the need for elaborate data collection or environmental expertise.	Product life cycle planning (LCP) – a methodology to help the designer establish an eco-design concept of a product and its life cycle by assigning appropriate life cycle options to the product components (Kobayashi, 2005).
		D4N – a tool to analyse the products' life cycle and provide guidelines for product redesign (Murtagh *et al.*, 1999).
		Environmental design industrial template (EDIT) – a tool to evaluate the design of products in terms of their 'end-of-life' effects and to help in developing suggestions for improvement (Spicer and Wang, 1997).
ORGANISATION TOOLS	Tools that give direction on how to organise e.g. a sequence of tasks or the co-operation of certain business functions and stakeholder. They include tools that guide eco-design implementation.	Eco-Design Maturity Model – a management framework with a step by step approach aiming to support companies in carrying out eco-design implementation (Pigosso *et al.*, 2013).
		The Access-Bridge-Create-Diffuse (A-B-C-D) Framework – eco-design implementation best practices (White *et al.*, 2008).
		Product Oriented Environmental Management Systems (POEMS) – approaches that encourage a structured environmental management approach that is underpinned by a lifecycle approach (Salomone *et al.*, 2013; Ammenberg and Sundin, 2005).
STRATEGIC TOOLS	Tools to identify and assess various factors relating to future products	Eco-Roadmap – a graphical tool that captures short- and long-term environmental drivers and customer requirements in one document (Donnelly *et al.*, 2006).
		Environmental Impact Assessment – assessment of environmental consequences (Fuller, 2005).
		Lifecycle Development Strategy (LiDS) Wheel – visualisation of the strategies that can be followed for eco-design (Brezet and Van Hemel, 1997)
ECO-INNOVATION TOOLS	Tools that are used when attempting to deliver new products and significantly decrease environmental impacts.	Toolbox for Eco-Innovation – existing innovation tools adapted for eco-innovation (O'Hare, 2010) Tools for Early Stage Eco-Innovation – simplified TRIZ tools for eco-innovation (Dekoninck *et al.*, 2007)

While the other tools can be relatively easy to use, the software and expert systems that are currently available are either too qualitative/subjective to be used by designers with limited experience, or too quantitative, costly and time consuming (Sakao *et al.*, 2008; Boks, 2006). Moreover, these tools are usually stand-alone and do not allow for easy integration with traditional design tools. The shortcomings of these tools mean they fail to offer practical solutions for day-to-day use in design and engineering departments and they only achieve limited industry penetration (Lofthouse, 2006). When developing tools, it is paramount that they can be integrated with other design tools, such as CAD, or that they are compatible with the way in which designers works, allowing them to make ecological design choices without losing sight of cost and other typical constraints seen in NPD in industry. In addition, there is a need for a strategic and systematic approach towards eco-design implementation, highlighting the importance of understanding the business context (Domingo *et al.*, 2015; Buckingham *et al.*, 2014).

Integrating Environmental Considerations into the NPD Process

Three key objectives are typically used for decision making in the traditional approach to product development: product performance, product cost, and development cost (Magrab *et al.*, 2009; Dasu and Eastman, 2012; Annacchino, 2003). However, the need to shorten the time to market, which resulted in 3DCE, also resulted in a fourth objective of development speed being added (Kaebernick *et al.*, 2003). When transitioning to ENPD an additional objective is required, environmental performance. This results in a trade-off model where five key design objectives have to be balanced against each other. Adopting this view aids in the attainment of full environmental requirement integration into the development process if they are given the same importance rating as all the traditional objectives.

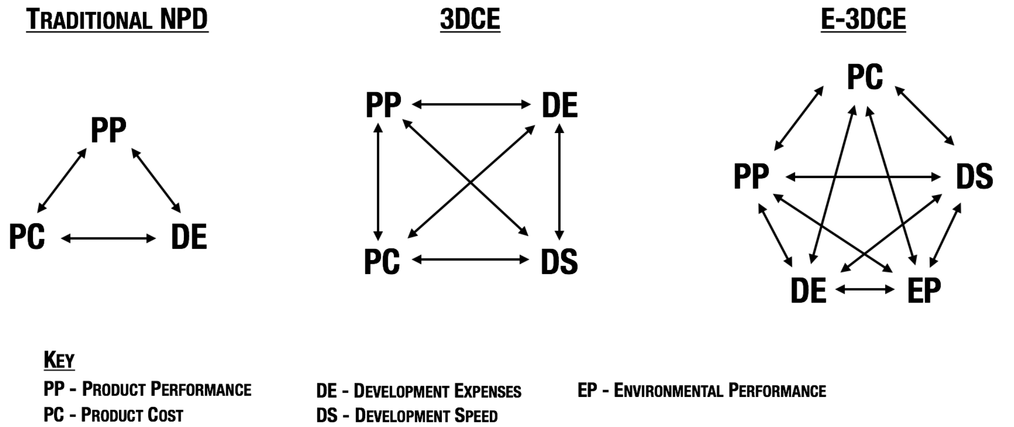


FIGURE 13: PRODUCT DEVELOPMENT TRADE OFF MODEL (MODIFIED FROM KAEBERNICK ET AL. (2003))

Significant environmental improvements can often be achieved by integrating environmental properties as an optimisation parameter in product development together with more traditional values such as production costs, functionality, aesthetics etc. One method that allows for this is that by Nielsen and Wenzel (2002b), illustrated in Figure 14 which takes its starting point in traditional procedures for product development and shows step-by-step how the environmental properties of the new product can be optimised and thus contribute to the overall competitiveness of the new product. It is based on quantitative lifecycle assessment to identify 'hotspots' in a reference product's lifecycle and to select new environmentally optimised solutions for a new product. The main steps in the product design and development phase are based on those commonly outlined in literature (Pahl and Beitz, 1991; Ulrich and Eppinger, 1994; Cross, 2008; Shigley, 2004; Pugh, 1991). The global view implicit in LCA makes it possible to address the environmental issues beyond the local boundaries of the product manufacturing phase.

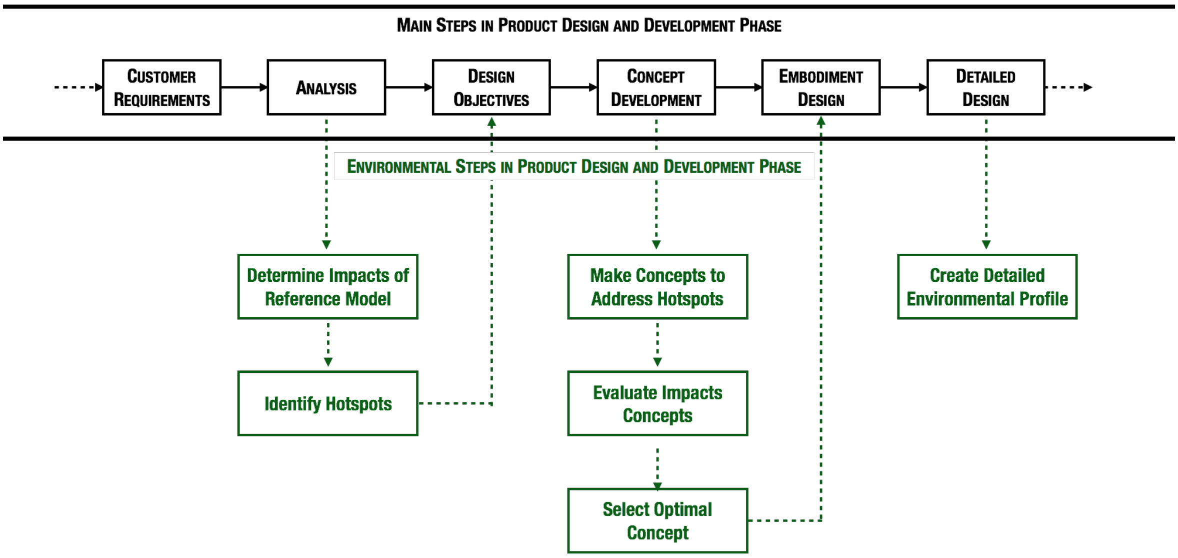


FIGURE 14: ENVIRONMENTAL PERFORMANCE STEPS INTEGRATED INTO NPD PROCESS (MODIFIED FROM NIELSEN AND WENZEL, (2002B))

Supply Chain Design within ENPD

Figure 15 shows the main supply chain related actions that typically occur during the product design and development phase. These are actions that are undertaken by the function within the organisation that is responsible for dealing with supply chain management. Within these actions are those that are particularly related to supply chain design; namely supplier sourcing and supplier selection. In Figure 16, these supply chain related actions integrated into the product design and development phase along with environmental performance steps.

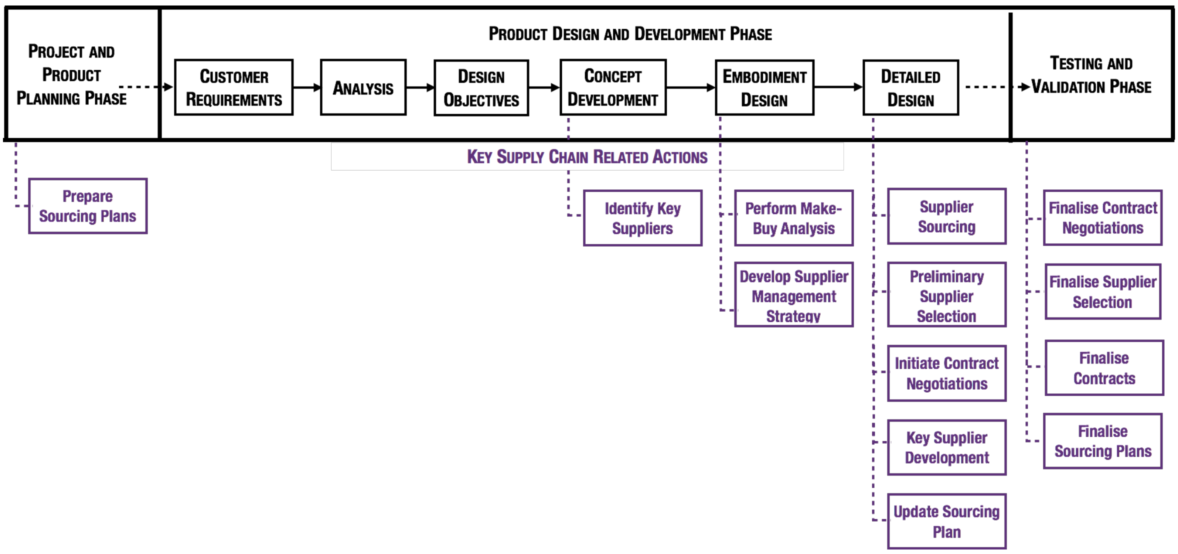


FIGURE 15: SUPPLY CHAIN RELATED ACTIONS DURING PRODUCT DESIGN AND DEVELOPMENT PHASE (BASED ON RAFINEJAD (2007))

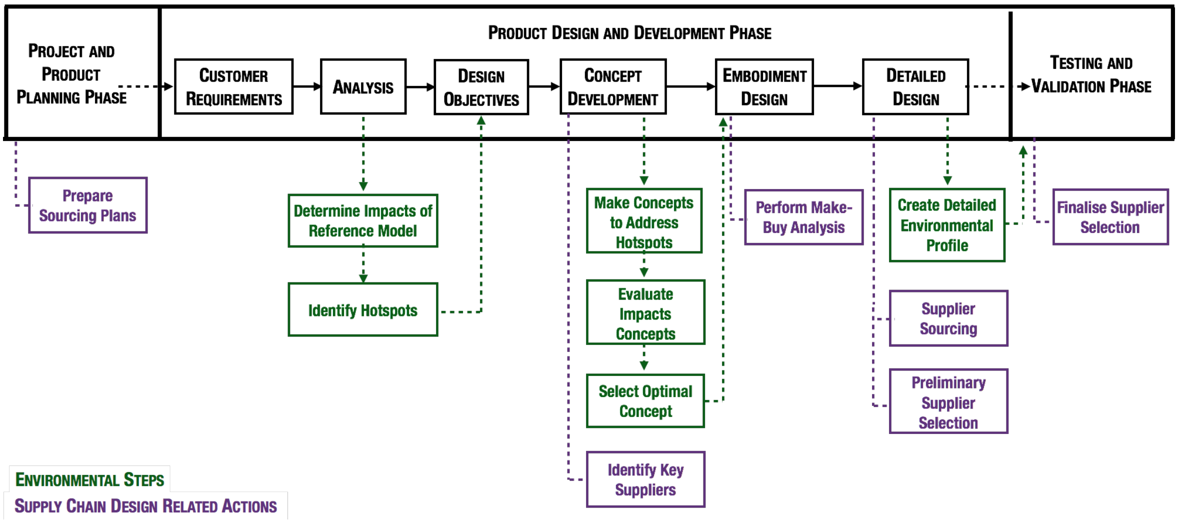


FIGURE 16: SUPPLY CHAIN DESIGN RELATED ACTIONS DURING AND ENVIRONMENTAL STEPS DURING PRODUCT DESIGN AND DEVELOPMENT PHASE (BASED ON RAFINEJAD (2007) AND NIELSEN AND WENZEL (2002B))

While there are a plethora of methods and tools aimed at various aspects of eco-design, what appears to be lacking are tools and methods that bridge the different levels (phase, process and product chain – see Section 2.2.1) and have a particular emphasis on maximising the role and input of suppliers. While there are a number of methods that incorporate suppliers, there aren't those that adequately incorporate the supply chain in ways that include environmental considerations.

2.2.3 Green Supply Chain Management

As with the quality revolution of the 80s and the supply chain revolution of the 90s, it has become clear that best practices call for the integration of environmental management into ingoing practices (Srivastava, 2007a). Green supply chain management (GSCM) is a practice that has been increasing in popularity among researchers and practitioners of operations and supply chain management. It aims to address the influence and relationships between supply chain management and the natural environment and has its roots in supply chain management and environmental management literature. Its importance is driven mainly by the deterioration of raw material resources, the increase in pollution and overwhelming waste sites. However, it is about more than just being environmentally conscious and friendly. It is also about good business sense and the attainment of the same, if not higher profits. GSCM is not a cost centre but rather, a business value driver (Wilkerson, 2005). Additionally, GSCM is being driven by consumer pressures and regulatory requirements.

GSCM includes a wide range of activities, spanning from reactive monitoring of general environmental programmes to more proactive practices performed through various Rs (Reduce, Reuse, Refurbish, Recycle, Rework, Remanufacture, etc.). GSCM aims to address the influence and relationships between supply chain management and the natural environment and has its roots in supply chain management and environmental management literature. As with supply chain management, the boundary of GSCM is dependent on the goal of the practitioner. Within literature, its definition has ranged from green purchasing to integrated green supply chain flowing from supplier to manufacturer to customer and even reverse logistics (Zhu and Sarkis, 2004). GSCM can be defined as 'integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of final product to the consumers as well as end-of-life management after its useful life' (Srivastava, 2007a).

Green supply chain design is a relatively young field that has a depth of literature associated with it. Comprehensive reviews have been published on repairable inventory (Guide and Srivastava, 1997c, a), green design (Zhang *et al.*, 1997), production planning and control for remanufacturing

(Bras and McIntosh, 1999; Guide, 2000; Guide and Srivastava, 1997b), reverse logistics (Carter and Ellram, 1998; Fleischmann *et al.*, 1997), logistics network design (Fleischmann *et al.*, 2000; Jayaraman *et al.*, 2003; Fleischmann *et al.*, 2001) and issues in green manufacturing product recovery (Guide *et al.*, 1996; Gungor and Gupta, 1999b). Additionally, sufficient literature related to areas of green purchasing (Zhu and Geng, 2001), industrial ecology and industrial ecosystems exists (Bey, 2001; Zhu and Sarkis, 2004; Boustead, 1979; Zhang *et al.*, 1997; Cairncross, 1992; Van Hoek, 1999; Graedel, 2002; Sarkis and Cordeiro, 2001; Hui *et al.*, 2001; Klassen, 2001; Min and Galle, 2001; Sarkis, 2001a). Roy and Whelan (1992) contribute with their work on recycling through value-chain collaboration, as do Bloemhof-Ruwaard et al (1995) when they deal with interactions between operational research and environmental management, Min et al (1998) and Lippmann (1999) when they discuss combined location-routing problems and elements for success in GSCM and Dowlatshahi's (2000) theory of reverse logistics.

According Gupta and Kumar (2013), GSCM practices provide the potential for cost savings, improved efficiency and attracting new suppliers and customers. In addition, they explained that specific reasons for adopting GSCM practices include improved brand reputation, compensating for global warming and increasing energy and commodity prices as well as improved supply chain integration. According to Koh et al. (2012), eco-product design implies effective use of materials and waste reduction; this can lead to better costs for the organization and better use of materials can positively impact environmental performance while eco-designed products can lead to improved brand image. A similar argument applies to eco-packaging design which is typified by reusable and recyclable packaging, waste minimization by means of reduced packaging and reduction or elimination of hazardous material in packaging (Carter and Carter, 1998; Walker *et al.*, 2008; Large and Thomsen, 2011; Buyukozkan and Cifci, 2012). Similarly, regulatory practices typically involve the reduction or elimination of hazardous materials in products and packaging and well as the adoption of recycling, reuse and environmentally-friendly disposal (Hitchcock, 2012) and these can all impact cost, company/brand image and the environment.

Green Sourcing

Green sourcing is one of the more accepted dimensions of GSCM practice. Lee (2008) suggests that buying organisations with green supply chain initiatives will pay attention to the green practices of their suppliers, especially small and medium enterprises. To ensure that suppliers meet their environmental objectives, the buying firm may deploy collaboration based activities including training environmental information sharing and joint research. It is also possible for organisations to adopt less collaborative approaches by simply demanding that their suppliers adopt environmental systems such as ISO14001. Heras-Saizarbitoria et al. (2011) and Vachon (2007) identified external motivators, particularly customer pressure, as key drivers of the adoption of ISO14001. Other green sourcing aspects that have been discussed in the literature include making the promotion and use of outputs of recycling, reuse and resource reduction part of the sourcing process (Large and Thomsen, 2011; Diabat and Govindan, 2011). There is evidence that some organisations adopt a compliance and evaluative approach to the GSCM practices of their suppliers. This involves evaluation of suppliers based on environmental criteria and a requirement for suppliers to develop and maintain some form of environmental management system (EMS) (Zhu *et al.*, 2012; Zhu *et al.*, 2005; Large and Thomsen, 2011; Min and Galle, 2001).

Performance Measures

The growth in the adoption of green practices is, in part, due to the effect of institutional pressures driven by regulatory and market demands (Curkovic *et al.*, 2000; Kumar and Putnam, 2009; Srivastava, 2007a). In their study, Zhu and Sarkis (2007) found that economic performance remains the top priority for manufacturers, in particular those in developing economies. There have been a number of studies that have attempted to link GSCM practices with organisational performance. Studies such as De Giovanni and Esposito Vinzi (2012) and Huang (2012) showed that there is no significant relationship between organisational performance and environmental practices; while those by Zhu and Sarkis (2004), Rao and Holt (2005) and Green et al (2012) found positive relationships. On the other hand, Azevedo et al. (2011) and Wu and Pagell (2011) found a mixed picture.

GSCM literature evidences that there is a lack of consensus on the impact of GSCM on performance outcomes. This has been recognised and discussed in a number of studies including those by Eltayeb et al. (2011) and Zhu et al. (2012). Zhu et al (2012) argue that these conflicting findings have the potential to become a barrier for organisations that intend to implement GSCM. Azevedo et al (2011) suggest that the type of green supply chain practices implemented can impact performance differently, Koh et al (2012) suggest that implementing GSCM practices in different stages can result in different performance outcomes and Zhu et al (2012) put forward that there are a variety of performance measures in use and this variation leads to complex relationships between practices and outcomes.

Murphy and Poist (2003) mentioned, in common with some of these findings, that there is a lack of unified framework about green practices. This lack of uniformity is clear in the literature. While studies such as such as Wu et al. (2011) claimed that green practices include cleaner production, green design, green purchasing and green innovation, others such as Diabat and Govindan (2011) argued that GSCM practices comprise green design, reducing energy consumption, reusing/recycling material and packaging, reverse logistics and environmental collaboration in the supply chain. Zhu et al. (2005) suggested that green practices include the sale of excess inventory, sale of scrap and used material, environmental auditing programs, commitment from senior managers and total quality environment management. Their study separated eco-design into product-related and packaging-related eco-design practices and also categorised green performance measures into environmental performance, economic performance, and intangible performance and included two control variables, low-cost business strategy and quality/time-based business strategy – to explain the variation in performance due to a firm's strategic focus.

Product Design

Buyukozkan and Cifci (2012) identified the importance of eco-design when they revealed that about 80% of product related impacts in the environment can be influenced during product design. Min and Galle (2001) suggested that cost saving opportunities at the beginning of the supply chain tend to be greater and that buying organizations need to actively seek opportunities to utilize recycled and reused components. Wu et al. (2011) took this further by stressing that the environmental impacts of a product occur at all stages of its lifecycle and they identified lifecycle assessment as a commonly used attribute of GSCM. Building on the theme of lifecycle impacts, Field and Sroufe (2011) noted that one of the sources of recycled materials is post-consumer waste. This research implies that it is important that organisations ensure that their products are made of contents that can be recycled or reused.

2.2.4 Supply Chain Design

Supply chain design involves the decisions about number of suppliers, supplier selection and evaluation, proximity to suppliers, planned capacities in each facility, definition of contractual terms, and reactions to the possible disagreements between channel members (Chopra and Meindl, 2007). As an example, supplier selection and evaluation has been a primary concern in the development of world-class manufacturers. The just-in-time philosophy supported the few supplier strategy and stressed the importance of selecting the best suppliers and establishing long-term relationships with those suppliers. Similarly, supplier capacities and locations have some degree of impact on the effective management of supply chains. Despite the significance of design issues in a supply chain, there seems to be a lack of attention on this in the academic literature although there are studies dealing with some individual dimensions of supply chain design, such as location factors, supplier selection, etc. (Bhatnagar and Sohal, 2005; Chen *et al.*, 2006). In their study, Bhatnagar and Sohal (2005) investigated the relationships between location factors and manufacturing performance. The location factors in their study are only one individual dimension of supply chain design. Several other factors exist, such as supplier selection, capacity planning, sufficiency of distribution channels, etc. These factors can be considered as the other dimensions of supply chain design.

2.2.5 *THE SUPPLY CHAIN AND THE NPD PROCESS*

Increasing reliance on external resources is a trend that can be observed in NPD processes. Handfield and Lawson (2007) conducted a study with 134 industrial firms and proposed that early supplier integration (ESI) in product development is an important coordinating mechanism for decisions that link product design, process design, and supply chain design together. Lack of integration with suppliers can result in problems concerning the continuity and the quality of supplies, which are crucial factors for companies. Their analysis showed that there can be major benefits for companies through coordination and the sharing of concepts and information in achieving agility (Khan and Creazza, 2009). It is necessary to improve misalignment between product design and the supply chain in order to leverage supply chain capabilities, enhance the effectiveness of new product launch and improve firm performance (van Hoek and Chapman, 2006). The alignment between NPD and SCM has been suggested to lead to an improvement in supply chain performance (Caprice and Sheffi, 1994); while design plays a strategic role which impacts the total supply chain (Abecassis - Moedas, 2006; Ragatz *et al.*, 1997). Pero et al. (2010) state that in order to achieve alignment, firms may not only match product features with the supply chain, but also long-term (supply chain configuration and collaboration) and short-term decisions (supply chain coordination).

2.2.6 *SUPPLY CHAIN MAPPING*

Supply chain mapping involves gathering, organising and presenting data visually to facilitate analysis of a supply chain (Lambert *et al.*, 2008). A supply chain map can be described as a visual representation of the flows of information, processes and money in both the upstream and downstream directions and through a firm (Gardner and Cooper, 2003). Due to its external focus, supply chain mapping can be viewed as the opposite of process mapping, where process mapping directs its attention to a single operation or system within a company. Supply chain awareness refers to having an understanding of the supply chain and its core processes and problems as oppose to only understanding and focusing on your company's problems and neglecting the effects your company has on the entire system (Holweg and Bicheno, 2002).

A strategic supply chain map is distinguished by its direct tie-in to corporate strategy; strategic supply chain mapping occurs in conjunction with the creation of a supply chain strategy or to ensure that the current supply chain conforms to the strategy already in existence. A strategic supply chain map is linked to strategic planning for the firm and for the supply chain. The map is a tool to help visualize the supply chain as it is and as it can be. Various authors have put forward compelling arguments supporting the benefits of strategically mapping the supply chain. Amongst other benefits, a well-executed map can enhance the strategic planning process, aid supply chain risk management, ease distribution of key information, facilitate supply chain redesign or modification, clarify channel dynamics, provide a common perspective, enhance communications, enable monitoring of supply chain strategy, and provide a basis for supply chain analysis (Gardner and Cooper, 2003; Lambert *et al.*, 2008; Farris, 2010; Roy, 2011).

Supply chain maps come in a number of shapes and styles and their focus could be on a particular use or user, on a theme such as a type of value added, or generic, covering all aspects of supply chain structure (Gardner and Cooper, 2003). Supply chain maps may or may not depict geographical relationships, individual organizations may be named or grouped, they may include multiple business processes in their visual display, or not. There are a number of supply chain processes that could be included in a map (Lambert *et al.*, 2008). Gardner and Cooper (2003) discussed about 14 examples of different mapping approaches and Farris (2010) presented solutions to some of the supply chain mapping issues identified by Gardener and Cooper.

While there are compelling reasons to produce strategic supply chain maps, there are some concerns that firms must address before publishing such a map, either internally or externally.

These risks include giving away competitive information, changing the chain dynamics, getting lost in too many details, and providing an ineffective perspective for management use (Farris, 2010; Gardner and Cooper, 2003).

Supply chain mapping is not a new process, however it is not thought to be as widely understood or developed as perhaps it could be (Roy, 2011). Independent research by Achilles indicated that 40% of businesses procuring only in the UK have information on Tier 2 suppliers and 18% had information about their Tier 2 suppliers across the world, it also found that only 8% of global procurement teams have mapped their company's supply chain for all the products that they supply, with this falling to 4% for businesses with 1,000 or more employees (Olivie, 2013). Supply chain maps may be linked to, or built directly from a database, or they can be built by hand (Gardner and Cooper, 2003). 2014 saw a 7.3% increase in the market for supply chain management and procurement software as companies looked to technology to help them manage their supply chains (Achilles, 2015).

Supply chain mapping is a valuable tool that helps companies understand and have information on the suppliers they buy directly from and those companies who indirectly contribute components or services across the extended supply chain. This is particularly beneficial for companies that practice ENPD as they have to have an understanding of the lifecycle impacts of their products. CIPS (2014) found that 90% of the procurement professionals they surveyed would support a partnership with a competitor in order to create a sustainable supply chain, showing that organisations are starting to embrace collaboration.

2.2.7 Supply Chain Information Sharing

We currently reside in an 'information age' where availability of information has been increasing exponentially over the last fifteen years or so. This explosion of information availability has given supply chain decision makers various opportunities and possibilities for supply chain efficiency improvements. As knowledge is power, in supply chains, information is power. Nahmias (2001) states that information provides the decision maker the power to get ahead of the competition, the power to run a business smoothly and efficiently, and the power to succeed in an ever more complex environment. Information plays a key role in the management of supply chain." The supply chain's performance depends critically in how its members coordinate their decisions. Information sharing is the most basic form of coordination in supply chains.

Modern business practices have changed, largely, due to advances in information technology; this has made collaborative SCM possible (Chatfield *et al.*, 2004; Li, 2002; Cachon and Fisher, 2000; Lee and Whang, 2000; Lee *et al.*, 2000). The competitive value associated with information has been widely heralded; it substitutes for inventory, speeds new product design, shortens order fulfilment cycles, drives process reengineering, and coordinates SC activities (Clark and Hammond, 1997; Lee *et al.*, 2000; Hult *et al.*, 2004; Kurt Salmon Associates Inc., 1993; Cachon and Fisher, 1997; Hammer, 1990).

There have been a number of review works that have been undertaken in the field of supply chain information sharing. These include Sahin and Robinson (2002), Chen (2003) and Huang et al. (2003). Their reviews are extensive and offer broad scopes in terms of supply chain models, methodologies and types of information being shared. There is also the review by Choi (2010) that gives a compact view as it limits the literature reviewed to mathematical modelling papers.

Integration and information sharing among members of a supply chain has become a necessity for improving supply chain effectiveness. These collaborative behaviours provide rapid access to the required information, more sensitivity towards the needs of the customers, and faster response times than the competitors. Past studies have reported positive relationships between the level of supply chain integration and performance (Kim, 2006; Cousins and Menguc, 2006; Zailani and Rajagopal, 2005; Armistead and Mapes, 1993). Well-integrated supply chains create value for the shareholders by decreasing costs and increasing market share (Lee, 2000). Firms that achieve successful integration in their supply chains have shorter cash flow cycle times, fewer inventories, reduced logistics and material purchasing costs, increased workforce efficiency, and improved customer responsiveness (Lummus and Vokurka, 1999).

Likewise, obtaining the demand information from the customers has been shown to result in decreased inventory costs in a supply chain (Cachon and Fisher, 1997; Lee *et al.*, 2000). Giving priority to the flow of information in a supply chain, over the physical flow of goods and materials, results in the possibility of inventory reductions and efficient use of recourses (Graham and Hardaker, 2000). The visibility and continuous communication capabilities provided by the advanced technologies and information systems allow for quick and timely inventory replenishment (Shapiro *et al.*, 1993; Handfield, 1994). Strader et al. (2002) demonstrated that sharing the supply and demand information with the supply chain helped reducing the inventory costs and shortening the order cycle times. It is also suggested that coordination and information sharing increases the ability of supply chains to react sudden changes in volatile demand environments (Lee *et al.*, 2000). There are many other studies that show that cooperative information sharing among supply chain members improves competitiveness and effectiveness of supply chains (Sahin and Robinson Jr, 2005; Ellram and Cooper, 1990; Li *et al.*, 2006; Li and O'Brien, 1999; Berry and Naim, 1996; Gopal and Cypress, 1993; Strader *et al.*, 2002; Zhao *et al.*, 2002; Bowersox *et al.*, 2002).

Information sharing can be found at the core of collaborative supply chain-based business models. One of the challenges confronting companies in their quest to leverage information as a viable enabler is a misperception regarding the nature of a valid information sharing capability. Many managers define and manage information sharing as a technology issue (Cachon and Fisher, 2000; Chatfield *et al.*, 2004; Robinson *et al.*, 2005; Lee, 2000; Zhang, 2002; Frohlich, 2002; Fiala, 2005). This is the result of the belief that by investing in technology, people and companies can be meaningfully connected; this perception leads to a reliance on the power of technological innovation to drive collaboration (Fawcett *et al.*, 2007). This results in technology being purchased and sold as the solution to a company's information sharing deficiencies. Regardless of this, for many companies, the sought after information sharing capabilities and higher levels of cross-enterprise collaboration never materialise (Fawcett and Magnan, 2001).

There are a number of technologies that are utilised in the sharing of information. Electronic data interchange (EDI) has been a major information sharing tool for years (Warkentin *et al.*, 2001; Davis and O'Sullivan, 1998; Lee *et al.*, 2000; Strader *et al.*, 1998). With the rise and evolution of the internet and e-commerce technology, there have been studies on how such technologies can improve supply chain performance, especially information sharing (Strader *et al.*, 1998; Kehoe and Boughton, 2001; Tan *et al.*, 2000; Croom, 2001; Warkentin *et al.*, 2001; Davis and O'Sullivan, 1998; Graham and Hardaker, 2000). Since internet communication technologies gained popularity as a means of simplifying business to business (B2B) communications they have been seen to have an impact on logistics process performance, purchase process efficiency and supplier relationships (Baglieri *et al.*, 2007). Given the wide range of information technologies (e.g. internet, extensible mark-up language (XML), common object request broker architecture (CORBA), enterprise resource planning (ERP), etc.), there is no clear consensus as to which technology is most suitable for enabling the sharing of information in supply chain.

Information sharing is not always beneficial to some supply chain entities due to inherent risks, high adoption cost of joining the inter-organisational information system, unreliable and imprecise information (Cohen, 2000; Swaminathan *et al.*, 1997). US National Research Council (2000) reported that there are some barriers (e.g. lack of mutual trust, expensive technology investment, personnel training, etc.) which hinder the sharing of information among small and medium sized enterprises (SMEs). Moreover, information sharing can be detrimental if the shared information is not used intelligently (Hong-Minh *et al.*, 2000). In their study, Fawcett et al (2007) found that there are some companies that manage to have more success with supply chain information sharing as they are able to manage the inherent risks and challenges. These are the companies who have sharing embedded in organisational cultures; communication augments investments in technology to create better relationships and raise the level of information sharing. These companies seem to recognize that a substantial gap separates technological connectivity and SC collaboration. An example of such a company is Toyota Motor Corporation and 'The Toyota Way' – a set of principles and behaviours that underlie its managerial approach and production system (Liker, 2003).

2.2.8 *Environmental Information*

As the systems-thinking paradigm emerged, focus on inter-organisational relationships in the product chain increased. Resultantly, mainly through the use of standardised questionnaires (Andersen and Choong, 1997; Brink *et al.*, 1998), supply chain management was seen as a vehicle for moving environmental information (EI) through the supply chain to product designers (Sarkis *et al.*, 1995; Nagel, 1998). Within companies, EI is used for various purposes, Erlandsson and Tillman (2009) make two main distinctions regarding the use of EI: (1) whether the information is for internal or external use and (2) whether the information pertains to the company and production or to products and services. Table 12 contains examples of these four classes of environmental information.

TABLE 12: FOUR CLASSES OF ENVIRONMENTAL INFORMATION WITH EXAMPLES (FROM ERLANDSSON AND TILLMAN (2009)

	Internal Use	External Use
Company Related	Company environmental policy Permits Documentation of chemicals Environmental management reports Documented targets and processes in environmental management systems	Company environmental policy Permit applications Mandatory reports to control bodies Voluntary reports to market actors Market communication
Product Related	Tools for product development, including: - Lifecycle assessment (LCA) - Product related environmental indicators - Checklists - Environmental product policies	Mandatory product information Marketing to individuals and households Marketing in business-to-business relationships Environmental product policies Product declarations or labels

Product development may be regarded as an information transformation process (Hubka *et al.*, 1988) or an information process, this results in relevant EI being considered as a prerequisite for making informed decisions in the various stages of the product development process (Aschehoug *et al.*, 2012). Relevant and understandable environmental information about production and products is needed in any attempt to mitigate environmental impact from production, products, and consumption. When attempting to decouple increased environmental impact, correct, unbiased, relevant, sufficient, and understandable information about the environmental impacts of production and consumption is necessary.

As EI has to be "collected, compiled, and disseminated" (Erlandsson and Tillman, 2009) and relevant information being found among the different actors of a system, dealing with environmental issues on the level of product design and manufacturing only, or on the level of a single firm, is insufficient (Baumann *et al.*, 2002). Distribution of environmental impacts throughout the product chain has implications for the particular information that is important to manage or a given company. When the use phase is the source of most of the impacts, the use-phase environmental information becomes important. If the impacts are mainly related to the company's own production processes, then up- and downstream become less important. If a majority of the impacts occur earlier in the product chain, it becomes important to collect information from suppliers. Supply chain impacts may include emissions, waste, use of energy and natural resources, and ecological harm, at many stages from production of raw materials to intermediate and final manufacture. To attain detailed information about the environmental performance of its products, a company also needs to know what happens in the stages of the product chain prior to its own operations. While average data are often available and can be applied e.g. by the association to which the company belongs, or may be included in the LCA software used, collecting information directly from the source is likely to result in greater accuracy (Erlandsson and Tillman, 2009).

Requesting information directly from the source can have the added benefit of fostering improved environmental awareness on the part of the supplier. Additionally, direct source information enables comparison of suppliers based on their environmental performance, and the environmental performance of the products they provide. However, suppliers are likely to have differing degrees of willingness to share environmental information about their products. In a survey of over 90 UK based companies, Deutz et al. (2013) found that only 9% of the companies they surveyed cited the value chain (including suppliers, customers and waste handlers) as a source for environmental information. The stronger position relative to suppliers gives a company a stronger bargaining position when requesting information. For example, the power relationship can depend on relative size and how dependant the company is on the supplier and vice versa (Erlandsson and Tillman, 2009). Ruigkrok and van Tulder (1995) suggested a classification of dependencies between core firm and partner; Table 13 is an adaption of this classification by Erlandsson and Tillman (2009) to the supplier-producer relationship. This classification distinguishes the relative degrees of influence between the actors, along with their absolute influence, as influence can be equal when ‘small’ or ‘considerable’.

TABLE 13:DEPENDENCY RELATIONSHIPS BETWEEN SUPPLIER AND PRODUCER (FROM ERLANDSSON AND TILLMAN (2009)

POSITION OF SUPPLIER	ATTITUDE OF PRODUCER	MUTUAL INFLUENCE
Independent	Cooperation	Small but equal
Independent with influence	Compliance	Supplier more influential
Interdependent	Coalition	Considerable but equal
Dependent with influence	Direct control	Producer much more influential
Dependent without influence	Structural control	Producer predominates

2.2.9 *PRODUCT INFORMATION, ENPD AND SCM*

Product information refers to the characteristics of products and their production process and one of its important characteristics is product structure, which refers to the product bill of materials (BOM). The structure and cost data in the BOM has a significant impact on production planning in a manufacturing supply chain. For example, component sharing and part standardization are common product design strategies which reduces production costs and cycle time (Lee and Sasser, 1995; Brown *et al.*, 2000). Only Wu and Meixell (1998) and Tan (1999) have investigated impacts of different product structure on information sharing and supply chain performance. It is obvious that the impacts of this factor on information sharing have not been fully explored in the literature.

After a product has been designed, an engineering bill of materials (EBOM) is produced; this is a BOM that is organised with regards to how the product is designed. It typically includes part names, part numbers, quantities, descriptions, procurement types etc. Although the procurement type is specified, this usually only goes as far as documenting how each part is purchased or made (i.e. off-the-shelf or made-to-specification) to create efficiencies in manufacturing, planning and procurement activities. Through ENPD where supply chain information is used during the development process, there is scope to enrich the EBOM by including supplier-specific information. This would include attributes such as location, energy efficiency, material efficiency etc. This would mean that the EBOM could serve as the foundation of the design of a supply chain that will support the developed product.

2.3 Situating the Study

Lastly, this section of the literature review acts as an evaluation of the previous section, which culminates with: key literature being identified; deficiencies in the literature being outlined; and the aim of the research project being explicitly linked to the literature.

2.3.1 Key Literature

In their 2007 paper entitled *Product-Process-Supply Chain: An Integrative Approach to Three-Dimensional Concurrent Engineering* Ellram et al drew upon literature in product and process, supply chain design, NPD, strategy and structure and system dynamics to highlight the substantial theoretical grounding that exists for 3DCE. In addition, they identified issues that currently hinder the adoption of the 3DCE framework, and provided propositions and theoretical generalisations, along with suggested research methods, in a bid to provide guidance to researchers in conducting future 3DCE research. Aside from *Clockspeed: Winning Industry Control in the Age of Temporary Advantage* by Fine, this is arguably the most important piece of work that is been written concerning 3DCE. Some aspects of this research project were conducted in accordance with the guidance provided by Ellram et al and were governed by some of the theoretical generalisations that they proposed.

2.3.2 Literature Deficiencies and Links to Project Aims

While the concept of 3DCE is simple, robust and non-controversial, its research and execution does not seem to be wide spread; this offers many new research opportunities, especially when the 3DCE framework is used in SCM and ENPD research. Although there is enough evidence in literature to suggest that environmental design initiatives result to varying degrees in the greening of the supply chain, this is yet to be investigated from a perspective where supply chain design has become an integral part of the product development process. It is important to note that this research was not conducted just to produce the first descriptions of various aspects of a concept that has not already been extensively studied. This research project aims to contribute to the field by investigating the relative effects of supply chain design and supply chain information sharing within ENPD.

Chapter Summary

Through a critical review of the literature related to the project aim, the focus for the research project was established. The review provides an up-to-date understanding of the 3DCE and its significance and structure and explores SCM in relation to ENPD. Not only did it assist in the creation of a conceptual research framework, it also guided the formulation of research questions and objectives. As it is informed by the views and research of experts in related fields, this literature review provides a basis against which the research findings can be compared and contrasted.

3. Building the Research Framework

Chapter Overview

This chapter presents a conceptual framework for the study before the research project is clarified through the identification and refinement of research questions and hypotheses. It is this clarification that establishes the groundwork for the research project and determines the direction the research will pursue.

Highlighted Contents

The work detailed within this chapter deals with setting the theoretical context within which the research was set and how the research questions and objectives were derived in such a manner that they are embedded within it. It shows how the research fits into what is already known (relationship to existing theory and research) and how it makes a contribution to the field and its intellectual goals.

3.1 3DCE as a Theoretical Lens

As the results of ENPD are affected by the design of the product, such as use of materials and components; the processes used to manufacture the product, such as waste management and production methods; and the supply chain, such as logistics and supplier selection; the integration of environmental considerations into the NPD process would benefit greatly from being viewed from a 3DCE perspective. The use of a theoretical perspective provides an overall orienting lens that provides direction for the research; in this way, a particular theory is used to provide a focus for research and to limit its scope (Tashakkori and Teddlie, 2010).

Prompted by the increasing interest in the state of the environment, Ellram et al (2008) conducted a study that found that using approaches suggested by the then relatively new theory of 3DCE in improving the outcomes of NPD and environmentally responsible manufacturing efforts held great promise for integrating ERM into mainstream NPD concerns. They came to the conclusion that 3DCE is a lens that can be used in demonstrating that ERM efforts can support traditional product development goals as well as environmental product development goals.

3DCE is ideally suited to being a theoretical lens for demonstrating that supply chain efforts can support the integration of environmental considerations into the NPD process. Through its adoption, it became a transformative perspective that shaped the research by placing emphasis on the integration of the supply chain to the already widely accepted and practiced concurrent engineering and was explicitly defined as follows:

> *View that the simultaneous design of product, process and supply chain leads to improved operational performance.* – 3DCE Theoretical Lens

When adopting a 3DCE approach, it is important to meet the requirements of business and industry in developing products with reduced environmental impacts and provide formalised support, adding to what is currently available. Lessons learned, from the literature analysis and conceptual understanding, propose the following key features as essential framework conditions for ensuring effective integration of environmental considerations with the support of the supply chain:

- Use of a strategy level approaches, which are integrated into existing corporate business, product development, supply chain and production systems
- Use of simple, flexible, non-resource intensive approaches designed to fit with business reality
- Bridging the phase, process and product chain levels of product development
- Compatibility with analytical eco-design tools and methods and supply chain management practices

3.2 Unit of Analysis and Levels within the Study

A key component within this study, the following definition of supply chain design as proposed by Chopra and Meindl (2007) was adopted:

> *"Supply chain design involves the decisions about number of suppliers, supplier selection and evaluation, proximity to suppliers, planned capacities in each facility, definition of contractual terms, and reactions to the possible disagreements between channel members."*

Resultantly, supply chain design was taken to be related to the determination of the configuration of a products supply chain through making various supplier related decisions. With an interest in both how organisations and individuals within those organisations behave, this study adopted the new product development process as its unit of analysis, where the new product development process is the process within the internal processes of a company, which in turn are embedded in a product chain, that is undertaken to develop products. Due to the context within which product development occurs (See Section 2.2.1), the study is concerned with three different levels of product development: the organisation, the new product development process and the design and development phase.

The first level, the organisational level, is relates to how product development is undertaken by an organisation that is part of a product chain; it adopts a product chain perspective and includes interactions with external organisations. The new product development process level is within the organisation and relates to the business strategy, management, marketing etc. relating to the product development process. Finally, the product design and development phase level deals with that particular phase of the new product development process and its tools. The relationships between these different levels is illustrated in Figure 17; figure shows the organisation within the product chain, the new product development process within the organisation and the design and development phase within the new product development process.

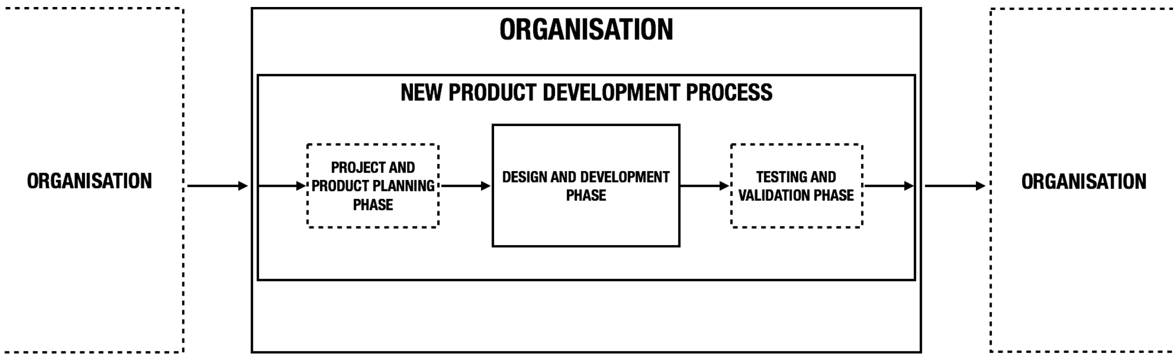


FIGURE 17: PRODUCT DEVELOPMENT LEVELS WITHIN THE SETTING OF THE RESEARCH

In addition, it is proposed that work covered in this study exists on three different levels within the organisation: the strategic, the tactical and the operational. Forming and viewing it this way allows for a holistic perspective that covers all encompassing factors from an organisation making the decision to go in a certain direction to the day-to-day activities that would aid in the realisation of the new goals. The strategic level is concerned with the overall direction of an enterprise and setting goals; this level concerns itself with examining where the organisation is now, deciding where it should go, and determining how it will get there. While strategy is concerned with the future vision, tactics involve the actual steps that are required to achieve that vision; these are the practical steps for implementing the strategy. This level is concerned with the method intended to fulfil a specific objective in the context of the overall plan. Lastly, the operational level is related to day-to-day activities that are carried out in the execution of the method. For example, this could be illustrated as follows using the key definitions in this research:

> *In a bid to attain competitive advantage in a future climate, a product development company strategically decides to make its products more environmentally competitive by working towards making environmental new product development a core capability. It tactically adopts a 3DCE-based approach when integrating environmental considerations into its product development process and executes this through by putting operations in place that promote the sharing of information from the supply chain and the use of this information during product design.*

These levels are represented graphically in Figure 18, where a further differentiation of supply chain and design related issues is highlighted; this serves to emphasise the functions that make up the main actors.

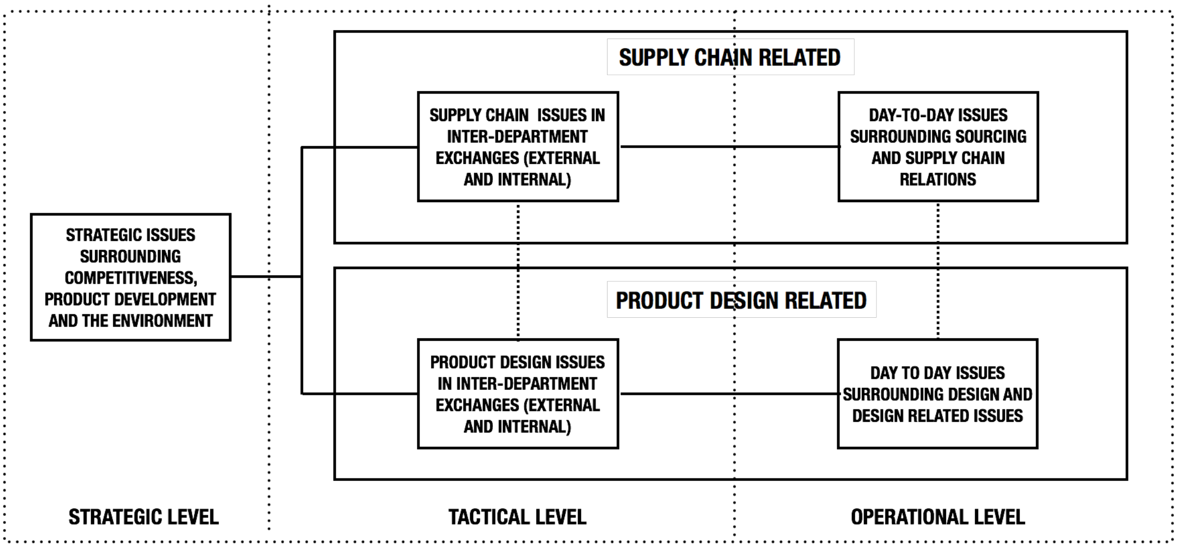


FIGURE 18: ORGANISATIONAL LEVELS WITHIN THE SETTING OF THE RESEARCH

3.3 Preliminary Conceptual Framework

Defined as "*a comprehensive theoretical framework emerging from an inductive integration of previous literature, theories, and other pertinent information*" (Maxwell and Loomis, 2003), a conceptual framework for a study consists of the theory relevant to the phenomena being studied that informs and influences the research. Within this study, this analytical tool was primarily used as the basis for setting the context within which the research is set and reframing the research objectives and questions. It was paramount to ensure the appropriateness of the utilised conceptual framework as a mismatch between it and the research questions and methods can create serious problems for the research.

Due to their presence within the setting, it was necessary to represent the different levels within the conceptual framework. The preliminary conceptual framework is made up of the following parts:

- A 3DCE-Based Approach to ENPD – outline of an approach that assimilates early supply chain design into the environmental new product development process; the approach covers the strategic and organisation levels.
- E-3DCE Contextual Dynamics – an exploration of contextual dynamics during the shift from NPD to ENPD through 3DCE; covers the strategic, tactical and organisation levels.
- Proposed Process Model for ENPD with Early Supply Chain Design – a representation of and an explanation of the operation and mechanisms of the process of ENPD with early supply chain design; covers the tactical, operational, process and phase levels.

3.3.1 A 3DCE Based Approach to ENPD

Mainly through eco-design, initiatives to reduce environmental impact have been evolving for some time to support companies developing more sustainable products. While various concepts, approaches and tools have been evolving to help industry meet this aim, those adequately incorporating the supply chain during the product design and development stage have been lacking. Supply chain impacts affect the environmental profiles of products: it is important that a company knows what happened in the stages of the product chain prior to its own operations. As result, there is need for mainstream, pragmatic approaches to ENPD that include the supply chain, in particular information, environmental or otherwise, from the supply chain.

The 3DCE approach assimilates **early** supply chain design into the product development process when environmental considerations are being integrated. Figure 19 illustrates the various points in the product design and development phase where early supply chain design can be implemented; in this case supply chain design takes the form of preliminary supplier selection, while Figure 20 details the actions that will be undertaken at during the various phase steps when the supply chain is designed early.

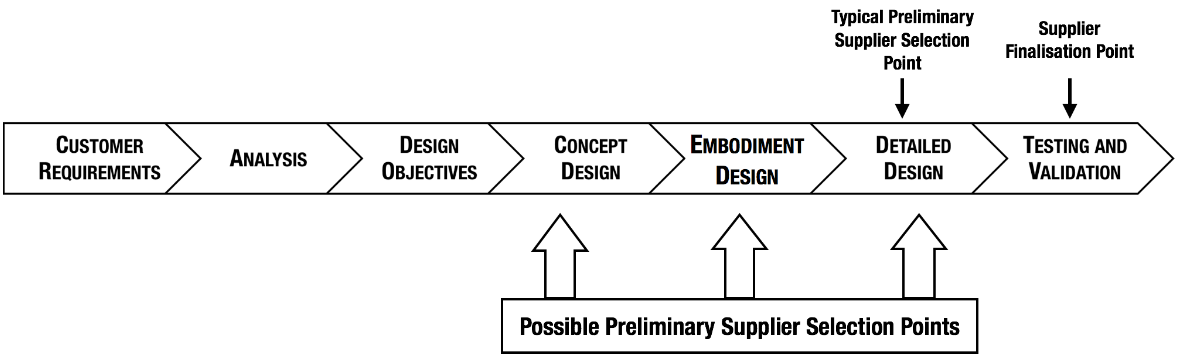


FIGURE 19: POSSIBLE EARLY SUPPLY CHAIN DESIGN POINTS IN PRODUCT DESIGN AND DEVELOPMENT PHASE

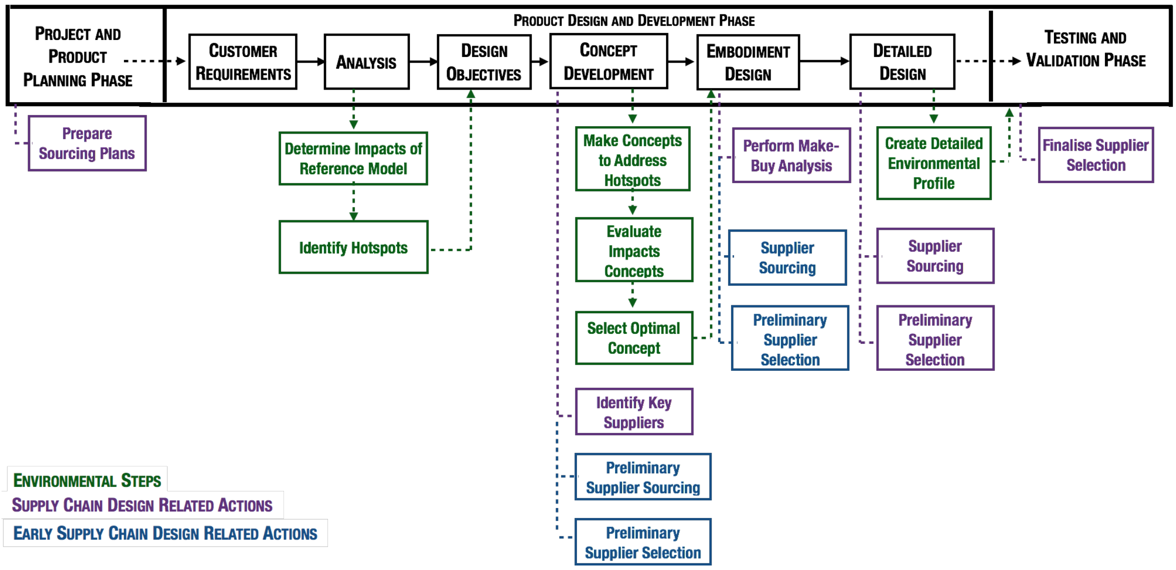


FIGURE 20: EARLY SUPPLY CHAIN DESIGN ADDED TO ENPD PROCESS

The approach also advocates for the simultaneous design of the product and the supply chain by the product designer as environmental performance considerations are integrated into the product design and development phase of the product development process. Figure 21 shows the responsibilities that the supply and design functions (i.e. supply and design teams) could have, the design function would assume responsibility for some of the preliminary supplier selection steps. If this is the case, product designers will have access to supplier-specific information to input into environmental assessments to allow them to accurately evaluate the environmental impacts of the products they are designing.

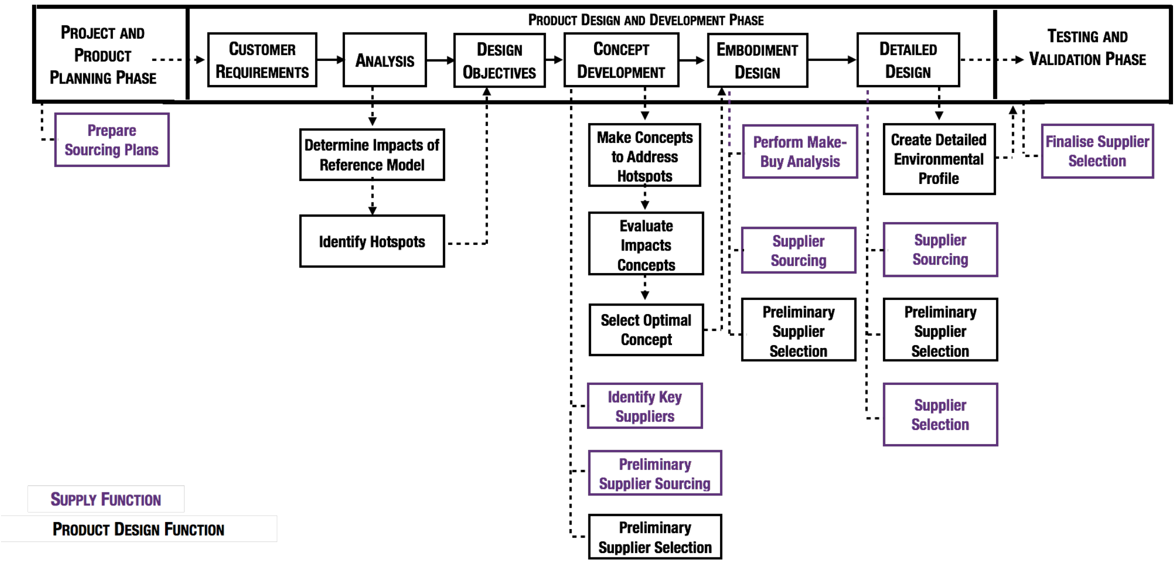


FIGURE 21: SUPPLY FUNCTION AND PRODUCT DESIGN FUNCTION RESPONSIBILITIES DURING PRODUCT DESIGN AND DEVELOPMENT PHASE

3.3.2 *E-3DCE Contextual Dynamics*

Figure 22 serves as a graphical representation of the real life situation surrounding the integration of environmental considerations into the new product development (NPD) process through a 3DCE based approach. It covers the contextual dynamics of E-3DCE, exists on the strategic and tactical levels and covers how an organisation decides on its overall direction and the method it uses to get there. Its primary function of this framework is to show how implementing ENPD might enhance competitiveness.

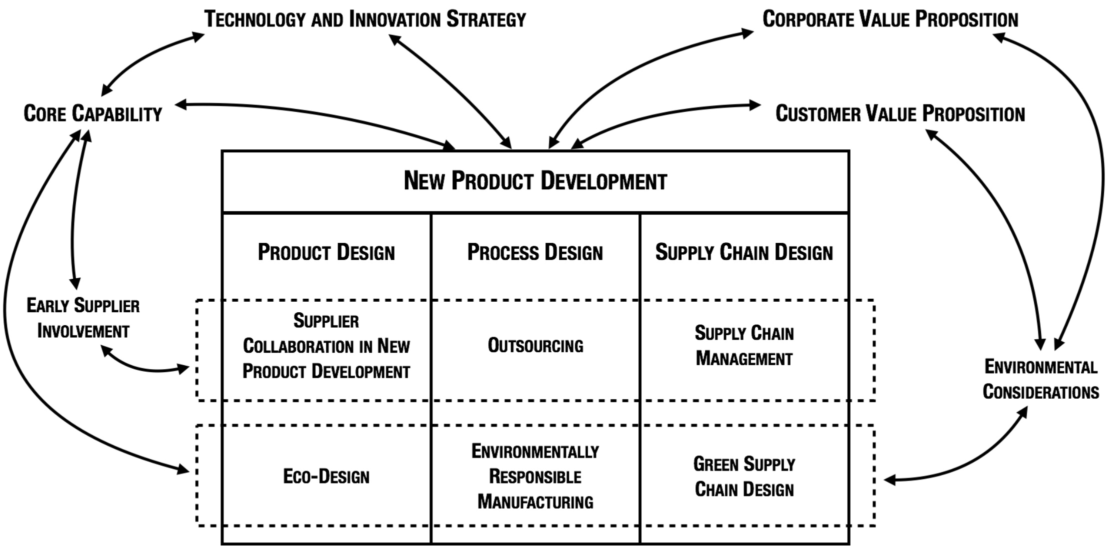


FIGURE 22: E-3DCE CONTEXTUAL DYNAMICS

The essence of effective NPD lies in creating products whose core attributes (which deliver the basic benefits sought by customers) and auxiliary attributes (which help to differentiate between products) meet the needs of customers and other internal and external stakeholders. The nature of NPD is such that its main purpose is to match the company's core capability, create customer value proposition and serve corporate value proposition; and these three, in turn, also serve NPD (Leonard-Barton, 1995). This means that when a firm conducts NPD it is either because it wants to improve or exercise its core capability, or it wants to meet its customers' needs or the needs of the firm itself. However, at the same time, those three aspects can be drivers for product development. Through the adoption of a 3DCE-based approach to product development, the process can be seen as being comprised simultaneously of product design, process design and supply chain design (Fine, 1998). If a firm possesses early supplier integration (ESI) as a core capability, the shift from traditional NPD to 3DCE can be instigated through practices such as supplier collaboration in new product development (SCNPD) (Chu *et al.*, 2006; Chung and Kim, 2003; Ragatz *et al.*, 1997; Stephan and Schindler, 2011; Flynn *et al.*, 2010) production outsourcing (van Echtelt *et al.*, 2008; Stephan and Schindler, 2011) and supply chain management (SCM) (Fraser *et al.*, 2003). In turn, competency at these three practices can lead to ESI as a core capability (Vera and Crossing, 2004). The core capabilities of a firm greatly influence its strategy, especially with regards to innovation strategy (Jansen *et al.*, 2006); it is this strategy that influences the NPD process. For example, if ESI is a core capability, then the firm is likely to adopt an open innovation approach to product development. This works the other way round in that a firm that applies an open innovation strategy to the NPD process is likely to develop ESI as a core capability. In terms of environmental considerations, these are likely to enter the NPD process due to either customer or corporate value proposition (Pujari *et al.*, 2003). Through the simultaneous practice of eco-design, environmentally responsible manufacturing (ERM) and green supply chain development (GSCD), a firm can then move from performing 3DCE to performing E-3DCE. As with ESI, the ability to successfully integrate environmental considerations into the product development process can become a core capability that leads to competitiveness.

To supplement Figure 22 and add more understanding, the reference model in Figure 23 highlights the interactions of various factors that are at play in the illustrated scenario. The model is based on splitting the product development into its motivations, which are corporate value proposition, customer value proposition and core capabilities (Leonard-Barton, 1995) and investigating how they are related to each other. The arrows represent the connections between the factors, with '+' and '-' representing where positive or negative connections have been found in literature; in some cases there is evidence of both positive and negative connections.

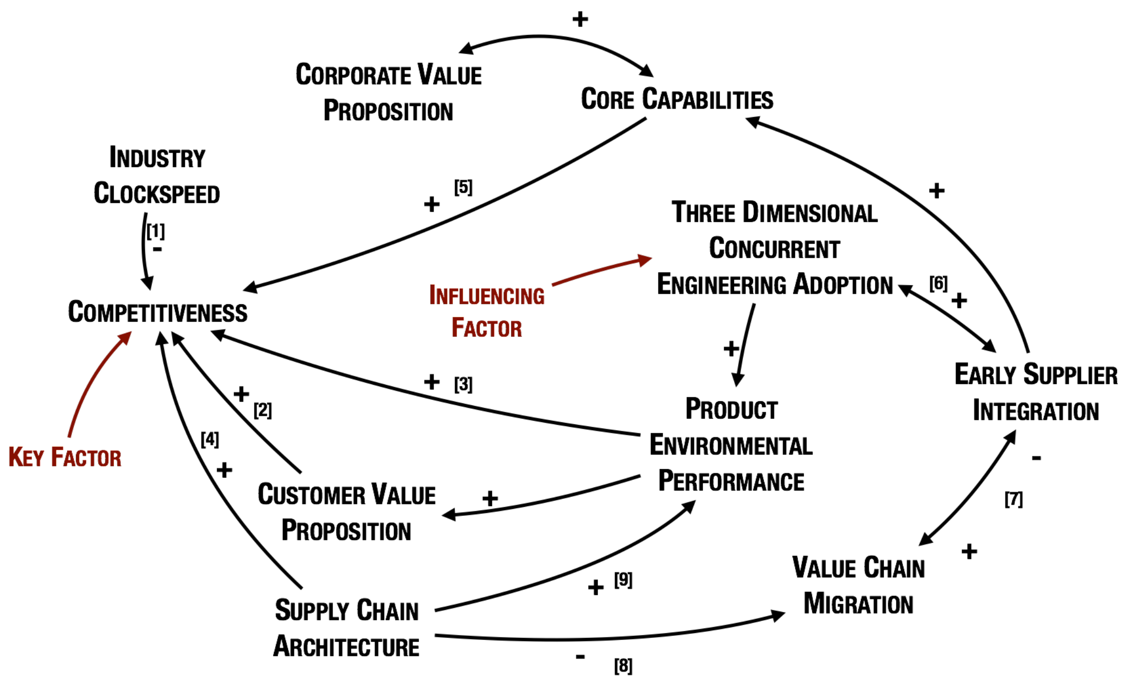


FIGURE 23: INTERACTIONS BETWEEN FACTORS AT PLAY IN E-3DCE DYNAMICS FRAMEWORK

The lifecycle of an industry, its clockspeed, has an impact on the competitiveness of the firms within that industry. The faster the clockspeed, or shorter the lifecycle, the less maintainable competitive advantage is (Fine, 1998) [1]. However, a firm's ability to be competitive is positively impacted by its ability to satisfy its customers' needs (Pujari *et al.*, 2003) [2], the environmental performance of its products (Porter and van der Linde, 1995; Horbach, 2008; Boons and Luedeke-Freund, 2013; Forsman, 2013) [3], the architecture of its supply chain (Fine, 1998) [4] and its core capabilities (Leonard-Barton, 1995) [5]. The adoption of a 3DCE-based approach is positively impacted by ESI, this means that the implementing firm will increase supplier involvement in a various aspects of their product development process (Petersen *et al.*, 2005); at the same time, having ESI within the firm makes the adoption of a 3DCE-based approach easier as early consideration of supply factors already exists (Stephan and Schindler, 2011) [6]. If not correctly managed, ESI can have a positive impact on value chain migration (Chung and Kim, 2003) [7]; this means that the initiating firm can unwittingly give up the value adding aspects of the product being developed to members of the supply chain. This pitfall results in firms approaching ESI with caution, however, the likelihood of value chain migration can be mitigated through superior supply chain design that is manifested in the architecture of the supply chain (Fine, 1998) [8]. Well-executed supply chain architectures have a positive impact on competitiveness as value creation is still within the firm (Fine, 1998) [4] and on the environmental performance of products produced as the firm will have more control of the components from the supply chain that are being incorporated into its products (Horbach, 2008; Boons and Luedeke-Freund, 2013; Forsman, 2013) [9]. Ultimately, the key factor is competitiveness; through the use of the 3DCE approach, firms can aim to attain a competitive advantage. In the future this advantage is likely to be influenced by the firm's ability to produce environmentally competitive products (Boons and Luedeke-Freund, 2013; Forsman, 2013).

The exploration of the E-3DCE contextual dynamics forms a theoretical base for the argument that the environmental performance of products (from ENPD) can be integrated as a driver of competitiveness. These dynamics are not empirically investigated within this study, but they frame the research and underpin the justification for it.

3.3.3 Proposed Process Model for ENPD with Early Supply Chain Design

Where the previous section (Section 3.2.3) addressed the strategic and tactical levels, this section tackles the tactical and operational levels; it presents a scenario that exists within the former and is guided by the 3DCE based approach to ENPD presented in Section 3.2.1. Figure 24 is a process model that is proposed to highlight how, operationally, an organisation can integrate environmental considerations into their NPD process through the early supply chain design; it embodies the concept of 3DCE and presents it within the context of ENPD. This model presents a hypothetical scenario where E-3DCE is practiced and forms the basis for the research questions.

Green products can take one of two forms; the first is pure green brands, which are products that are designed with environmental considerations from scratch while the other is green brand extensions, which are products that are the result of an existing product design being upgraded to include environmental considerations (Majid and Russell, 2015). The proposed process model is set within the context of an organisation that is looking to develop, through ENPD, a product that is a green brand extension. Starting in the top left corner, the organisation's supply network (e.g. part suppliers, service providers, dismantlers) is encouraged to practice supply chain information sharing.

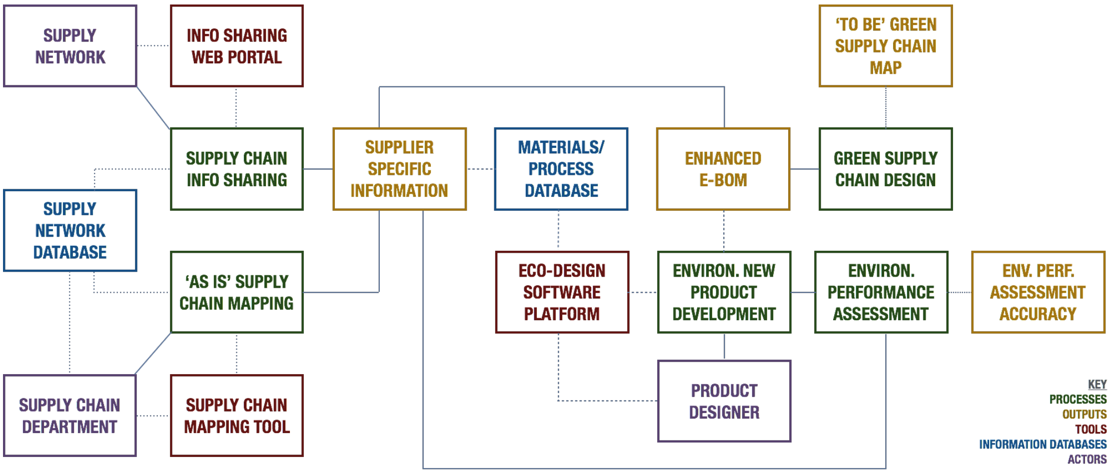


FIGURE 24: PROPOSED PROCESS MODEL FOR ENPD WITH EARLY SUPPLY CHAIN DESIGN

Typically, information sharing within the supply chain is associated with maximising responsiveness and efficiency while minimising cost (Lee *et al.*, 2000; Yu *et al.*, 2001; Lee and Whang, 2000; Zhou and Benton Jr, 2007), with the relationships formed handled by the procurement and/or logistics department; while, information sharing within the product development chain is allied with the acquisition of resources and capabilities to improve product offerings (Kim *et al.*, 2006; Zhang *et al.*, 2004), with the collaborative relationships formed more likely to have a research and development focus. On the one hand, there is Kanter's notion of collaboration advantage, defined as " *a significant leg up in a global economy due to a firm's well developed ability to create and sustain fruitful collaborations*" (Kanter, 1994), which is associated with the product development chain; while on the other, there is the resource-based theory view that one source of differential performance between firms is the way in which they organise exchange activity (Conner and Prahalad, 1996), which is related to the supply chain. Therefore, it would seem logical to then deduce that amalgamation of the two forms of information sharing would result in advantages gained through the unified use of the formed relationships, enriching the depth and quality of information shared via both design and supply chains. With particular focus on design chains and collaborative design, utilising supply chain information sharing relationships and methods within the product development process would offer a means of augmenting the match between product and process, which most companies accomplish through concurrent engineering, with an additional consideration of supply chain configuration. This is particularly key with ENPD because the environmental performance of a product is the amalgamation of its environmental impact through all the stages of its lifecycle, from the extraction of raw materials to its end of life, it is dependent on the totality of the supply chain in both upstream and downstream directions throughout its lifecycle. To fully understand the environmental profile of the product being designed, it is necessary to take into account the product's impact throughout the various stages of its lifecycle as well as the environmental performance of the various supply chain partners associated with it through the parts and services that they provide. This means that the information required from the supply network is varied in nature, including product related information (e.g. cost, performance, materials, manufacturing processes, etc.) and company related information (e.g. location, transport, waste management, etc.).

The exact type and format of information required from the supply chain is dependent on: the product being designed; environmental assessments that are to be carried out; and the structure put into place to support the process. The fact that some of it will constitute information that is not traditionally exchanged will result in asymmetric information as not all members of the supply chain will have all the required information pertaining to the products and services they provide. Although asymmetric information - which refers to various members of the supply chain having differing states of information relating to cost, resources, performance status and market conditions - exists within today's supply chains, firms are continuously working to fill in existing gaps to avoid misunderstandings, opportunism and making sub-optimal decisions. As an example, a component manufacturer is likely would to be able to supply information regarding the materials and manufacturing processes related to aspects of the component that they have designed in-house; however, without requesting it from their own suppliers they would not be able to provide the same information for parts that they buy in. It is expected that with time, as the supply chain becomes more familiar with information requests for ENPD purposes, the sharing of it through the supply chain will increase, along with its completeness.

In an ideal scenario, the organisation conducting ENPD would request and attain from their supply chain network eco information (such as results of various environmental assessments on their products, services and themselves) that they would be able to embed into their ENPD process. However, not all members of the supply network will have access to that type of information and in some cases when they do, they could class it as proprietary information and be unwilling to share it. One way of mitigating the presence of asymmetric information is to take a step back and ask for information that is not environmental in nature but rather information that allows the organisation to conduct their own environmental assessments on the products and services that various supply chain members provide.

Only when companies are willing and able to share vital – and often proprietary – decision-making information can trust be established and collaboration promoted. Technology becomes a tool to augment and promote information sharing and real collaboration. Supply chain information sharing can be facilitated through the use of a web-based information-sharing portal. Supplier portals have been found to: promote information sharing and coordination of operational flows (McIvor and McHugh, 2000); support supplier management; and create a sense of community among buyers and suppliers; and increase the stability of relationships and suppliers' loyalty to their customers (Roberts, 1999). Shifting from being utilised only as an e-procurement tool, the collaborative potential within supplier web portals means that they can aid in the sharing of supply chain-based information that can be used in the ENPD process.

The information coming in from the supply chain though the web portal can be stored in a supply network database, this is a database that the organisation's supply chain department would oversee to ensure that the information being input is of the right nature and format. Responsible for mitigating supply chain risk and ensuring supply chain visibility to heighten responsiveness, the organisation's internal supply chain function (i.e. supply chain team) might already be familiar with strategic supply chain mapping. Well-executed supply chain mapping can enhance the strategic planning process, ease distribution of key information, facilitate supply chain redesign or modification, clarify channel dynamics, provide a common perspective, enhance communications, enable monitoring of supply chain strategy, and provide a basis for supply chain analysis (Gardner and Cooper, 2003). In this case, information from the supply network can be used to create a descriptive 'as-is' map of the product that the organisation is looking to make green. This map aims to be a graphical representation of all the supply chain members that interact with the product at all stages of its lifecycle (from raw material extraction to end-of-life) and will aim to contain as much information as possible pertaining to these supply chain members. Essentially, the supply chain department will be responsible for encouraging information sharing within the company's supply network, attaining supply chain maps that are as complete as possible and ensuring that the information in the supplier database is as up to date and complete as possible.

The information stored on the products and services will be intrinsically linked to those that are providing it and it can be described as being supplier-specific information. It is this supplier-specific type of information that will be key in integrating the supply chain into the ENPD process. It means that when the product designer is confronted with selecting a component to use in a product design, they can select a specific product from a specific supplier and use the supplier-specific attributes of that product in any environmental assessments that they conduct to ensure that they have as accurate as possible a representation of the environmental performance of the product that they are designing, they can also compare the effects of using different parts from different suppliers on the environmental profile of the product they are designing.

This supplier-specific information can enter the ENPD process in a number of ways, the most likely within an organisation setting being in conjunction with a materials and processes databases through the use of eco-design software platforms. Such eco-design platforms (e.g. G.EN.ESI, GaBi, SimaPro and Sustainable Minds) can be completely integrated with other main design tools, such as CAD and PLM software, and help designers make ecological design choices without losing sight of cost and typical practicalities of industry. Essentially, the architecture of these software platforms is based on the integration of various tools into the same structure, with the tools communicating to support the entire product design process; an example of a tool is a S-LCA tool which identifies where environmental hotspots are, or processes where emissions of particular interest occur in the lifecycle of the product. Each tool within such a platform will examine design choices from a specific point of view while simultaneously possessing the ability to provide information to the designer on environmental issues. This connection between the tools will allow for an immediate check of the congruence of the choices with other key design parameters.

As with any other form of assessment, you get out what you put it; this means that the richer the information used when conducting environmental assessments, the more accurate and representative of the real life scenario the outputs will be. Additionally, allowing the designer to not only select the product, but also to specify who supplies, it not only allows designers to evaluate how the supplier impacts the profile of the product, but it could also cut down product development time as they will not have to get the supply chain department to source the suppliers before conducting environmental assessments. Essentially, supply chain design becomes an output of the ENPD process, as by selecting the products they want, the designers will also be determining who will be supplying them. The designers should only be presented with options from the database, this constitutes suppliers that the supply chain department has vetted and has current working relationships with.

Having supplier-specific information available to during the ENPD process means that the EBOM, a traditional output of the design process, can be enhanced to include supplier information. This would allow it to serve as a foundation of the design of the supply chain that will support the designed product and can result in a ‘to-be’ supply chain map for the product being designed. The early supply chain design would result in the basic configuration of the supply chain being outlined based on the suppliers whose contributions have informed the product development process. Supply chain design includes making decisions relating to suppliers and their selection, proximity to supplier and the like, these same decisions have an impact on the environmental performance of product, and it is the availability of such information during the product development process that not only allows for accurate environmental assessments to be carried out but also improves their accuracy. The configuration of the supply chain, which is determined through supply chain design, is important as it is one of the factors that are critical in the determination of supply chain effectiveness and efficiency. As the designer is designing a product, they will also be evaluating the environmental performance of those in the products supply chain; they will be determining what the ‘as-is’ supply chain map will look like. This means that there is scope for them to not only conduct supply chain design but to conduct green supply chain design when they make an active effort to ensure that the product they are designing is supported by a supply chain whose environmental profile has been evaluated.

Linking it to the previous framework in Figure 22, the richer the assessments that the organisation can carry out, the better the environmental profiles of the products that they can produce and the more competitive they can become. The more they conduct ENPD this way, and focus on getting a stream of accurate, up-to-date and complete information from their supply network, the more they exercise their capability and the closer they become to making it core. This vital flow of information from the supply chain into the design process is key to ENPD and is how environmental considerations and early supply chain design can be introduced into the product development process. Here lies the potential to encourage sustainability competitiveness within industries, while stimulating eco-efficiency throughout the whole supply network.

Supply Chain Design within the ENPD Process

As ENPD is essentially NPD with an added constraint, it is not a radically different process to conventional NPD. It does however involve adding a further level of complexity into the NPD process and it is important to recognise what changes are required when this move is initiated through a 3DCE-based approach. This resulted in the following research question:

> *Research Question 1: When transitioning to a 3DCE-based approach to ENPD, (a) how should the supply department support the product development process and interact with the external supply chain, and (b) what changes are required in the way in which designers work?*

The investigation into its answer should shed light on how the supply and design departments interact and work (internal and external) and should help in the formulation of recommendations on how to improve the utilisation of the supply chain in the product development process.

Supply Chain Information Sharing

As the sharing of information is the key component of the proposed process model, it is necessary to gain a deeper understanding of the dynamics surrounding supply chain information sharing and how it can be facilitated. This led to the following research question being formulated:

> *Research Question 2: What are the challenges associated with supply chain information sharing and how can the practice be improved through the use of supply-based methods and relationships for the benefit of product development?*

Supply Chain Awareness

Through the use of supply chain mapping, firms can have an accurate picture of the supply chain of their products, in both up and downstream directions. Not only does this aid in the attainment of product information from the supply chain but it also allows for greater supplier chain visibility. Firms will be able to acquire information pertaining to not just first-tier suppliers but potentially second- and third-tier suppliers too. It is this potentially vital role that supply chain awareness has that led to the formulation of the following exploratory research question:

> *Research Question 3: What is the state of supply chain awareness in companies and how can it be used/improved for the benefit of supply chain information sharing?*

3.4 Research Objectives

The ENPD with supply chain design framework represents a shift from traditional concurrent engineering, through a 3DCE based approach, which places emphasis on the simultaneous design of the product and process by adding supply chain design. Not only does it advocate for the inclusion of supply chain design, it urges that the supply chain design be carried out as early as possible. Due to this added element of supply chain design within the ENPD process, a 3DCE-based approach makes specific demands on external and internal design and supply chain departments. Consequently, it becomes important to have a holistic understanding of what these demands are and how they translate into changes that need to be made by the involved actors. This led to the formulation of the following research objective:

> *RO1: Establish what is required of (a) the internal and external supply and (b) design departments when adopting a 3DCE based approach to ENPD.*

The adoption of 3DCE as an approach to NPD can be realised by a number of different tools and methods. To fully explore the benefits that lie within it, it is important to provide tools or methods that can be applied directly to the environmental product development process to show explicitly how environmental considerations can be integrated into the product development process thorough supply chain design. As 3DCE encourages the early consideration of the additional element of supply chain design, it stands to reason that methods developed based on it should focus on the supply chain and how to seamlessly integrate it into the development process. This resulted in the formulation of the following research objective:

> *RO2: Develop a method, based on 3DCE and with a supply chain focus, which can be utilised during the environmental new product development process.*

The method to be developed for the integration of environmental considerations into the NPD process should be rooted in early supply chain design, this being achieved by allowing designers access to supplier-specific information during the ENPD process. As the aim of the developed method is to help in the early integration of environmental considerations, it is important to critically assess its performance in this regard. The need to critically assess the outputs of the ENPD process carried out with early supply chain design, in terms of predetermined environmental attributes, led to the following penultimate research objective being formulated:

> *RO3: Critically assess the impact of early supply chain design on environmental new product development outputs.*

When proposing a new tool or method, to ensure its widespread use and successful adoption, it is important to offer and have support mechanisms in place. In this case, the support will be offered in terms of recommendations and guidance on how the supply chain can best be utilised during the ENPD process. While the developed method will focus on supplier-specific information, it is important to offer recommendations that are all-encompassing and include other supply chain-related issues such as supplier collaboration, supply chain awareness and supply chain mapping as activities that can be useful in the integration of the supply chain into the environmental product development process. This resulted in the formation of the following research objective:

> *RO4: Make recommendations to support and improve how the supply chain is considered during the ENPD process.*

Implied in the presented research objectives is a need to have an in-depth understanding of the dynamics that are inherent within the ENPD process.

3.5 Components of Research Study

To provide the overall picture of the study, Figure 25 is presented as a graphical representation of the research components. It shows how the research objectives and questions relate to each other and how they are in accordance with the title and aim of the project.

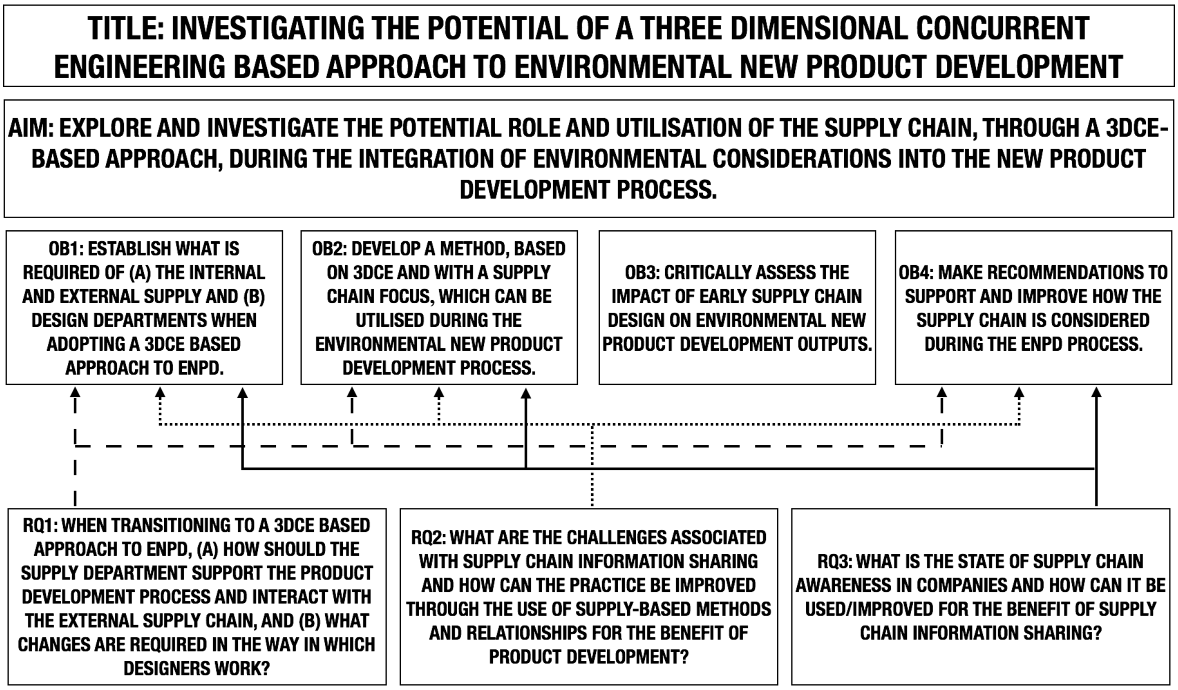


FIGURE 25: OVERVIEW OF RESEARCH COMPONENTS

Chapter Summary

After introducing 3DCE as a theoretical lens and outlining the new product development process and organisational levels the study applies to, a conceptual framework was developed. The framework addresses three different organisational levels that the research project aims to cover. Firmly rooted in literature, observations of ENPD and SCM provide pertinent themes that can act as a point of departure for the research. the framework introduced does not impose causality or relationships between themes, allowing data to induce findings; it allows further categories to be added if events or findings evoke them. Lastly, it is holistic because it is bringing together topics that are currently being considered individually (supply chain design and NPD) and it includes a number of levels of analysis (i.e. strategic, tactical and operational). It is from this framework that, research objectives and questions that will guide the research project were formulated.

4. The Research Design

Chapter Overview

This chapter outlines the design of the research study; it spans from broad philosophical assumptions that underpin the research to detailed methods of data collection, analysis and interpretation. Throughout, decisions made regarding the research design are continually linked to the nature of the research problem. Issues of triangulation and credibility are also covered in the chapter.

Highlighted Contents

As the design of a research study to address a problem or answer a question is invariably constrained by both the practicable and ethical, within the research design it is important to have an understanding of the outer layers of research philosophy, methodological choices, strategies, and time horizons and their inter-relationships (Saunders *et al.*, 2009). This is paramount as it helps ensure that they core of data collection techniques and analysis procedures used in the research are both appropriate and coherent. The main aim of this chapter is to present the research design and to show that it is the result of a series of decisions that are not only based on methodological literature and previous work, but also whose justification flows logically from the research questions and the conceptual framework (Marshall and Rossman, 2006).

4.1 Nature of the Research

As a project that aims to integrate supply chain design into new product development, this project falls in an area overlapping design research and supply chain management research. On the one hand, design research is concerned with the formulation and validation of models and theories about the phenomenon of design as well as developing and validating knowledge, methods and tools founded on these models and theories with the aim to improve design (Blessing and Chakrabarti, 2009). While on the other, it can be said that SCM is concerned with the same aspects from the perspective of supply chain related issues with the aim to improve supply chains. Combined, these two fields focus on improving the chances of successfully designing, producing and supplying products, and for this research project the focus is specifically on products designed with environmental considerations. As pointed out by Robson (2011), it is normal for a research project to have more than one purpose, as the enquiry purpose may change over time. Such was the case with this study; various parts aim to fulfil various purposes as classified in Table 14.

TABLE 14: RESEARCH STUDY PURPOSES

Purpose	Description	Study Component
Exploratory	Explore what is happening and ask questions about it (Saunders *et al.*, 2009).	Literature Review and Research Framework
Descriptive	Provide a picture of a phenomenon as it occurs naturally (Hedrick *et al.*, 1993).	RO1, RQ1, RQ2 and RQ3
Prescriptive	Developing support to enhance, eliminate or reduce the effect of certain critical factors (Blessing and Chakrabarti, 2009).	RO2 and RO4
Explanatory	Discover causal relationships between variables (Robson, 2011).	RO3

4.2 Layers of the Research Design

The approach used to study a topic is central to research design, as such is should be informed by the researcher's philosophical assumptions, procedures of enquiry, and specific research methods of data collection, analysis and interpretation. This decision should also be based on the nature of the research problem, the researchers personal experience and the audience of the study (Creswell, 2013). As recommended by Saunders *et al*. (2009) the research design of this study was based around the analogy of the onion, which starts off by outlining the philosophical assumptions that ground the research and zones in by peeling off layer by layer until it reaches the activities that constitute the research. This is illustrated in Figure 26 and the layers are explained in the subsequent sections.

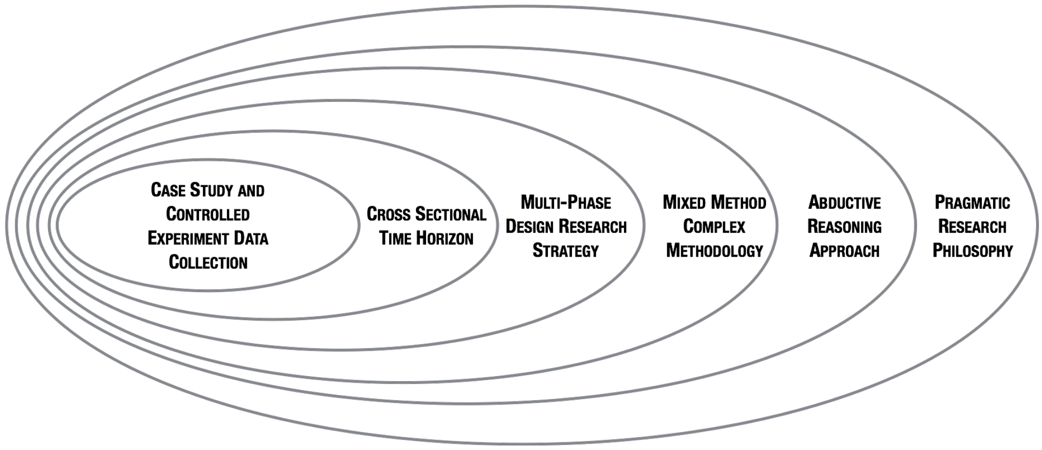


FIGURE 26: RESEARCH ONION REPRESENTING LAYERS OF THE RESEARCH DESIGN (BASED ON SAUNDERS ET AL (2009))

4.2.1 Pragmatic Research Philosophy

Stemming from *The Structure of Scientific Revolutions* (Kuhn, 1962), paradigms are belief systems that researchers adopt which guide them throughout their research and influence the decisions they make (Lincoln *et al.*, 2011; Mertens, 2010); others have referred to them as worldviews (Guba, 1990), epistemologies and ontologies (Crotty, 1998), or broadly conceived research methodologies (Neuman, 2009). While they remain largely hidden in research, they still influence the practice of research and need to be identified; it is these paradigms that determine the research approach adopted. Making explicit what larger philosophical ideas are espoused helps in explaining why certain approaches were chosen for the research.

Research projects traditionally fit into either the socio-constructivist paradigm (typically allied with qualitative research), or the positivist paradigm (typically linked to quantitative research), each with its own set of epistemological assumptions, research cultures and researcher biographies (Brannen, 1992). Socio-constructivism is based around understanding, multiple participant meanings, social and historical construction, and theory generation; while positivism is based around determination, reductionism, empirical observation and measurement, and theory verification (Creswell, 2013). Both design and SCM research can either be quantitative or qualitative; however, the focus and social-science nature of this research project lends itself to the social-constructivist paradigm which endorses qualitative research methods as the most appropriate. However, adopting just this paradigm presents limitations as quantitative positivist methods that utilise natural science tools are completely neglected (Creswell, 2004). As a result, this project will adopt a pragmatic paradigm based on compatibility theory, which acknowledges the different philosophical assumptions, strengths and weaknesses associated social-constructivism and positivism and advocates for the use of methods within the two paradigms in the same study; this is represented in Figure 27. Pragmatism derives from the works of Peirce, James, Mead, and Dewey (Cherryholmes, 1992). While there are many forms of this philosophy, pragmatism as a world-view arises out of actions, situations, and consequences rather than antecedent conditions (as in positivism).

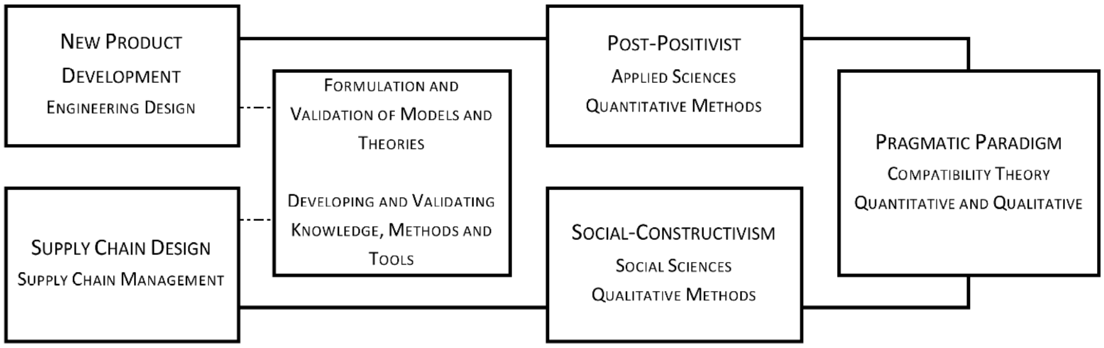


FIGURE 27: THE ADOPTED RESEARCH PARADIGM

Philosophical Assumptions and Implications

Table 15 details the philosophical assumptions made by the researcher as the research study was undertaken, it outlines the characteristics of the assumptions and explicitly details the implications they had during the study.

TABLE 15: PHILOSOPHICAL ASSUMPTIONS AND IMPLICATIONS FOR PRACTICE (FROM CRESWELL(2012))

Assumption	Characteristics	Implications for Practice
Ontological	Reality is multiple as seen through many views	Researcher reports different perspectives reported as themes develop in the findings.
Epistemological	Subjective evidence from participants; attempts to lessen distance between researcher and what is being researched	Researcher uses quotes from participants as evidence and collaborates with participants, becoming an "insider".
Axiological	Researcher acknowledgement that research is value-laden and biases are present	Researcher openly discusses values that shape the narrative and includes own interpretations in conjunction with interpretations of participants.
Methodological	Researcher use of inductive logic, topic studied within its context and use of emerging design	Researcher works with particulars (details) before generalisations, describes in detail the context of the study and continually revises questions from experiences in the field.

4.2.2 Mixed Method Complex Methodology

Pragmatists are not wedded to either positivism or interpretivism as 'dualism', or theory of opposing concepts; they view this dichotomy as unhelpful and choose instead to see these philosophical positions as either end of a continuum, allowing a choice of whichever position or mixture of positions that will help in the undertaking of the research (Tashakkori and Teddlie, 2010). The nature of the research question, the research context and likely research consequences are driving forces determining the most appropriate methodological choice (Nastasi *et al.*, 2010). Both quantitative and qualitative research are valued and the exact choice will be contingent on the particular nature of the research. Resultantly, this lead to a multiple methods research design being employed for this research project; its diversity presents an excellent fit as it mirrors the array of issues related to SCM and design research and it is also increasingly advocated for within management research (Bryman, 2006). It is also desirable because it gives a more complete view and can be designed to match requirements during the different phases of the research project which make very specific demands on a general methodology (Brannen, 2005) and is likely to overcome the weaknesses associated with using only one method as well as providing scope for richer data collection, analysis and interpretation (Saunders *et al.*, 2009). As opposed to multi-method research, where more than one data collection technique is used with associated analysis procedures, but restricted within either quantitative or qualitative design (Tashakkori and Teddlie, 2010), this research will be mixed methods.

In mixed methods research qualitative and quantitative research are combined in a single research design; this matches the research methodology suggested by Snow and Thomas (1994) and Wacker (1998) for the development of new understanding, to better develop the study's hypotheses and to ground a set of constructs for empirical testing. When conducting research, adopting a methodology results in a better-planned research process, thereby increasing the chances of obtaining valid and useful results. However, the nature of methodology is heuristic, rather than algorithmic, and such outcomes cannot be guaranteed (Blessing and Chakrabarti, 2009). With researchers possessing differing backgrounds and interests, each research process is unique; a methodology can only support this process.

Mixed methods research resides in the middle of the qualitative and quantitative research continuum because it incorporates elements of both; it integrates two forms of data using distinct designs that may involve theoretical frameworks and theoretical assumptions. The core assumption of this form of inquiry is that the combination of qualitative and quantitative approaches provides a more complete understanding of a research problem than either approach alone (Collins *et al.*, 2006). Mixed methods research can be formally defined as the class of research where the research mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study (Creswell, 2013). Philosophically, it is the "third wave" or third research movement, a movement that moves past the paradigm wars by offering a logical and practical alternative; it makes use of the pragmatic method and system of philosophy. Mixed methods research also is an attempt to legitimate the use of multiple approaches in answering research questions, rather than restricting or constraining researchers' choices (i.e., it rejects dogmatism). It is an expansive and creative form of research, not a limiting form of research as it is inclusive, pluralistic, and complementary, and suggests that researchers take an eclectic approach to method selection and the thinking about and conduct of research (Collins *et al.*, 2006).

The ways in which quantitative and qualitative research may be combined, as well as the extent to which this may occur, has led to the identification of a number of dimensions or characteristics of mixed methods research (Creswell and Plano-Clark, 2007; Nastasi *et al.*, 2010). Based on these, choices were made regarding this research project such that it can be characterised as adopting a complex mixed-method methodology as shown in Figure 28. The methodology is classed as complex due to the manner in which method mixing occurs and the involved levels of integration; this will be discussed further, along with the research strategy adopted, in Section 4.2.4.

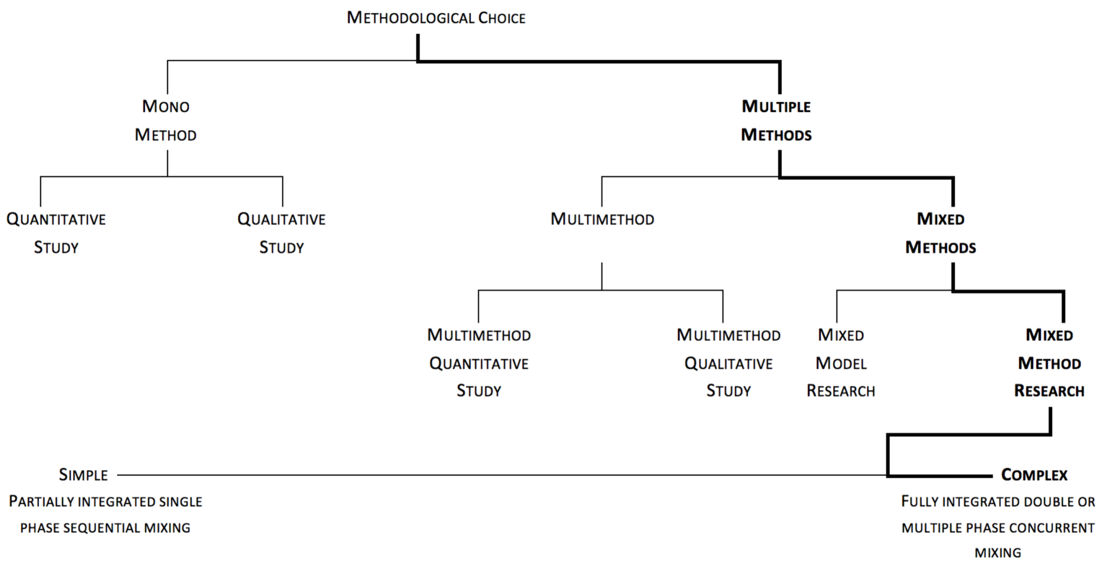


FIGURE 28: METHODOLOGICAL CHOICE (BASED ON SAUNDERS ET. AL (2009))

4.2.3 *Abductive Reasoning Approach*

The logic of inquiry within mixed methods can take the form of induction (or discovery of patterns), deduction (testing of theories and hypotheses), or abduction (uncovering and relying on the best of a set of explanations for understanding one's results) (de Waal, 2001). Instead of moving from theory to data (as in deduction) or data to theory (as in induction), an abductive approach moves back and forth, in effect combining deduction and induction (Suddaby, 2006). Thus, the reasoning approach adopted has implications on the research. While a multiple methods research design may use either a deductive or inductive approach, it is likely to combine both and use an abductive approach (Tashakkori and Teddlie, 2010). It is an approach that is heavily utilised within business and management research (Saunders *et al.*, 2009).

"Abduction is inference to the best explanation" - Eliott Sober (2012)

No approach should be thought of as better than the other. The reasoning approach applied to a research project depends on the emphasis of the research and the nature of the research topic. Easterby-Smith et al. (2008) suggest that establishing the reasoning approach is important as it allows for decisions to be made regarding the research design, informs decisions regarding research strategies and methodological choices, and having knowledge of different research traditions allows the researcher to adopt a research design that caters for constraints.

Adopting an abductive approach allows for more information and understanding to be gathered which enables the modification or expansion of the existing body of literature on 3DCE and ENPD. In practical terms, adopting this approach meant developing a conceptual framework on the basis of an in-depth analysis of the literature. From the framework, a series of research objectives and questions were developed; data collection and analysis allow for the refinement of the conceptual framework. During abductive research, data is collected to explore a phenomenon, identify themes and explain patterns, to generate a new or modify an existing theory, which will subsequently be tested thought additional data collection. Due to its usefulness in the development of new theories, this study made use of systematic combining, where theoretical framework, empirical fieldwork and case analysis evolve simultaneously (Dubois and Gadde, 2002). Figure 29 details how logic, generalisation, use of data and theory are utilised during abductive research.

Logic Known premise used to generalise testable conclusions	**Generalisability** Generalisations made from the interactions between the specific and the general
Use of Data Data collection used to explore phenomenon, identify themes and patterns, locate these in a conceptual framework and test through subsequent data collection and so forth	**Theory** Theory generalisation or modification, incorporating existing theory where appropriate, to build new theory or modify existing

FIGURE 29: ABDUCTION REASONING APPROACH (FROM SAUNDERS ET. AL (2009))

While abduction does offer a number of advantages, it is important to be aware that there are some issues associated with it that should be taken into consideration. It tends to be protracted, especially when compared to deductive research; often the ideas, based on much longer data collection and analysis, have to emerge gradually. In addition to not providing absolute proof, there is an inherent risk that no useful data patterns and theory will emerge from the data. Reverberating the feeling of Buchanan et al. (1988) who argue that 'needs, interests and preferences (of the researcher)… are typically over-looked but are central to the progress of fieldwork'. Hakim (2000) argues that not all decisions regarding the choice of research approach should be practical. The approach adopted, just like that of a designer, may reflect the preferred style of the researcher. Not only did adopting an abductive approach match the preferences of the researcher, it also did not result in any changes to the essence of the research questions, which is a common pitfall to be cautious of.

4.2.4 Multi-Phase Design Research Strategy

Different combinations of mixed methods research characteristics lead to various research strategies. Adopted research strategies should be guided by research questions and objectives, the extent of existing knowledge, the amount of time and other available recourses, as well as the researchers philosophical underpinnings (Saunders *et al.*, 2009).

This research project adopts a multi-phase design strategy; a choice based on the project's aim to understand the need for an impact of an intervention program and the expected outcomes being a formative and summative evaluation. Multi-phase mixed methods is an advanced design in which the researcher conducts several mixed methods projects with a common objective for the multiple projects (Creswell, 2013). In the case of this research study, the research design contains two recursive phases. One phase is a qualitative phase where multiple sources of data are used to explore processes and activities based on participant meanings. The second phase is characterised by an embedded mixed methods design and was selected due to a need to understand participant views within the context of an experimental intervention and whose expected outcomes would lead to an understanding of experimental results by incorporating perspectives of individuals. Using Morse's (1991) notation system, this research strategy design can be expressed as follows:

QUAL ➔🡐 QUAN(qual)

The research strategy is characterised in terms of implementation, priority, stages of integration and theoretical perspectives shown in Table 16. Figure 30 and Figure 31 are visual representations of the multi-phase strategy and the procedure used to carry it out.

TABLE 16: MULTI-PHASE RESEARCH DESIGN TYPE BY CRITERIA

	Research Design Type	Implementation	Priority	Stage of Integration	Theoretical perspectives
	Multi-Phase Design	Concurrent collection of qualitative and quantitative (qualitative) data	Equal	Interpretation Phase	Conceptual Framework
Phase 1	Qualitative	-	-	-	Conceptual Framework
Phase 2	Concurrent Embedded	Concurrent collection of qualitative and quantitative data	Quantitative	Analysis Phase	Conceptual Framework

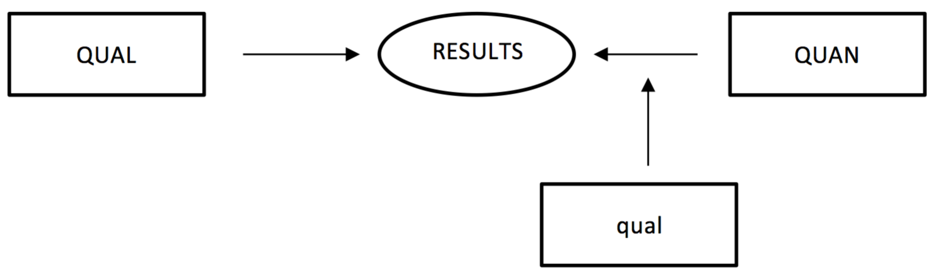


FIGURE 30: VISUAL REPRESENTATION OF MULTI-PHASE PROCEDURE

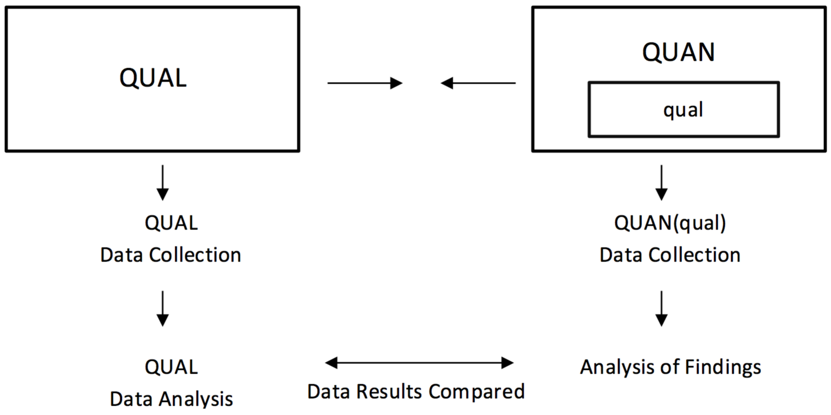


FIGURE 31: MULTI-PHASE DESIGN VISUALISATION

4.2.5 *Cross-Sectional Time Horizon*

The penultimate layer of the research onion represents the time horizon over which the research is undertaken. As the research project was undertaken to explore supply chain design within ENPD at a particular time, it's time horizon is considered to be cross-sectional (it is a snap shot of the opportunity being explored at a particular time). This is opposed to longitudinal studies, which are repeated over an extended period.

4.2.6 *Case Study and Controlled Experiment Data Collection*

The innermost layer of the research onion represents the methods, techniques and procedure that make up the study. Essentially, these are the activities that will be carried out in order to answer the research questions and fulfil the research objectives. This section aims to summarise the methods, techniques and procedures presented in more detail in Chapter 5 and Chapter 6. The QUAL phase is based on case studies, while the QUAN(qual) phase of the research strategy is realised through controlled experiments. Table 17 outlines what is entailed in the stages of the two research approaches and Figure 32 maps the approaches to the primary data collection methods, research objectives and research questions.

TABLE 17: STAGES OF RESEARCH APPROACHES (BASED ON TASHIKKORI AND TEEDIE (2010))

	Research Problems/ Data Questions	Data Collection/ Method	Data Analysis/ Procedure	Data Interpretation
Qualitative Case Study	Exploratory Process Based Descriptive Phenomenon of Interest	Interviews Open-ended Process	Description Identifying themes/categories Looking for connectedness among categories/themes	Particularisation (contextualising) Larger sense-making Personal interpretation Asking questions
Quantitative (Qualitative) Controlled Experiments	Confirmatory Outcome based Exploratory Process Based Descriptive	Instruments Score oriented Closed-ended process Predetermined hypothesis Interviews	Descriptive statistics Inferential statistics Description Identifying themes/categories Looking for connectedness among categories/themes	Generalisation Prediction based Larger sense-making

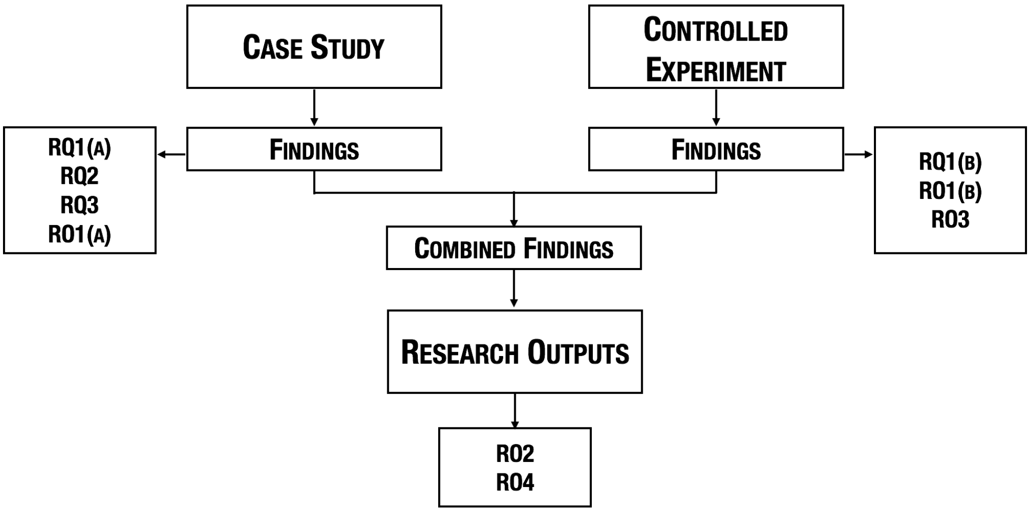


FIGURE 32: MAPPING RESEARCH APPROACHES AND METHODS TO QUESTIONS AND OBJECTIVES

With the addition of secondary data from formal theory and literature reviews, Table 18 provides a summary of the research methods used within this study, based on their relative strengths and weaknesses in comparison with other methods that are used within management and organisational research. Combining research strategies can leverage strengths of various methods; use of both qualitative and quantitative research methods enables researchers to have greater faith in their findings and make greater contributions to their field.

TABLE 18: MANAGEMENT AND ORGANISATIONAL RESEARCH METHODS USED WITHIN STUDY (TASHAKKORI AND TEEDIE (2010))

	Management and Organisational Research Methods						
	Realism	Access to Participants	Detail	Measurement Precision	Control	Statistical Conclusion Validity	Generalisability
Interviewing	High	High	Moderate	Moderate	Low	Low	Moderate
Experiment	Moderate	High	Moderate	High	High	High	Low
Formal Theory/ Literature Reviews	Low	Low	Moderate	Low	Low	Low	High

4.3 Mapping Activities to Research Objectives

Table 19 summarises the activities carried out to fulfil the research objectives, along with the associated research method.

TABLE 19: MAPPING RESEARCH ACTIVITIES TO RESEARCH OBJECTIVES

Objective	Activities	Research Method
RO1: Establish what is required of (a) the internal and external supply and (b) design departments when adopting a 3DCE based approach to ENPD.	Define what characteristics a 3DCE based approach to ENPD would have	Formal Theory/ Literature Review
	Determine what supply and design departments currently do during NPD and ENPD	Interviewing
	Determine what supply and design departments have to do for a 3DCE based approach to work	Formal Theory/ Literature Review/Interviewing
RO2: Develop a method, based on 3DCE and with a supply chain focus, which can be utilised during the environmental new product development process.	Isolate supply chain aspects that can be integrated into a ENPD method	Formal Theory/ Literature Review
	Develop a method for ENPD that has supply chain aspects integrated within it	Formal Theory/ Literature Review/ Interviewing/ Experiments
RO3: Critically assess the impact of early supply chain design on environmental new product development outputs.	Determine environmental attributes to assess and how to assess them	Formal Theory/ Literature Review/ Experiments
	Assess the environmental attributes in a product design setting	Experiments
	Analyse the assessment outputs to determine the effectiveness of early supply chain design to improve ENPD	Experiments
RO4: Make recommendations to support and improve how the supply chain is utilised during the ENPD process.	Holistically assess the outputs of the Case Study and Experiments	Formal Theory/ Literature Review, Interviewing and Experiments
	Make inferences pertaining to how supply chain utilisation can be improved to support ENPD	Interviewing and Experiments

4.4 Triangulation

As multi-methodology employs different research techniques, the strategy of triangulation – where the choice of methods is intended to investigate a single social phenomenon from different vantage points (Denzin, 1970) – can be adopted. Figure 33 illustrates the three different types of triangulation that will be carried out within this research project. The first is methodological, which refers to the use of multiple methods to study the same research problem; this is achieved through the use of the multi-methodology approach. The second is data triangulation where a variety of data sources are utilised in the research; in this it is the use of interviews and experiments.

It is important to note that one cannot assume that data collected from different methods will corroborate as implied in the triangulation strategy (Denzin, 1970). Data collected from different methods cannot be simply added together to produce a unitary or rounded reality. When methods are combined, there are a number of possible outcomes; corroboration, where the findings are similar, is only one of at least four possibilities (Morgan, 1998; Bryman, 2001; Hammersley, 1996). The others include contradiction, where findings conflict; complementary, where findings differ but offer insights and elaboration, where one set of findings exemplify how the other set of finding applies in particular cases (Brannen, 2005). Additionally, it is important to note that while triangulation can reduce the chance of error by gathering data from various sources, it does not eliminate it (Gray, 2006). The third and last type is theory triangulation where by multiple perspective are used to interpret the results; this does not come into effect until after the data collection phase has been concluded. Drawing upon data across the qualitative/quantitative spectrum can take place at all phases of the research process, shaping the concepts and ideas at the start of the enquiry and influencing the process of analysis, as well as occurring at the later stage when conclusions are drawn (Brannen, 2005).

TRIANGULATION

DATA	METHODOLOGICAL	THEORY
THE USE OF DATA FROM EXPERIMENTS, PROTOCOLS AND INTERVIEWS.	THE USE OF CASE STUDIES AND CONTROLLED EXPERIMENTS TO STUDY THE RESEARCH PROBLEM.	THE USE OF MULTIPLE PERSPECTIVES (ENPD AND SCM) TO INTERPRET THE RESULTS.

FIGURE 33: TYPES OF TRIANGULATION WITHIN PROJECT

4.5 RESEARCH DELIVERABLES

According to O'Leary (2005), to influence the level of effectiveness and relevance it is essential to ensure that project deliverables: engage communication; are based on useful outcomes; and have a broad dissemination in the real world. With this in mind, this project aimed to deliver the following in addition to the research account:

- Procedures associated with the 3DCE based method for ENPD
- Recommendations and guidelines to support the method
- Tools to support the method

Details on these can be found in Chapter 7.

4.5.1 ASSESSMENT

As the researcher must have some way of demonstrating that the findings are 'true', the assessment and verification of a research study is vital. In the absence of verification, the study would lack credibility and, as Silverman (2006) has stressed, *credibility is essential for all research* whether it be qualitative or quantitative in nature. The credibility (or validity) of research should be demonstrated as part of the research process and should not be taken for granted. For research to achieve credibility it needs to demonstrate that its findings are based on practices that are acknowledged to be the basis of good research. Due to its mixed methods nature, various parts of this study were subject to different evaluation factors; these are outlined in Table 20.

TABLE 20: FACTORS FOR QUANTITATIVE AND QUALITATIVE RESEARCH ELEMENT ASSESSMENT

Qualitative	
Factor	Description
Credibility	The accuracy and precision of the data. Also concerns the appropriateness of the data in terms of what is being researched.
Confirmability	The quality of the results produced by an inquiry in terms of how well they are supported by informants involved in the study.
Dependability	Refers to the stability or consistency of the inquiry processes used over time.
Transferability	Refers to the applicability of findings in one context (where the research is done) to other contexts or settings (where the interpretations might be transferred).

Quantitative	
Factor	Description
Internal Validity	Refers to correlation questions (cause and effect) and to the extent to which causal conclusions can be drawn.
External Validity	The extent to which it is possible to generalise from data to a larger population or setting.
Construct Validity	Concerned with the measurement of abstract concepts and traits.
Statistical Validity	The extent to which the study has made use of appropriate design and statistical methods that will allow it to detect effects that are present.
Content Validity	The extent to which a measure represents all facets of a given construct.
Reliability	Indication of consistency between two measures of the same thing.

4.5.2 Core Assumption

As it incorporates elements of both, mixed method research resides in the middle of the qualitative and quantitative research continuum; it integrates two forms of data using distinct research designs that may involve theoretical frameworks and theoretical assumptions. The core assumption of this form of inquiry is that the combination of qualitative and quantitative approaches provides a more complete understanding of a research problem than either approach alone.

Chapter Summary

Based on compatibility theory, the research project adopted a pragmatic philosophy, which acknowledges the different philosophical assumptions, strengths and weaknesses associated social-constructivism and positivism and advocates for the use of methods from the two paradigms in the same study. This was supported by a mixed method complex methodology and abductive reasoning, which resulted in a multi-phase design research strategy. The research strategy can be described as QUAN(qual)➔🡐 QUAL, with the QUAN(qual) phase being realised through experiments and the QUAL phase through case studies. Research activities were also mapped to research objectives and research methods that would inform them. The chapter concludes by addressing triangulation and assessment issues that are embedded in the research design.

5. Multi-Case Study Exploring Supply Chain Management and the New Product Development Process

Chapter Overview

This chapter covers the multiple-case study that was conducted to help fulfil Research Objectives 1(a), 2 and 4 and to provide answers for Research Questions 1(a), 2 and 3. The main aim of the multi-case study was to explain the complex causal links in real-life NPD and SCM interaction and describe and explore the real life context within which environmental considerations are introduced into NPD. The chapter contains details on selected cases, the developed protocol, data collection and analysis, and individual and cross-case reports. The chapter concluded with a presentation of the outputs of the multi-case study in the form of proposed tools.

Highlighted Contents

		Section
Define, Design & Prepare	Identification of issues and questions of interest	5.1
	Review of relevant literature and theories	3
	Case Selection	5.2.1
	Development of data collection tools and protocol	5.3
Collect & Analyse	Collection of data	5.3
	Evidence analysis	5.4
	Individual case study report write up	5.5.2
Analyse & Conclude	Draw cross-case conclusions	5.5.1
	cross-case report write up	5.5.2
	Outputs	5.6

Defined as "an empirical study that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2003), the case study is ideal when a holistic, in-depth investigation is needed (Feagin *et al.*, 1991) as it explores themes and subjects from a much more focused range of people, organisations and contexts.

5.1 The Multi-Case Study

The case study approach was adopted with the aim of explaining the complex causal links in real-life NPD and SCM interaction and describing and exploring the real life context within in which environmental considerations are introduced into NPD. As the case study approach focuses on one (or just a few instances) of a particular phenomenon with a view to providing an in-depth account of events, relationships, experiences or processes occurring in that particular instance, it can prove invaluable to adding to understanding, extending experience and increasing conviction about a subject (Stake, 2000).

While, traditionally, the case study method is used to address 'how' and 'why' questions, Levy (1988) and Tellies (1997) successfully used the method to address 'what' and 'who' questions in their information technology studies; this project adopted a similar approach. This multi-case study aimed to answer the following 'what' and 'how' questions:

> *RQ1a: When transitioning to a 3DCE based approach to ENPD, how should the supply department support the development process and interact with the external supply chain?*
>
> *RQ2: What are the challenges associated with supply chain information sharing and how can the practice be improved through the use of supply-based methods and relationships for the benefit of product development?*
>
> *RQ3: What is the state of supply chain awareness in companies and how can it be used/improved for the benefit of supply chain information sharing?*

It addresses the following research objective:

> *RO1a: Establish what is required of the internal and external supply when adopting a 3DCE based approach to ENPD*

The outputs and insights gained from the case study also partially fed into the fulfilment of the following research objectives:

> *RO2: Develop a method, based on 3DCE and with a supply chain focus, which can be utilised during the environmental new product development process.*
>
> *RO4: Make recommendations to support and improve how the supply chain is considered during the ENPD process.*

An empirical investigation of a contemporary phenomenon within its real-life context, like the investigation into environmental new product development with supply chain design, is one situation in which case study methodology is applicable. The way in which the research questions are framed determined the research strategy that is adopted. Comprised of 'what' questions that justify an exploratory study, and 'how' questions that make it explanatory as well, this study can be described as being an explanatory-exploratory case study. The exploratory strategy comes from the need to examine the current relationship between various product development and supply chain management issues that have the potential to impact the introduction of environmental considerations into the NPD process; while the explanatory strategy looks to establish how these issues can be applicable to internal and external collaboration, supply chain information sharing and supply chain awareness.

5.2 Case Study Design

The study adopted an embedded multi-case study design; this means that it contains more than one case and involves more than one unit of analysis. Figure 34 is a 4x4 matrix that illustrates the characteristics of this design in comparison with other basic case study designs. Multiple case designs have distinct advantages and disadvantages in comparison to single case designs. The evidence from multiple cases is often considered more compelling and the overall study is therefore regarded as being more robust (Herriott and Firestone, 1983). The rationale for multiple case designs derives directly from an understanding of literal and theoretical replications. The multi-case design follows a replication, not sampling, logic. This means the multiple cases are not to increase the sample, rather to replicate the findings of one case over a number of instances, to lend compelling support for an initial set of propositions. Embedding various units of analysis into the study allows for more sensitivity and for any slippage between research questions and the direction of the research study to be identified. It is important to note and keep in mind that one of the dangers of embedded designs is that the sub-units of analysis may become the focus of the study itself, diverting attention away from the larger elements of the analysis.

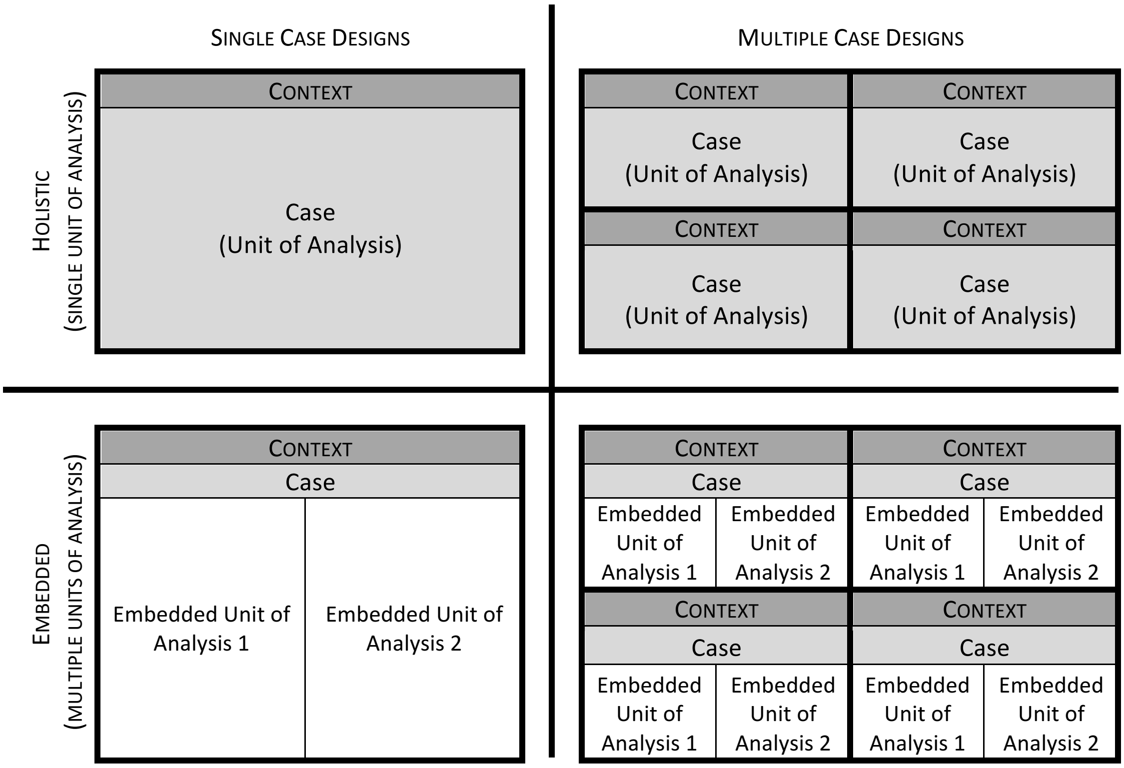


FIGURE 34: BASIC TYPES OF DESIGNS FOR CASE STUDIES (FROM YIN (2003))

The Study Cases

The cases within this study are organisations that conduct product development. The cases serve in a manner similar to multiple experiments, with similar results (a literal replication) or contrasting results (a theoretical replication) predicted explicitly at the onset of the investigation. The cases were chosen carefully and for the reasons described in Table 21; the table also states the replication logic associated with each of the selected cases. In total, 6 organisations were analysed, the organisations can be split into 4 different cases. Data was not pooled across cases, rather the results were part of each individual case study and for each case an embedded case design was used. In the ENPD context, the cases mainly focus on procurement as it relates to the sourcing activities, negotiation and strategic selection of goods and services (the aspect of SCM that is of interest as this is where supply chain design is typically conducted).

TABLE 21: CASES WITHIN THE STUDY

		CASE	DESCRIPTION	REPLICATION LOGIC	BASIS OF SELECTION
Context: Prospective ENPD Organisation	CASE 1	New Product Development and Supply Chain Management	An organisation that currently does not but is actively looking to practice ENPD		Insight into how companies that are looking to conduct ENPD deal with SCM and NPD issues.
	CASE 2	New Product Development and Supply Chain Management	An organisation that currently does not but is actively looking to practice ENPD.	Literal Replication of Case 1	
Context: ENPD Organisation	CASE 3	Procurement	How an organisation that conducts ENPD deals with procurement issues.	Theoretical Replication of Case 1	Learnings from a company's procurement.
	CASE 4	Procurement	How an organisation that conducts ENPD deals with supply chain risk issues.	Literal Replication of Case 3	Learnings from a company's procurement.
	CASE 5	Green Procurement	How an organisation that conducts ENPD deals with green procurement issues.	Literal Replication of Case 3	Learnings from a company conducting green procurement.
	CASE 6	Compliance Management	How an organisation that conducts ENPD deals compliance management.	Literal Replication of Case 3	Learnings from a company tackling compliance management.

The Unit of Analysis

The unit of analysis is a critical factor in the case study; within the context of this study, it was SCM issues within NPD. Due to its more complex or embedded design, the unit of analysis also incorporated subunits of analysis. Based on the questions that the study aimed to answer the subunits of analysis were defined as outlined in Table 22; the subunits are also linked to the research questions that they aimed to address. These sub-units represent the issues that are fundamental to understanding SCM issues within NPD, the unit of analysis being examined.

TABLE 22: SUBUNITS OF ANALYSIS

UNIT OF ANALYSIS	SUB-UNIT OF ANALYSIS	DESCRIPTION	LINK TO RQS
SUPPLY CHAIN MANAGEMENT ISSUES WITHIN NEW PRODUCT DEVELOPMENT	PRODUCT DEVELOPMENT	The process that the organisations use to carry out product development.	RQ1(a), RQ2
	SUPPLY CHAIN MANAGEMENT ISSUES	The manner in which the company manages various supply chain issues related to product development.	RQ1(a), RQ2, RQ3
	INTERNAL AND EXTERNAL COLLABORATION	How the product development and supply chain management functions (or teams) within the company interact with each other and with any external entities.	RQ1(a), RQ2
	ORGANISATIONAL INFORMATION SHARING	How the organisation deals with information sharing, internally and externally.	RQ2, RQ3

Summary

Bringing together all the components discussed above, the embedded multi-case study design for this research is shown in Figure 35.

Prospective ENPD Organisation		Prospective ENPD Organisation	
Case 1: Supply Chain Management and New Product Development		Case 2: Supply Chain Management and New Product Development	
New Product Development	Supply Chain Management Issues	New Product Development	Supply Chain Management Issues
Internal and External Collaboration	Organisational Information Sharing	Internal and External Collaboration	Organisational Information Sharing
ENPD Organisation		ENPD Organisation	
Case 3: Procurement		Case 4: Supply Chain Risk Management	
New Product Development	Supply Chain Management Issues	New Product Development	Supply Chain Management Issues
Internal and External Collaboration	Organisational Information Sharing	Internal and External Collaboration	Organisational Information Sharing
ENPD Organisation		ENPD Organisation	
Case 5: Green Procurement		Case 6: Compliance Management	
New Product Development	Supply Chain Management Issues	New Product Development	Supply Chain Management Issues
Internal and External Collaboration	Organisational Information Sharing	Internal and External Collaboration	Organisational Information Sharing

FIGURE 35: EMBEDDED MULTI-CASE STUDY DESIGN

5.3 Evidence Collection

The underlying objective within this chapter was to obtain first-hand information and knowledge from industry that could aid in the attainment of the project aims. The collection of this evidence was guided by a case study protocol. The protocol contained an overview of the case study project, field procedures, case study questions and a guide for the case report. An over view of the developed protocol can be found in Appendix 5.1: Multi-Case Study Protocol Sections and Table of Contents. Table 23 presents an overview of the characteristics of the case study companies and interview informants. The sector classification is based on the International Standard Industrial Classification of All Economic Activities (UN Statistics Division, 2008). Multiple sources of data were used; the evidence collected for each of the cases is detailed in Table 24. An evaluation of the strengths and weaknesses of the evidence is available in Appendix 5.2: Evaluation of Strengths and Weaknesses Used Evidence. The rationale for using multiple sources of data is the triangulation of evidence. The documentation for the study is available in two collections. The first is the evidentiary database, or the collected raw data, and the second collection is made up of the reports produced by the investigator.

TABLE 23: OVERVIEW OF CASE STUDY COMPANY AND INTERVIEW INFORMANT CHARACTERISTICS

	Company Characteristics					Interviewee Characteristics		
	Company	HQ Location	Sector	No. of Employees	ENPD Practice	Number	Location	Department
Case 1	C001	Italy	C28 - Manufacture of machinery and equipment	3 000	No	5	Germany	R&D and SCM
Case 2	C002	Switzerland	C32 - Other manufacturing	9 000	No	3	Italy	R&D, Production and SCM
Case 3	C003	UK	C29 - Manufacture of motor vehicles, trailers and semi-trailers	32 000	Yes	3	UK	Cost Engineering and Group Engineering
Case 4	C004	Japan	C29 - Manufacture of motor vehicles, trailers and semi-trailers	330 000	Yes	1	Japan	SCM
Case 5	C005	Japan	C32 - Other manufacturing	56 000	Yes	1	Japan	SCM
Case 6	C006	UK	C30 - Manufacture of other transport equipment	54 000	Yes	2	UK and Germany	SCM and HSE

TABLE 24: EVIDENCE COLLECTED FOR CASE STUDY BY CASE

		Evidence
Case 1	C001: Supply Chain Management and New Product Development	Interviews with five key informants from R&D and SCM; Two Day Site Visit including tour of production; Site Visit Notes; Company Profile; Sustainability Report; Annual Report; R&D Presentation; Organisation Chart; IDEF0 Diagrams; Case Notes
Case 2	C002: Supply Chain Management and New Product Development	Interviews with three key informants from R&D, Production and SCM; Two Day Site Visit including tour of production; Site Visit Notes; Company Profile; Sustainability Report; Annual Report; R&D Presentation; Organisation Chart; IDEF0 Diagrams; Case Notes
Case 3	C003: Procurement	Interviews with three key informants in Cost Engineering and Group Engineering; Company Profile; Annual Report; Cost Engineering Presentation; Case Notes
Case 4	C004: Procurement	Interviews with one key informant in SCM; Company Profile; Annual Report; Case Notes
Case 5	C005: Green Procurement	Interviews with one key informant in SCM; Environmental Presentation; Company Profile; Sustainability Report; Annual Report; Case Notes
Case 6	C006: Compliance	Interviews with two key informants in SCM and HSE; Half Day Site Visit; Site Visit Notes; Company Profile; Annual Report; Compliance Presentation; Supply Chain Risk Presentation; Case Notes

5.4 Evidence Analysis

Data analysis consists of examining, categorising, tabulating, testing or otherwise recombining evidence, to draw empirically based conclusions.

5.4.1 The Analysis Procedure

Generally, researchers interpret their data in one of two ways: holistically or through coding. Holistic analysis does not attempt to break the evidence into parts, but rather to draw conclusions based on the text as a whole; while with coding data are systematically searched to identify and/or categorise specific observable actions or characteristics. Both were used in this study as the informant interviews, which form the focal point of the data analysis, were coded and the outputs holistically interpreted along with the other forms of evidence to inform the narrative write up. Through this procedure, patterns among the data were identified as well as patterns that give meaning to the case study. The holistic and coding data analysis were both supported by the computer aided data analysis software Nvivo.

Coding

The interview transcripts were explored using the thematic approach; this involves the extraction of key themes from narrative data (Teddlie and Tashakkori, 2009). The coding was divided into two coding cycles as recommended by Saldana (2013); during the first coding cycle, the initial coding of data occurs and then in the second cycle the outputs of the first cycle are analysed. The different cycles use different methods, with different methods resulting in different types of codes being generated. Additionally, as recommended by Miles and Huberman (1994) the coding process was kick-started by a provisional 'start list' of categories generated from the conceptual framework, research questions and literature review. This provisional 'start list' is available in Appendix 5.3: Provisional 'Start List' of Categories and Codes. As the coding progressed, codes were added until all data of interest in the interview transcripts were assigned a code. Together, Table 25 and Table 26 detail the procedure that was undertaken during the coding analysis. Table 25 links the coding cycles to the methods used within them and the types and descriptions of the codes that were generated and Table 26 shows the sequence in which the different types of coding were used and examples of the output codes; simultaneous coding was carried out throughout the whole first cycle whenever appropriate.

Outputs

Details on the outputs from the coding process are contained in Table 27. The outputs related to Case 1 are presented in Appendix 5.4: Case 1 Coding Output Codes in their entirety to show the form that the outputs for each of the cases took. The same treatment was applied to all the cases; the combined outputs of the cases will be addressed in the cross-case data exploration detail in Section 5.4.2.

TABLE 25: CODING METHODS AND TYPES

	Type of Method	Type of Coding	Description
First Cycle	Grammatical	Attribute Coding	Logs essential information about the data and demographic characteristics of the participants for future management and reference.
		Simultaneous Coding	When two or more codes are applied to or overlap with a qualitative datum to detail its complexity.
	Elemental	Structural Coding	Applies a content-based or conceptual phrase representing a topic of inquiry to a segment of data to both code and categorise the data corpus.
		Descriptive Coding	Assigns basic labels to data to provide an inventory of their topics.
	Affective	Values Coding	Assesses a participant's integrated values, attitudes and belief systems at work.
		Versus Coding	Acknowledges that humans are frequently in conflict, and the codes identify which individuals, groups or systems are in contradiction.
		Evaluation Coding	Focuses on how we can analyse data that judge the merit and worth of interventions and methods.
	Exploratory	Holistic Coding	Applies a single code to each large unit of data in the corpus to capture a sense of the overall contents and the possible categories that may arise.
		Provisional Coding	Begins with a 'start list' of researcher generated codes based on what preparatory investigation suggests might appear in the data before they are analysed.
Second Cycle		Pattern Coding	Develops the "meta-code" – the category label that identifies similarly coded data. Pattern codes not only organise the corpus but also attempt to attribute meaning to that organisation.

TABLE 26: SEQUENCE OF CODING AND EXAMPLES OF RESULTANT CODES

	Step	Code Type	Example Codes	Data Point Examples
First Cycle	1	Attribute Coding	Company	"Inverter and gear manufacturing company, specialising in software solutions for individual companies"
	2	Holistic Coding	Barriers	"Management are not so interested but do see some marketing benefit"
			Competition	"Competition at the moment is mainly based on motor efficiency"
	3	Provisional Coding	Supply Chain Awareness	"We thought our supply chain was pyramid shaped, but it turned out to be barrel-shaped"
			NPD Process	"During the design phase the physical design and functional design are completed in addition to all parts and components"
	4	Structural Coding	Competitiveness	"We are in another part of the world but Chinese factories are hard to beat cost wise"
			Duplicity	"Within the industry, companies are willing to highlight the different environmental initiatives that they have but they do not share the results of any of their findings. C001 said that they too would not be willing to share their findings"
	5	Descriptive Coding	SCM (Dynamics)	"Interviewer: So there is competition between your suppliers and that is a benefit to you as I am guessing that they would maybe lower cost or quality. Interviewee: Yeah and this is a tool of pressure for us to tell them 'hey, you are not alone, I am requesting from company A, B or C'"
			The Industry (Trends)	"Quite a lot of the customers are now asking for environmental reports"
	6	Values Coding	Barriers (Lack of Corporate Buy In)	"X001 does not seem to deem the undertaking of environmental projects as necessary"
			Barriers (Priorities)	"Time and priorities are having an impact in the implementation of environmental projects"
	7	Versus Coding	Them vs. Competitors	"If the company has an online system to order parts, you have a direct access to a database and you can directly analyse where the company is living and you see the complete structure of your business. That is what we do not have today, but it is usual for our larger competitors"
			Relationship vs. Cost	"You get better prices if you have the contact with a supplier who is already delivering components."
	8	Evaluation Coding	SCM [Supplier Sourcing (Challenging)]	"Not to meet certain of those targets can be quite punitive. To mistakenly include small elements of products from certain countries that are embargoed by certain others that you would like to deliver into also means that your product however wittingly achieved can no longer be sold in that particular market"
Second Cycle	9	Pattern Coding	C003 [C003 and the Environment (Organisational Learning)]	"I think what have got to do at this time is communicate the right level of knowledge so that people go and get it"
			C004 [Operational Supply Chain Management (Supply Chain Configuration)]	"8 to 10 supply chain tiers"
			C006 [Operational New Product Development (Environmental Considerations)]	"Developing products with minimal environmental impact by raising energy efficiency, switching to refrigerants with the least possible burden on the environment, and making products easier to recycle."

TABLE 27: OUTPUTS OF THE CODING PROCESS

Analysis Stage		Outputs	Details
Coding	First Cycle	Thematic codes and how they relate to each other	The main aim of this stage was to gain a better understanding of the data and to broadly categorise it. Outputs for Case 1 are shown in Appendix 5.4: Case 1 Coding Output Codes.
	Second Cycle	Major themes and how they relate to each other	With the relevant data categorised broadly, the aim of this stage was to explore it further by assigning it to more specific categories. Outputs for Case 1 are shown in Appendix 5.4: Case 1 Coding Output Codes.
Memoing		Analytic Memos	When coding data there is a risk that the context in which the information was offered is lost, with this in mind, it was important to make memos of any contextual issues and insights which would be of interest when drawing together the results from the coding. A sample of generated memos for Case 1 is in Table 28.

TABLE 28: SAMPLE OF CASE 1 ANALYTIC MEMOS

Analytic Memos
- Not only are they under pressure to become more environmentally conscious but also they have some customers that are asking questions about how ethical their products are. This suggests that perhaps in the future they will have to ensure that they are responsibly sourcing their materials and components.
- There was a long pause when asked if they would encourage their suppliers to also go green. The interesting thing here is that just because the organisation wants to go green does not mean the people within it are on board. It is important to instil the company values into the employees.
- They recognised that you can have management systems that allow you to visualise your whole business and business processes, internal and external. They said some companies have these but these tend to be large companies and they are a small company so they do not have that. Size has implications on how they do things.

5.5 Results and Discussion

In the following section, the results from the evidence analysis will be presented, interpreted and explained. Cross-case data exploration (See Section 5.5.1) and case-study reports (See Section 5.5.2) will be used as a vehicle for presenting and discussing the results. The results in the cross-case exploration are the outcome of the thematic coding and the case reports in this section are informed by holistic analysis of all the data which does not attempt to break the evidence into parts, but rather to draw conclusions based on the data as a whole.

5.5.1 Cross-Case Data Exploration

The meta-matrix is a master chart assembling descriptive data from each of cases in a standard format. It contains all relevant, condensed data that would inform the answers to the research questions; it is ordered by case and can be seen in Appendix 5.5: Case Based Meta-Matrix. Following that, the data was condensed further, clustered by case and partitioned by research question to create separate matrices. Having a single descriptive matrix addressing a single research question made cross-case analysis simpler as overview of the data was easier. Elements of the research questions that would inform answers to the questions were isolated and these make up the column headings. The row readings are made up of the cases and the relevant results fit into the matrices. Based on the topics covered by the research questions that the multi-case study aimed to answer, the matrices relate to the supply chain department (RQ1b), information sharing (RQ2) and supply chain awareness (RQ3).

Supply Chain Department

> *RQ1b: When transitioning to a 3DCE based approach to ENPD, how should the supply department support the development process and interact with the external supply chain?*

RQ1b was split into 'supply department supporting product development process' and 'supply chain interaction with supply chain'; Table 29 is the case-ordered matrix that contains distilled results that relate to these.

There are more similarities than differences between the companies that practice ENPD; there is a lot of overlap in practices. Within these companies, the supply function has a highly active role in product development. The supply chain department works closely with both internal functions and the external supply chain. Cross case analysis of the companies that practice ENPD shows strong replication of results.

The results for C002 are closer those of the companies that practice ENPD than to C001, the other prospective ENPD company. This shows that C002 is in a better position than C001 to adopt 3DCE based ENPD as its supply chain department already supports the product development process and works closely with suppliers. C002's supply department currently has a more active role in the product development process than C001's. The differences between the organisations that are looking to practice ENPD show that there are likely to be variations in the starting positions of companies looking to implement ENPD and it is important for an organisation have awareness of their current state so they know exactly what they need to do in order to increase the likelihood of implementing ENPD successfully.

TABLE 29: CASE ORDERED DESCRIPTIVE MATRIX SHOWING DATA RELATING TO RQ1B

		Supply department supporting product development process	Supply department interaction with supply chain
Context: Prospective ENPD Organisation	C001	Procure parts and materials Source component suppliers Not actively involved in product design process	Procurement centred on cost and delivery Outsourcing data collection and sourcing activities Mainly sole sourcing Strategic supplier management Supplier collaboration for cost reduction
	C002	Procure parts and materials Source component suppliers Early involvement in NPD process Part of cross-functional product development team Interface and work closely with R&D and other internal functions Interface between supply chain and other internal functions	Procurement focused on cost, quality and delivery Interface between supply chain and other internal functions Mainly sole sourcing Strategic supplier management Supplier collaboration for quality
Context: ENPD Organisation	C003	Procure parts and materials Source component suppliers Ethical sourcing Interface and work closely with R&D and other internal functions Part of cross-functional product development team Interface between supply chain and internal functions Supplier collaboration management Supply chain risk management	Procurement focused on cost, quality, delivery and risk Outsourcing and licensing Interface and work closely with supply chain and other internal functions Shift from sole to multi-sourcing Strategic supplier management Supplier partnerships Supplier development Multi-faceted supplier collaboration Shift from emotional to data driven sourcing Dissemination of best practices

	C004	Procure parts and materials Source component suppliers Interface and work closely with Engineering and other internal functions Early involvement in NPD process Central role in product development Part of cross-functional product development team Interface between supply chain and internal functions Supplier collaboration management Supply chain risk management Supplier collaboration management	Procurement focused on cost, quality, delivery and risk Interface and work closely with supply chain and other internal functions Shift from sole to multi-sourcing Strategic supplier management Supplier partnerships Supplier development Multi-faceted supplier collaboration Dissemination of best practices
	C005	Procure parts and materials Source component suppliers Green procurement Interface and work closely with Design and other internal functions Central role in product development Part of cross-functional product development team Interface between supply chain and internal functions Supplier collaboration management Supply chain risk management Actively promote eco-design to suppliers	Procurement focused on cost, quality, delivery and environment Interface and work closely with supply chain and other internal functions Strategic supplier management Supplier partnerships Supplier development Multi-faceted supplier collaboration Dissemination of best practices Dissemination of green practices
	C006	Procure parts and materials Source component suppliers Interface and work closely with Engineering and other internal functions Interface between supply chain and internal functions Supplier collaboration management Supply chain risk management	Procurement focused on cost, quality, delivery and risk Materials declarations Interface and work closely with supply chain and other internal functions Strategic supplier management Supplier partnerships Supplier development Multi-faceted supplier collaboration Dissemination of best practices

Upon further analysis, the data in the matrix was condensed into Table 30; it is a summary table that contains data from across all the cases that contributed to answering RQ1b in Section 9.1.1.

TABLE 30: SUMMARY TABLE WITH CROSS-CASE DATA RELATING TO RQ1B

HOW THE SUPPLY DEPARTMENT SUPPORTS THE PRODUCT DEVELOPMENT PROCESS	HOW THE SUPPLY DEPARTMENT INTERACTS WITH THE EXTERNAL SUPPLY CHAIN
Procure parts and materials Source component suppliers Early involvement in NPD process Part of cross-functional product development team Interface and work closely with design and other internal functions Interface between supply chain and internal functions Supplier collaboration management Supply chain risk management	Procurement focused on cost, quality, delivery, environment, risk etc. Shift from sole to multi-sourcing Interface and work closely with supply chain and other internal functions Strategic supplier management Supplier partnerships Supplier development Multi-faceted supplier collaboration Dissemination of best practices

Information Sharing

> *RQ2: What are the challenges associated with supply chain information sharing and how can the practice be improved through the use of supply-based methods and relationships for the benefit of product development?*

RQ2 was split into 'information sharing challenges', 'information sharing practices' and 'supply methods and relationships'; Table 31 is the case ordered matrix that contains distilled results that relate to these.

Much like the data relating to the supply chain department, the data for information sharing is mostly replicated among the companies that currently practice ENPD and C002 is closer to those organisations than to C001. Looking at the data holistically shows that information sharing issues can be split into those relating to: information technology; availability of information; and willingness to share. It is those companies that have open and trust-based relationships with their suppliers that seem to be able to obtain information. There is also the recognition, particularly among the ENPD companies, that information sharing is an industry-wide issue that can be tackled by the industry working together.

TABLE 31: CASE ORDERED DESCRIPTIVE MATRIX SHOWING DATA RELATING TO RQ2

<table>
<tr><th></th><th></th><th>INFORMATION SHARING CHALLENGES</th><th>INFORMATION SHARING PRACTICES</th><th>SUPPLY METHODS AND RELATIONSHIPS</th></tr>
<tr><td rowspan="2">Context: Prospective ENPD Organisation</td><td>C001</td><td>Cultural and language barriers
Mistrust of users of information
Information unavailability
Non-sharing culture
Limited resources
Cost of information technology
Information technology security concerns</td><td>Reticent to use web portal due to complexity
Information mainly shared through data sheets
Product testing to generate technical information</td><td>Supplier segmentation
Strategic supplier relationship management
Relationship-based supplier collaboration</td></tr>
<tr><td>C002</td><td>Cultural and language barriers
Information unavailability
Non-sharing culture</td><td>IT used to collate and share information internally
Product testing to generate technical information
Focus on information regarding critical components
Relationship cultivation for information sharing benefits</td><td>Supplier segmentation
Strategic supplier relationship management
Relationship-based supplier collaboration</td></tr>
<tr><td>Context: ENPD Organisation</td><td>C003</td><td>Cultural and language barriers
Complex and large supply chain
Too much IT variety
IT infrastructure not fully supportive of advanced information sharing
Organisation structures hamper information sharing</td><td>IT used to collate and share information internally and with supply chain
Encouragement of industry consolidation of information sharing
Promotes industry wide information sharing</td><td>Supplier segmentation
Strategic supplier relationship management
Relationship-based supplier collaboration
Use of IT to manage relationships and information sharing
Bonus-Malus supplier evaluation system</td></tr>
</table>

	C004	Cultural and language barriers Applying IT to information sharing Management of operational impacts of IT Non-sharing culture	IT used to collate and share information internally and with supply chain Collaboration and relationship cultivation through information sharing Internally information flows freely up, down and across hierarchy Openness builds trust and that improves supply chain information sharing Promotes industry wide information sharing	Supplier segmentation Strategic supplier relationship management Relationship-based supplier collaboration Use of IT to manage relationships and information sharing Use of KPIs to evaluate suppliers
	C005	Cultural and language barriers Mistrust of users of information Non-sharing culture	Openly shares information with suppliers Openness builds trust and that improves supply chain information sharing Active promotion of information sharing amongst suppliers Willingness to share information a procurement requirement IT used to collate and share information internally and with supply chain Disclosure of environmental information Promotes industry wide information sharing	Supplier segmentation Strategic supplier relationship management Relationship-based supplier collaboration Use of IT to manage relationships and information sharing Dissemination of best practices Strong organisational culture
	C006	Cultural and language barriers Constantly updating information Suppliers no resources to spare on information sharing Information unavailability Non-sharing culture	IT used to collate and share information internally and with supply chain No expectation that all supply chain members will share information Information sharing restricted internally to combat information overload Educating suppliers for the benefit of information sharing Information sharing embedded in some contracts Promotes industry wide information sharing	Supplier segmentation Strategic supplier relationship management Relationship-based supplier collaboration Use of IT to manage relationships and information sharing Cross functional supply chain management teams

Upon further analysis, the data in the matrix was condensed into Table 32; it is a summary table that contains data from across all the cases that contributed to answering RQ2 in Section 9.1.1.

TABLE 32: SUMMARY TABLE WITH CONDENSED CROSS-CASE DATA RELATING TO RQ2

INFORMATION SHARING CHALLENGES	INFORMATION SHARING PRACTICES	SUPPLY METHODS AND RELATIONSHIPS
Cultural and language barriers Information unavailability No resources to spare on information sharing Non-sharing culture Mistrust of information users IT and information sharing issues Organisation structures hamper information sharing Supply chain complexity	IT used to collate and share information internally and with supply chain Openness builds trust and that improves supply chain information sharing Focus on information regarding critical components Product testing to generate technical information Promoting industry wide information sharing Information sharing embedded in some contracts No expectation that all supply chain members will share information	Supplier segmentation Strategic supplier relationship management Relationship-based supplier collaboration Use of IT to manage relationships and information sharing

Supply Chain Awareness

> *RQ 3: What is the state of supply chain awareness in companies and how can it be facilitated for the benefit of supply chain information sharing?*

RQ3 was split into 'state of supply chain awareness' and 'supply chain awareness and information sharing'; Table 33 is the case-ordered matrix that contains distilled results that relate to these. There is no data relating C005 because upon analysis the evidence collected did not offer sufficient insight into the state of supply chain awareness within C005.

TABLE 33: CASE ORDERED DESCRIPTIVE MATRIX SHOWING DATA RELATING TO RQ3

		STATE OF SUPPLY CHAIN AWARENESS	SUPPLY CHAIN AWARENESS AND INFORMATION SHARING
Context: Prospective ENPD Organisation	C001	Awareness of tier 1 suppliers Limited awareness beyond tier 1 Some components supplied with supply chain information due to legislation Supply chain awareness not an objective Acknowledgement of its importance for supply chain risk management No awareness of product users beyond those in direct contact	
	C002	Awareness of tier 1 suppliers Limited awareness beyond tier 1 Supply chain awareness not an objective No awareness of product users beyond those in direct contact	

Context: ENPD Organisation	C003	Awareness of Tier 1 Reasonable awareness beyond Tier 1 Awareness essential for risk management Strategic supply chain mapping evident Mapping conducted as part of business intelligence Multi-sourcing makes supplier mapping more challenging Traceability a major issue with multi-sourcing Collaborating to develop industry solution to supply chain visibility	Incomplete information due to lack of supply chain awareness Lack of information sharing hampers supply chain mapping
	C004	Awareness of all supply chain Tiers Awareness essential for risk management Strategic supply chain mapping Experience of risks associated with lack of supply chain visibility beyond Tier 1 Supply chain visibility precursor to comprehensive supply chain management Collaborating to develop industry solution to supply chain visibility	Information flowing from sub-tier suppliers increases visibility
	C006	Awareness of Tier 1 Some awareness of beyond Tier 1 Awareness essential for risk management Strategic supply chain mapping evident Whole supply chain too complex to map Bottlenecks in chain hampers mapping activities Shift from trying to map whole supply chain to mapping critical parts Collaborating to develop industry solution to supply chain visibility	Incomplete information due to lack of supply chain awareness Lack of information sharing hampers supply chain mapping

Supply chain awareness, gained through supply chain mapping, is not something that is widespread, however, there is consensus amongst all the cases that it is an important practice, particularly for supply chain risk management. Across all the cases, there is awareness of tier 1 suppliers, moving beyond that results in varied levels of awareness. For the organisations that are not practicing ENPD, supply chain mapping is currently not an objective. The ENPD organisations practice some form of mapping which allows them to gain greater visibility of their supply chain and mitigate supply chain risks. Information sharing and supply chain awareness pose a causality, to map your supply chain you require information sharing and to have supply chain information sharing you have to have visibility of your supply chain. While mapping is individual to the company, like information sharing, supply chain visibility is seen as an issue that can be tackled at an industry level as it affects the all the companies within an industry.

Upon further analysis, the data in the matrix was condensed into Table 34; it is a summary table that contains data from across all the cases that contributed to answering RQ3 in Section 9.1.1.

TABLE 34: SUMMARY TABLE WITH CONDENSED CROSS-CASE DATA RELATING TO RQ3

STATE OF SUPPLY CHAIN AWARENESS	SUPPLY CHAIN AWARENESS AND INFORMATION SHARING
Awareness of tier 1 suppliers Varied awareness beyond tier 1 Awareness essential for risk management Strategic supply chain mapping evident Whole supply chain in majority of cases too complex to map Bottlenecks in chain hamper mapping activities Multi-sourcing makes mapping more challenging Traceability a major issue with multi-sourcing Collaborating to develop industry solution to supply chain visibility	Incomplete information due to lack of supply chain awareness Lack of information sharing hampers supply chain mapping Information flowing from sub-tier suppliers increases visibility

5.5.2 *CASE STUDY REPORTS*

Six individual case reports and one cross-case report were written, Figure 36 relates the type of case study conducted to the case reports that were produced and also outlines their form and structure. The case study report for C001 is presented here in full; for the rest of the case companies only the conclusions are presented – the full reports are in Appendix 5.6: Case Study Reports for Case 2 – Case 5. The cross-case report is also presented in full.

TYPE OF CASE STUDY	REPORT STRUCTURE	
MULTIPLE CASE STUDY	Narrative Case Study 1 ~ Narrative Case Study 6	Context Setting New Product Development Internal and External Collaboration Supply Chain Management Organisational Information Sharing Conclusions
	Cross-Case Report	The Nature of Green Competitiveness Supply Chain Management and New Product Development Supply Chain Information Sharing Supply Chain Mapping Conclusion

FIGURE 36: REPORTS AND THEIR STRUCTURE

Case 1: Prospective ENPD Organisation

In operation for over 60 years, X001 is a family run Italian company that developed into a global organisation providing electric motors, gearboxes, and other drive solutions for industrial machinery, industrial equipment and the photovoltaic and wind power industries. Now the X001 Group, consisting of the parent company and three subsidiaries, it has an annual turnover of €600 million and employs approximately 3000 people in 17 countries. The group spends approximately €3 million annually on R&D and employs around 100 people in its research and development labs.

One of its subsidiaries, acquired in 2001, is C001, a German company that manufactures electric motors, inverters, and gearboxes and specialises in the development of individual software solutions to control the hardware for its clients. C001 pride themselves on the individual service that they offer to clients and they consider the specialist knowledge they utilise in the design, development and support of their products to be a core capability. For a largely domestic company, the acquisition by X001 gave them the opportunity to realise their strategic goal of developing an export market and competing on a global scale. Through the acquisition, X001 assimilated C001 with their specialised knowledge and expertise and were able to offer more specialised products and software under their name, a departure from X001's more typical 'off the shelf' product offerings. On the other hand, C001 gained access to X001's dedicated worldwide distribution channels and were able to operate globally. Their complementary assets were the basis of the acquisition as C001 had the expertise but lacked the capacity to be a global player and X001 had the capacity but lacked the expertise that allowed them to provide technically competitive products.

Context Setting

As they look to the future, C001 are interested in expanding their operations to capture what they see as an emerging Asian market. They believe that they can thrive in that market, against the backdrop of possible indigenous competition, if they offer products that cannot be imitated or matched in terms of quality and technical performance. Along with looking to expand their operations, C001 actively keep an eye on the market they are currently servicing to ensure that they remain competitive there. Their marketing department is in charge of undertaking intensive market analysis processes where they benchmark their company's product offerings against the competition. The results of these analyses are what direct R&D efforts, which underpin the development of new products.

C001 have found that the dynamics of the industry they operate in are changing; an emerging theme is that of 'environmental sustainability', as their customers implement environmental management and audit systems (EMAS) under ISO 14001. ISO 14001 is a family of standards related to environmental management that exists to help organisations minimise how their operations negatively affect the environment, comply with applicable laws, regulations and other environmentally oriented requirements, and continually improve. It is similar to the ISO 9000 quality management family of standards in that both pertain to the process of how products are produced, rather than to the products themselves.

With this move, customers are asking for information that goes beyond trying to satisfy legislative standards in a bid to protect themselves against cheap competition by providing products with proven environmental legacy. The adoption of EMAS has resulted in C001 increasingly getting requests to supply environmental reports or material and energy certification information relating to their products. Nowhere else is this more prevalent than with the American market where these requests became so common place that providing this information was made regulatory. As a consequence, there is a barrier to entry and if C001 are to compete in that market, not only do they need to be able to provide material and energy certification information but they also need to improve the environmental profiles of their products.

In the markets that they currently serve, many of C001's competitors have adopted a traditional lifecycle costing (LCC) perspective and started publishing LCC calculation results related to their products to help customers consider through life costs. They currently do not conduct lifecycle assessments (LCA) of their products and here C001 see an opportunity.

> *"It would be good for us to focus on becoming market leaders in environmental impacts of energy transmission and be able to provide complete energy reports and full LCA's for our motors." – R&D Informant*

The industry as a whole is not yet in a position to comfortably comply with some of their customers' requests but they are working towards it. This suggests that being ahead of the competition by offering fully detailed environmental reports could be a source of advantage. C001 are fully aware of the implications that come along with being that open about their products; they would only be comfortable sharing any environmental reports if the results showed that their products were environmentally competitive compared to other offerings on the market.

C001 find themselves in a situation where retaining current markets, defeating barriers to entry of currently inaccessible markets and capturing emerging markets depends on their ability to effectively create environmentally competitive products. While they cite in their corporate literature that they aim to "promote sustainable and shared development around the world" by "supporting development while respecting the environment", it is evident that their drivers for environmental product development are not only driven by a desire to be lessen environmental impacts on the planet. Rather, environmental product development plays a more central role as it allows them to meet trending market needs and attain a competitive position; both are key to their survival as a company going into the future.

The scenario surrounding electric motors makes motors the ideal product for C001 to initially focus their environmental development efforts on. One major performance attribute of the electric motors provided by C001, which customers consider when selecting products to purchase, is the product efficiency. The fact that higher efficiency rates are looked upon more positively works in C001's favour. Within their buyer's industries, offering more efficient motors is a way of introducing more environmentally-friendly products due to the reduced use-phase impacts. In this case, improving the environmental performance of the motor is intrinsically linked with improvements in the client's product performance. The fact that the industry currently competes mainly based on motor efficiency can be viewed as the industry engaging in a form of green competition. The main challenge faced by C001 is that of trying to balance the cost of the motors they produce with their efficiency; here their positioning in the supply chain has strategic implications as shown in Figure 37. The main driver for creating a more efficient motor is that it is more cost-effective for the end user; however, their direct customers are not always the end users. Increasing the efficiency of the motor usually increases the cost of the motor and its price, when the direct customer is the end user the benefits of the reduced in-use costs offset this increase in price. When the opposite is true and the direct customer is not the end user, the situation becomes a bit more complex. In this case the direct customer will be incurring additional costs but not gaining any in-use benefits. This means that unless the end users start requesting better efficiency these direct customers will favour the cheaper and less efficient motors.

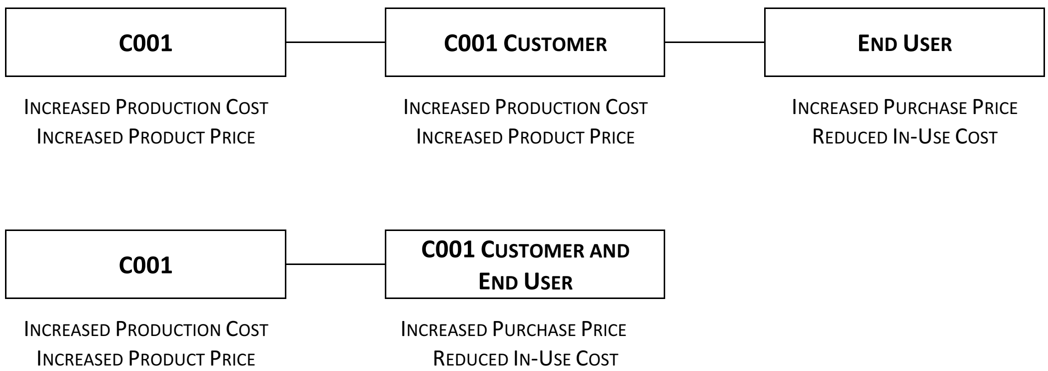


FIGURE 37: IMPACT OF C001'S SUPPLY CHAIN POSITIONING

Not only are C001 looking to offer environmentally competitive products, they are also looking to implement an EMAS of their own in accordance with ISO 14001. They are aware of at least four of their major competitors that are actively pursuing and focusing on integrating environmental considerations into the design and development of their electric motor, making time of the essence. Focusing on improving motor efficiency provides a starting point for C001 as they work toward producing environmentally-competitive product, however this is the obvious place to start and there is no doubt that this is where their competitors are starting too. To truly have competitive impact it is essential that they improve, not only other attributes of their products, but also the processes by which they produce their products.

New Product Development

Central to C001's business activity is their product development; throughout their history, they have cultivated their specialist knowledge through product development, so much so that they see it not only as a core capability but also as their main source of competitive advantage, alongside the design customisation service that they offer to go with their products. C001 produces both 'off the shelf' and 'made to order' products to ensure that they are capable of providing solutions for whatever needs their target customer base might have. Through these two product types, the company adopts different innovation strategies. With the standard parts they practice new product innovation where they aim to develop and introduce to the market products that are new and through incremental innovation, where small improvements are made, they create various product families of the standard parts. The custom products they offer are variants of the standard parts where they practice product application innovation; in this case the innovation centres on how the standard parts are used, they are altered so that they can be used in non-conventional applications. C001 mainly focus on low volume/high mix products and pride themselves on the after-sales service that they offer, which includes installation and maintenance. The product development cycle for a typical C001 motor takes approximately 2-3 years, with incremental improvements on the basic technology over 5-10 years resulting in the development of a product series. Throughout the lifetime of the products, software and electronic adaptations are made. Figure 38 illustrates the phases that typically make up C001's product development process, much of the development work is carried out during the feasibility and development phases.

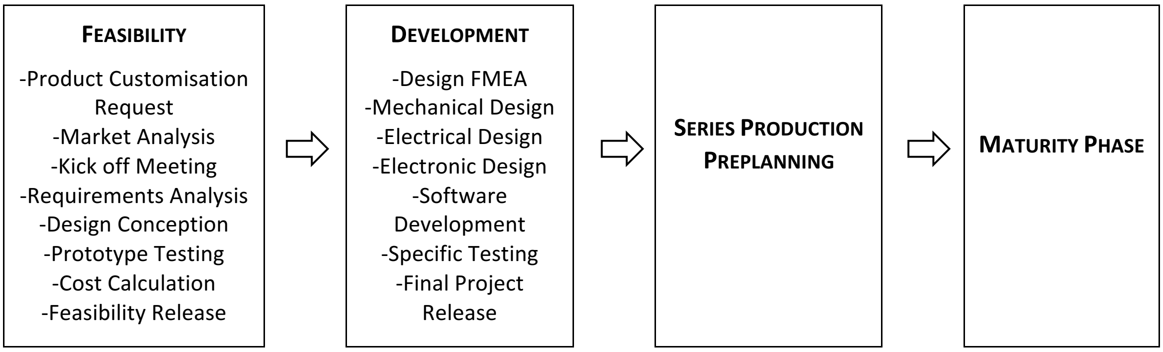


FIGURE 38: C001'S PRODUCT DEVELOPMENT PROCESS (FROM C001 DOCUMENTATION)

Internal and External Collaboration

C001's operations are centred mainly on four departments: Research and Development (R&D), Supply Chain Management (SCM), Drive Services Centre (DSC) and Sales. The R&D department is mainly concerned with the development the products, the SCM department is concerned with production and distribution of the products, the DSC offers after-sale services and the sales department handles sales. Figure 39 is a partial representation of C001's organisational structure; it focuses on the Inverter and Motor Business Unit and shows distinctions between the operational, tactical and strategic levels.

C001's R&D department undertakes a range of development projects; some are confined to the individual groups but others require multi-disciplinary teams with members from a number of the five R&D groups. Creating teams with members from these engineering disciplines and departments, which are currently strictly separated as a result of the organisation structure, is a challenge for the Inverter and Motor Business Unit. The difficulty lies in the specialist nature of the disciplines; it makes communication between them difficult. Problems manifest at interface point, especially with mechanical and electrical hardware. Another challenge faced by C001's R&D department is the direct result the company's acquisition by X001. Since the acquisition, they have found coordinating geographically distributed teams with different cultures a struggle. Additionally, they have had to contend with the two organisations using differing software packages (including CAD packages) and numbering systems. This causes particular problems when individual component designs are brought together; sometimes they find that the components do not fit.

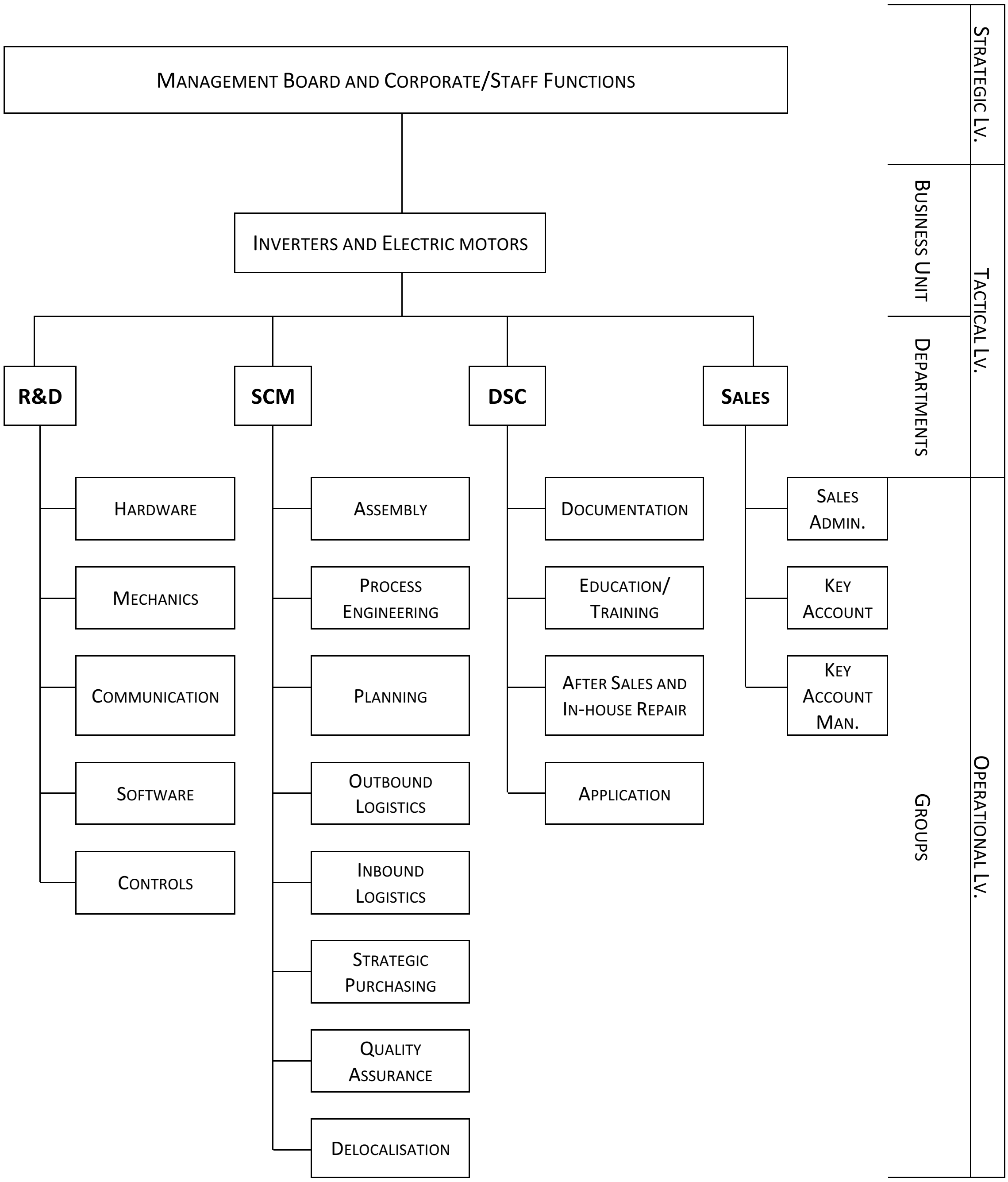


FIGURE 39: PARTIAL ORGANISATION STRUCTURE FOR C001 (FROM C001 DOCUMENTATION)

C001 does not have any in-house manufacturing capabilities beyond assembling and testing. The nature of the products that they produce means that all of their physical components are either mechanical or electronic in nature. As it is, the supply chain department mainly interacts with the R&D department during the product development process through the strategic purchasing group; it is the responsibility of the strategic purchasing group to source suppliers as they outsource mechanical parts to contract manufacturers and purchase electronic parts from component suppliers. C001 has a decentralised strategic purchasing department; requirements concerning supply issues are introduced into the development process (see Figure 38) during the requirements analysis stage of the feasibility phase. R&D specifies the parts and components that they require and hand over relevant drawings and specifications to the purchasing department whose prerogative is to get the products at the best price and logistics scenario. For approx. 85% of the electric components, the R&D department outlines the exact component that they require and the supplier manufactures it. This is due to the nature of the components; it is very important that R&D knows exactly how the components will perform. If the purchasing department were to suggest an alternative component or one from a different supplier, the R&D department would have to test the component to ensure that it functioned appropriately. However, there is a bit more flexibility with mechanical components as the purchasing department are given the autonomy to source a supplier that can provide the specified components. The supply chain department would like to have a more balanced relationship with R&D where there is more effort exerted to ensure that the interests of both departments are taken into consideration during the product development process.

> *"… R&D is not asking so much to SCM group 'what can we do' cause they say 'this is the product, try to find suppliers and try to find the best price' and that is it. So we will not have a discussion. Point of discussion is not so strong." – SCM Informant*

As it is, there is distinct conflict in supply and R&D objectives (cost and logistics vs. functionality) and nature of the relationship currently favours the interests of the R&D department.

Supply Chain Management

With sourcing components for the lowest possible price as their primary objective, the purchasing department is constantly engaging in negotiations and discussions with the external supply chains; ideally they prefer these interactions to occur as face-to-face interactions during site visits. In addition to the challenges associated with having a globally-dispersed supply chain, they have to contend with challenges that are based on the products that they are sourcing and the relationships that they have with various suppliers.

C001's products are comprised of electrical and mechanical components and these two component types pose particular sourcing challenges and require different strategies. The electrical components are the most restrictive; the R&D specifies exactly what they require and while they have good working relationships with the suppliers, they do not have any leverage due to the low volume that they purchase. This means they do not have enough clout behind them to drive suppliers to design components especially for them and they buy off-the-shelf components. These relationships do yield cost savings and recommendations of alternative components. With electrical component suppliers, switching to a different supplier is cumbersome as the entire process can take months, as alternative components require testing and therefore this is seldom done. For these they practice multi-sourcing and aim to have at least two suppliers for a single component.

Mechanical products offer more flexibility, both in terms of what R&D specifies and the number of suppliers to select from. For these components, R&D supplies component drawings and the purchasing team is free to source a supplier they deem appropriate. They usually practice sole sourcing because switching suppliers is as easy as taking your drawings elsewhere and getting the manufactured components in a couple of week's time. With these components, they adopt more of a personal relationship as they can specify exactly what they require, unlike with the electronic components. Figure 40 shows the classifications that C001's bought-in components fall into, based on their strategic significance and Table 35 summarises the scenarios and relationships that are associated with each of the product classifications.

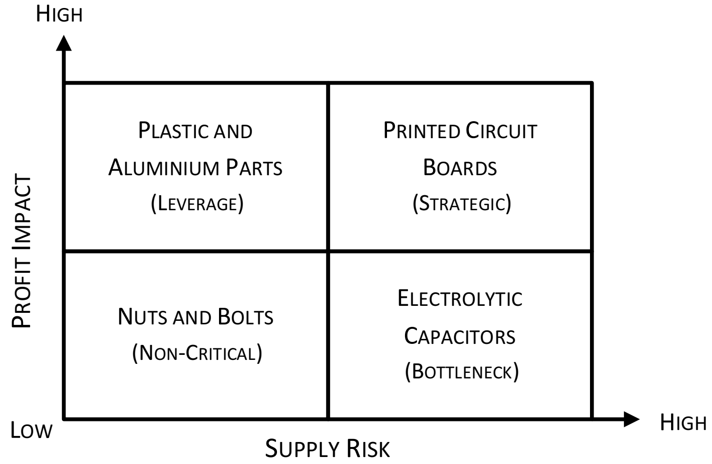


FIGURE 40: CLASSIFYING COMPONENTS STRATEGIC SIGNIFICANCE

TABLE 35: IMPACT OF PRODUCT CLASSIFICATIONS

PRODUCT CLASSIFICATION	EXAMPLE	SCENARIO AND RELATIONSHIP DESCRIPTION
LEVERAGE	Plastic and Aluminium Parts	Large number of suppliers capable of fulfilling requirements. Flexibility to select suppliers that offer the best price and product. Wide range of alternative suppliers to select from results in sole sourcing.
STRATEGIC	Printed Circuit Boards	Critical components available from a limited number of suppliers. To ensure long-term supply of components, good working relationships are cultivated.
BOTTLENECK	Electrolytic Capacitors	Components available from a limited number of suppliers. Practices multi-sourcing to ensure supply and maintains good relationships.
NON-CRITICAL	Nuts and Bolts	Low value and highly abundant components. Contract in place with shop owner where shop owner replenishes supplies at regular intervals.

Usually during the sourcing process, C001 considers suppliers who are capable of meeting their requirement, the nature of any existent working relationships and evaluates the possible alternative suppliers and the economics associated with each different supply scenario. What they find is that the best prices are those they get from suppliers that they already have working relationships with and new suppliers offer worse prices; the impact of relationships on component costs means that supplier-switching costs are high.

For C001, sourcing rarely involves finding completely new suppliers as the pool of suppliers that is available to them is pretty limited due to the industry that they are in. However, whenever they do select completely new suppliers, they perform a site visit and perform a quality audit as guided by their supplier evaluation checklist.

> *"You get better prices if you have the contact with a supplier who is already delivering components. If we look for a new supplier each time we need a new inverter we always get a very small part of them and worse prices." – SCM Informant*

To fully take advantage of the specialist knowledge that their suppliers are in possession of, one of the strategies that C001 employs as it aims to attain competitive prices from suppliers is that of supply chain collaboration that focuses on cost reduction. C001 occasionally outsources the sourcing of components to some of its suppliers, particularly electrical component suppliers. This results in suppliers offering alternative products to use; the suppliers even take on the role of gathering information regarding the proposed components. Additionally, C001 also uses the relationships it has with distributers to get the best possible prices for components and then supplies those components to its other suppliers so they can be used in products that will be supplied to them. This is exemplified in the scenario illustrated in Figure 41 where C001 has negotiated for the best component and PCB prices with the electronic component distributor and PCB supplier, these components are not used by C001 as they are but instead are supplied to the PCB compiler who will assemble the various components together before supplying them to C001. The solid lines represent the physical flow of goods and the dotted lines connects C001 to those that it pays for the good and services.

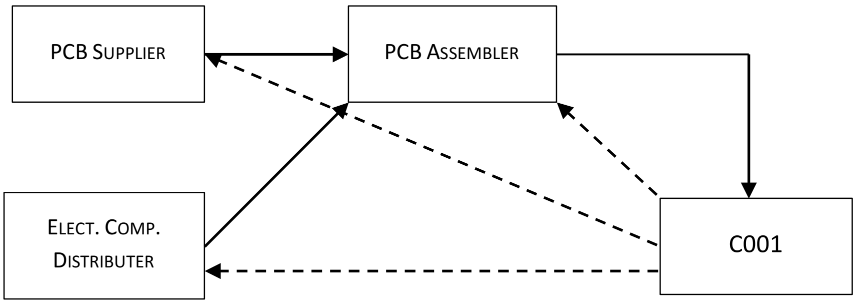


FIGURE 41: C001 SUPPLYING COMPONENTS TO ITS SUPPLIERS

Based on past experiences, wherever possible C001 aims to account for approximately 10-15% of a supplier's business. This is because any less means that they do not have any leverage with the supplier and any more they become too important to the supplier which complicates things if they ever decide to take their business elsewhere.

C001 does not have any green procurement practices in place. Green considerations do creep in as they aim to cut down costs by reducing the amount of packaging used and avoiding the use of air-freight when it is not necessary. When evaluating suppliers, C001 do not openly share what they are doing with potential suppliers to induce price competitive bidding. Because of the specialised nature of the industry, the suppliers communicate amongst themselves and know any moves that C001 makes which indirectly puts pressure on certain suppliers to offer certain incentives to retain their custom.

Organisational Information Sharing

Currently, C001 are content with using simple software programs with Microsoft Excel and Access to manage the information that they have within the company. However, to keep up with the shifting global landscape and ever changing technology, they are finding that it is becoming increasingly evident that they need to communicate internally with relational databases and perhaps externally too. While they have access to X001's web-based information-sharing portal, C001 prefer to exchange information with the external supply chain through data sheets and discussions as they find the portal too cumbersome and complicated. Some members of their base have asked that they share information through the use of a web-portal and this is something that C001 is investigating. They have concerns regarding how the information that they share will be used and have consulted their Internet security company to see if they can keep track of how their data is handled. C001 has non-disclosure agreements in place with its supply base but they concede that ultimately these are just pieces of paper that one cannot put too much faith in.

Assembled PCBs make up 80% of the cost of inverters, and since their primary objective is to keep costs as low as possible, C001's purchasing department requires that these are provided by their suppliers with a priced bill of materials so that they know exactly how much everything costs. This is an example of when certain suppliers provide them with specific information that is perhaps not usually shared; the importance of this information is such that if they do not supply it, they will lose C001's custom. On the technical front, while electrical components are supplied with technical datasheets, these tend to be basic. To combat this lack of information, as knowing the exact performance of electronic components is paramount, the R&D department tests the components to generate more data. The mechanical components are different as they tend to be made to fit specifications supplied by the R&D department, this means that they have more information pertaining to them.

Information-sharing behaviours, surrounding the environmental sustainability trend that is emerging within the industry that C001 is in, can be split into two. On one hand, there are the large enterprises that openly publish information regarding the environmental performance of their products. These companies have open databases where prospective customers can get information regarding cost, LCC result etc. and use that information to instantly compare various products before selecting the one they prefer. These companies offer a wide range of products and are secure in the technical and efficiency performance of their products, and resultantly, are comfortable with disclosing all this information. On the other hand, there are SME's like C001 whose information sharing is hampered by competitiveness. Unlike the large enterprises, not only are these companies reluctant to disclose too much information regarding the environmental performance of their products, they are also uncomfortable with having their products compared to others. In the case of C001, they are not in favour of selection databases that are employed by the bigger companies. Instead they prefer to withhold important information regarding their products so that potential customers contact them to discuss the merits of the products. They are open to discussing any environmental initiatives that they are undertaking but are reluctant to share findings.

> *"If you would publish all the parts and all the environmental impacts and what else of a complete part, everybody could see what elements are used and it's not our interest to publish this" – R&D Informant*

C001's biggest concern with sharing information through emerging information sharing technologies such as databases is that the users of the information will use it to unjustly compare them against their competitors, especially if they focus mainly on price comparisons. There is a belief that it is hard to encapsulate in writing what makes their products special and that only through talking to them directly can potential customers get a true sense of the products and the services that they provide. For C001, sharing information through databases poses particular challenges when it concerns the custom products that they produce. With such a wide mix of products, inputting data on custom products can be time consuming making it difficult to have a standard database that contains product information.

At the moment, C001 are only comfortable with sharing typical technical data as they have traditionally done. As they look to a future where they will be assessing the environmental performance of their products, they admit that they are not comfortable with the idea of having to share environmental performance information. They can envisage themselves sharing the outputs of the environmental assessments to highlight how their products perform but not having an open detailed database that contains all the information that was input into the environmental assessments. This is mainly due to the fact that they have concerns as to how that information would be used if it were shared; there is a fear that they would leave themselves exposed to reverse engineering.

Supply Chain Mapping

C001's supply base is made up of approx. 85-90 suppliers; 30% of these are producers while the rest are distributors; producers mainly supply mechanical components and distributers the electronic components. Most of the knowledge C001 has regarding the supply networks of the components they use is related to their tier 1 suppliers. This is especially the case for electronic components; for these they only have knowledge of the distributors that they buy from. They do not know where the production facilities for the components are and due to their position, they have no leverage to pressure the suppliers into disclosing information that goes beyond the data sheet that is supplied with the components. In cases where they have supplied component manufacturers with parts to use, C001 have information that extends to the second tier. Lastly, due to safety standards surrounding printed circuited boards (without components), the boards are supplied with information on the whole supply chain. Figure 42 illustrates how C001 could possibly map its supply chain to include some tier 2 suppliers. The map shows the suppliers of the mechanical components and the material suppliers they use along with the suppliers of electronic components that supply both directly to them and to some of their other suppliers.

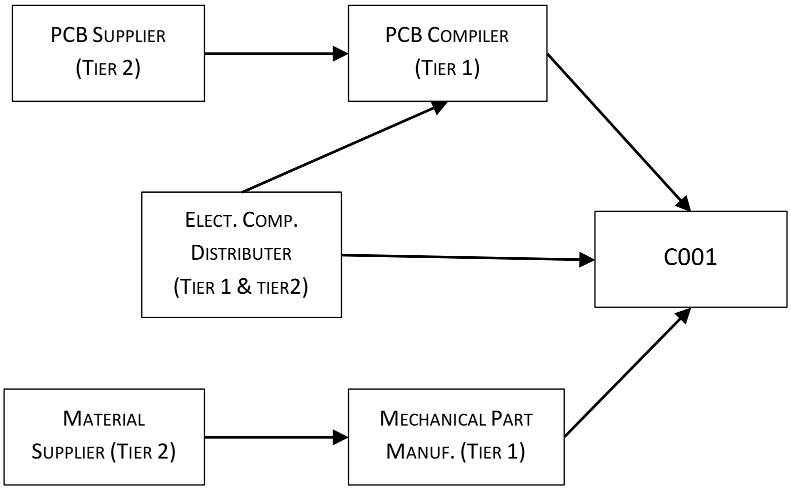


FIGURE 42: AN EXAMPLE OF A PARTIAL SUPPLY CHAIN MAP

Looking forward in the supply network, how much C001 knows about where their products end up is very much dependent on the type of product in question. Where they have designed a custom product they have intimate knowledge of who the end user is. This changes for the ‘off the shelf’ offering as they distribute and sell these through X001’s channels all over the globe; they have none, to very limited, information regarding the end users.

C001 do not have a lot of awareness of their supply base and while they acknowledge that attaining that awareness and being able to map your supply chain is important for ethical considerations, they admit that it is not something that they deem as necessary at the moment. They do however sense that it is something whose importance is likely to increase and that they should start thinking about it.

Conclusions

C001 perceive successfully developing environmentally competitive products is a potential key to retaining current markets, defeating barriers to entry of currently inaccessible markets and capturing emerging markets. At the moment, the company does not engage in any specific environmental initiatives. In addition to practicing ENPD, C001 are also keen to follow some other companies within their industry in implementing and EMAS under ISO14001. This trend in adopting EMAS within industry means that C001 have been getting requests from their suppliers to provide environmental reports or material and energy certification information relating to their products. By adopting their own system, C001 will be in a position to easily comply with these requests.

C001’s marketing department is responsible for all customer-based market research where they benchmark the company’s products against the competition; the results direct R&D efforts as new products are developed. Two forms of supply chain-based market research are undertaken within C001. The first, technology market research, is undertaken by the R&D department to determine which components they should use in the products they design. The other is supply market research that is undertaken by the purchasing group within the SCD; this research focuses on supplier capability, cost and logistics. These two forms of market research, which are essentially undertaken on the same supply base, are conducted separately within C001. This is mainly due to the company's highly segmented organisational structure where forming cross-functional teams is a challenge. There is an opportunity to amalgamate the two forms of supply-based market research. At the moment, the R&D department specifies the parts and components that they require and hand over relevant drawings and specifications to the purchasing department whose prerogative is to get the products at the best price and logistics scenario. The supply chain department would like to have a more balanced relationship with R&D where there is more effort exerted to ensure that the interests of both departments are taken into consideration during the product development process. This can be achieved by ensuring that purchasing is involved early in the product development process, before the components to be used are determined by R&D.

C001 practices a mixture of sole and multi-sourcing depending on the risk of supply and where they have working relationships with suppliers they find that they can yield cost savings and expert advice regarding components. In addition, there are occasions where C001 outsources to its suppliers the role of gathering information regarding proposed alternative components. Coupled with the fact that EMASs are gaining popularity within industry, and organisations are getting more used to environmental information requests, this means that there is an opportunity here for C001 to ask their suppliers to provide environmental information that pertains to any products they propose to supply. This request for information can feed not only into C001's product development process but also into their EMAS.

At the moment, C001 are able to get priced bills of materials regarding PCBs that are usually not shared with other products; this information is shared because it is very important to C001 and without supplying it, the suppliers would lose C001's custom. C001 uses this information to work with the supplier to gain an in-depth understanding of where the product costs are coming from. This means that if C001 are truly dedicated to attaining information regarding the environmental performance of the parts that they use then they could treat it in the same manner where the information is viewed as being part of the product that is being supplied, where custom will be lost if the information were not supplied and they work with the supplier to gain a deep understanding of the environmental aspects of the product components. It is important that this might come at a premium cost for C001 or might require them to switch to different suppliers.

When it comes to sharing information, C001 admit that they sometimes find it challenging to get their suppliers to share information beyond data sheets as they lack leverage to convince their suppliers to share extra information with them. One of the ways that they are able to ensure that they have all the technical information that they require is to test products themselves. This is something that they can also do to determine the environmental performance of the products that they purchase if they find their suppliers unwilling to provide it. It might seem ironic that C001 would like their suppliers to share information more freely so that they can input it into their product development process, but they themselves are reticent to share any of their environmental information with anyone else. While they see themselves sharing environmental assessment outputs information if the results showed that their products were environmentally competitive compared to other offerings on the market, they would not share any of the information that was input into the environmental assessments, as they fear it would leave them exposed to reverse engineering. This highlights how information being considered proprietary and lack of trust in what happens when others have information regarding your products can hamper information sharing for environmental objectives. However, it is not necessary that C001 share all the information regarding their products. Just sharing environmental performance outputs would allow their suppliers to input that information into their own environmental assessments, provided that they information provided was accurate.

While currently content with using simple software programs, if they are to implement an EMAS and ensure that there is an accurate flow of environmental information into their product development process from the supply chain, C001 has to improve the information systems that it uses. It needs to look to enterprise management systems that consolidate various forms of organisational information sharing and management. They are also getting requests to share more information electronically, something that they are concerned about due to the security of using IT for information sharing. While their concerns are not unfounded and information security is a legitimate concern, it is one that can be mitigated through various technological encryption measures. Using IT for information sharing is a practice that is mature in a number of different industries and is as much about the software as it is about managing the organisational implications on a human level. This means that in addition to adopting secure information sharing IT systems, education within the organisation can facilitate an understanding of the practice so that they are not averse to it.

C001 do not have much visibility of their supply chain beyond the first two tiers for most of their products. The PBC supply chain is an exception as they are fully visible due to legislation. This shows that legislation can be a driver for supply chain information sharing and if in the future there is environmental legislation that the organisations have to comply with, then supply chain information sharing will vastly improve. This will also lead to greater supply chain visibility and allow companies to manage supply-based risk more efficiently. In the meantime, as C001's shares their suppliers with other companies within the same industry, there is scope to form a consortium that drives various industry environmental wide initiatives.

Case 2: Prospective ENPD Organisation Conclusions

Looking to pave the way within the X002 group, C002 are looking to adopt a formal approach to ENPD that will allow it to produce eco-friendly and commercially viable products. While there are no clear market drivers for eco-products that go beyond in-use energy efficiency improvements, C002 sees an opportunity to attain first mover advantages by pushing eco-friendly products to the market. However there is a lack of understanding of the potential that lies within eco-friendly products outside of the R&D department. This means that the R&D department is in a position to not only learn how to practice efficiently ENPD, they also currently have the responsibility of disseminating environmental understanding to the rest of the company.

C002's R&D department takes the lead role in product development. While ultimately the make-up of a project team depends on the specific requirements of the projects, representatives from each of these groups are present at all kick off meetings. During product development cross-functional teams work closely together. As a result, members of R&D and other functional departments have cross-functional knowledge and enough awareness of issues that relate to more than just the group that they belong in. This culture of organic organisational learning should allow the R&D to spread environmental awareness across the whole of the company.

C002's industrialisation team which is in responsible for sourcing and supply chain design gets involved early on in the product development process. Whenever necessary, they are responsible for co-ordinating collaboration efforts with suppliers. The impending legislation that requires display the energy consumption of their products at the point of sale has resulted in C002 working even more closely with its suppliers. Unlike in the past, C002 now gives light and electric motor suppliers power and energy consumption targets that the products they supply should meet. This is not something that they did in the past as it was not necessary, however it now is due to legislation and suppliers are working to comply with these needs. This shows that there is potential for C002 to request that their supplier provide them with products that meet certain environmental performance targets, if C002 are dedicated to implementing ENPD. C002 have a history of paying more to ensure that they get the best quality possible, such a practice could be extended to environmental consideration if they pay more to get products that have higher environmental performance.

C002 practices both sole and multi-sourcing; they prefer sole sourcing as it allows them to cultivate strong ties with their suppliers. Where they practice multi-sourcing, it is mainly due to individual suppliers not having enough capacity to miss their demand. By mainly favouring sole sourcing, C002 are exposing themselves to supply risk. If there were to be a problem with their suppliers, they would likely find themselves in a situation where they could not meet their product demands.

Due to a number of different factors, which include cultural and language barriers, C002 are not always able to get the information that they require from their supply chain. In these cases, they do their own tests to determine a range of technical aspects relating to the products. There is there possibility of utilising the same tactic to acquire information related to the products they buy in to use in environmental assessments. It the moment C002 do not know if their suppliers have information relating to the environmental performance of the products that they supply and if they would be willing to share it. C002 plan to supplement the information they get from suppliers and in-house testing with information that is available in environmental and materials databases. Their priority will be to ensure that they have the most accurate information regarding the components that are the most critical in terms of environmental aspects.

C002's industrialisation team are able to gather a wealth of information and share it within the organisation through the use of enterprise software. This is information that is captured during various product development projects through phone calls, visits, data sheets, reports etc. There are a series of databases that contain information that designers can access from their workstations. This means that these databases can be used to ensure that information that is coming from the supply chain is available to the designers as they design products. This means that designers can make environmental decisions using information that comes in from the supply chain. Information for ENPD can be enriched if C002 adopts an EMAS, resulting in more information regarding suppliers' environmental issues being available to designers.

Even though C002 does not map its supply chain and has no visibility beyond tier 1 and 2 suppliers, it can use its enterprise system and the information within it to build supply chain maps. As they practice ENPD, C002 will need to ask their suppliers for information that can be used to map their supply networks beyond the first tier.

Case 3: Procurement in ENPD Organisation Conclusions

C003 is a company that is driven by customer needs and emerging trends; they are finding through their market research that some customers are demanding cars with improved environmental performance. This supplements C003's internal drivers for environmental product development. Internally, environmental drivers trickle down from the very top of the business and are embedded in practices that the employees have to adopt.

To aid Group Engineering during ENPD, C003 has the Cost Engineering group playing an interfacing role with internal functions as well as the supply chain. Due to the important role that the supply chain plays within ENPD, C003 works closely with their suppliers to ensure that they understand what C003 is trying to achieve and how they fit into the picture. Essentially, they try to disseminate environment awareness to their supply chain. With C003 working collaboratively with their suppliers to improve cost, quality and potential to deliver, it is not out of scope that they would also work with their suppliers to improve environmental performance where possible. C003 extensively maps their supply base in terms of a number of different factors as a form of business intelligence that allows them to have an in depth understanding of industry dynamics.

A shift from sole to multi-sourcing is proving challenging to C003 in terms of traceability for risk management. It is now harder to know exactly where components are coming from and to keep track. This also likely adds complexities to ENPD as an increase in suppliers means more information is needed from more sources. C003 is looking to address some of the issues associated with managing supply chain relationships through the use of a web-based system that helps the automotive industry better understand where key sustainability risks lie in their supply chains. As many of the companies within the industry share customers and suppliers, by consolidating the information sharing, what may be difficult to do for an individual organisation becomes easier to achieve collectively as an industry. However, this is more than a technology issue and it is essential that the right organisation structures are in place that make sharing information easier.

Case 4: Procurement in ENPD Organisation Conclusions

C004 is an organisation that is driven by its strong organisational culture and its success is deeply rooted in the knowledge and understanding it has of itself as an organisation. It offers its customers a range of both conventional and eco-motor vehicles that are globally competitive. Supply chain considerations come into C004's development process early, even though finalisations are not made until the second phase of development, during the first stage manufacturing and engineering jointly decide on trade-offs. In the second phase, the supply chain is then designed. Within this phase, supply chain design has a great impact on the product design as products are designed to share parts to make supply chain management easier. This means that the procurement department has a pivotal role in product development as it influences how the products are designed. The relationship between engineering and procurement is a two-way one where one influences the other. In addition to sourcing components and collaborating with internal engineering, the procurement department is also responsible for supply chain relationships for both procurement and supplier collaboration in new product development.

As a large company, C004 practices are spread through a top down approach internally and with its supply chain and those associated with their business. C004 promotes cross-functional teamwork to ensure that all internal and external parties are collaborating to continuously improve both processes and operations; this feeds into a strong company culture of improvement. This culture of improvement extends outside of the company as C004 expects its suppliers to share their innovations with others that supply similar products. Through this all the suppliers benefit from innovations and ideas generated across the supply network. C004 encourages informal information systems to exist, with information flowing freely across the organisation and across the supply chain information technology aids information sharing. While there are challenges that C004 faces when inducting new suppliers to its way of doing things, over time the benefits of being part of such a system are soon evident. While it might seem like being open would leave you exposed to various kinds of business risks, C004's way of doing things shows if managed correctly otherwise competing companies can work together for mutual benefits.

While many of C004's initiatives have been successful, when it streamlined it supply base to single suppliers for some parts, C004 exposed itself to supply risk. Because it did not have full visibility of its supply chain, it was not able to adequately manage the risk that was associated with some of its sub-tier suppliers. C004 has made assumptions about its supply chain, assumptions that turned out to be erroneous. This incident highlights why it is important for organisations to have adequate visibility of their supply chain. This is a practice that is not only essential for the management of business risk but also one that is key to ENPD. This is not an issue that affects C004 alone and they are working collaboratively with others within the industry to develop technology that enhances the industry's understanding of complex supply networks.

Case 5: Procurement in ENPD Organisation Conclusions

C005 has a culture that has environmental sustainability embedded deep in everything that it does; this extends from all its internal functions to its supply chain members. For C005, integrating environmental incentives into corporate management can lead to business performance, business expansion, and further credibility with outside parties. It not only aims to have all 80 of its production bases adopt EMSs but also to have its suppliers do the same and encourage their suppliers to do the same as well. In C005's view, the future will centre on environmental issues and it aims to be a leader in society through the development of products, technologies, and business opportunities that contribute to sustaining and improving the environment.

During product development, C005 considers product environmental performance on par with other basic development factors. This means that it is not seen as an afterthought but is an integral part all the products that they develop. It is important that products only make it to market if they have better environmental performance compared to their predecessor. This environmental focus extends to their procurement activity where they aim to procure parts and materials to use in their products that have as little environmental impact as possible. The procurement function practices green procurement, the environment is considered a factor on par with other traditional procurement factors such as cost, quality and delivery. The procurement function also supports the product development process by encouraging suppliers to practice their own ENPD. They try to purchase eco-friendly products wherever possible. When coupled with their emphasis that their suppliers adopt EMSs, this behaviour means that ENPD flows backwards through C005's supply chains helping to turn the whole chain green.

C005 does not leave all of this to chance; it has a number of internal and external guidelines that are support various environmental initiatives. Additionally it is proactive and hands on when managing its suppliers and encourages open communication. It even takes extra measures to ensure the reliability of data coming in from the supply chain and improve its mechanisms for environmental management by having data verified by a third party and extending its management to sub-tier suppliers within its supply chain. C005 takes a very comprehensive approach to managing it environmental initiatives.

Case 6: Compliance in ENPD Organisation Conclusions

With its products having the most environmental impacts in the use phase, and with environmental requirements addressing fuel consumption, emissions and noise an integral component of product specifications, many of C006's products are market leaders in terms of environmental performance. While they focus mainly on 'in-use' environmental improvements as those have the biggest impacts, if other phase improvements are proven to transform into a business benefit, either through customer value or by reducing operation costs, then C006 are open to exploring them. C006's strategy is to focus on those improvements that have the most impact on the environment.

As a system integrator with very large product, C006 has a very complex and large global supply chain. C006 manages it supply chain through frameworks and information technology and encourages its suppliers to adopt initiatives, such as EMS, that will improve them. Within procurement, risk is considered on par with traditional procurement factors such as price, delivery and quality. The key to its supply risk management lies in collaboration and information sharing within the supply chain; this is supported by the use of a web based supply chain portal.

When REACH was pending C006 was proactive in devising guidelines and procedures that would ensure that it and its critical suppliers would be ready for authorisation. One of the key parts of C006's process was ensuring that there was enough knowledge within organisations about what the regulation actually entailed. Much like with ENPD, the key to the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation is in supply chain information sharing and it requires cross-functional teams to work together.

Initially C006 was hoping that if it acted as the initiator at the top, the authorisation would flow naturally backwards. What it found however was that there were bottlenecks in the supply chain, caused mainly by SMEs with limited capability that they had to overcome. This resulted in C006 strategically targeting those supply chain members that were most critical and bypassing those that were not. While C006 took an incremental approach to tackling the issue, it did not aim to inform everyone within the organisation about it. Only those that were directly responsible for gathering information, like the purchasing and materials, are involved with REACH matters. Designers for example who work with some of the substances affected have no working knowledge of risk, what they are presented with is a list of substances that they can use in product development that has already been deemed REACH compliant. Due to the size of the organisation, and with legislative agenda continually changing, C006 made a strategic decision to focus on managing the situation rather than ensuring widespread understanding among the employees.

For C006, REACH is an issue that can be tackled by developing relationships with suppliers, suppliers that the whole industry shares. As a result it supports the development of REACH standardisation for the aerospace industry.

Cross-Case Report

Across all the cases, in varying degrees, there is evidence that environmental performance is emerging as a new source of competitive advantage. The case companies find themselves in positions where retaining current markets and capturing emerging markets can be linked to their ability to effectively create environmentally-competitive products. For the companies that practice ENPD (C003-C006), environmental incentives are integrated into corporate management and form a key component of their strategy. These companies highlight how the production of environmentally-competitive products can be supported by strategy and corporate culture that extends across all business functions.

New Product Development and Supply Chain Management

Fundamentally, a 3DCE based approach to ENPD advocates for the early integration of the supply chain into the product development process. Through this integration the product, production processes and supply chain can be designed simultaneously resulting in the reduction of product development cycle time. The added consideration of supply chain means that during the product design process the designers are in a better position to take a life cycle view of the environmental impacts of the products.

Across the case companies, there are varying degrees of early supply chain integration in the product development process; this is usually through the procurement function being part of cross-functional product development teams from the onset of the development process. On one end, there is C001, a prospective ENPD organisation, where procurement only becomes involved in the development process once engineering has finished designing the product and on the other there is C005 and C004, ENPD organisations, where supply chain design is considered on par with product design. There it has a central role in product design resulting in products being designed with supply chain design in mind. Within these companies, the internal supply chain function has a highly active role in product development and works closely with both internal functions and the external supply chain.

All the case companies have multi-disciplinary product development teams; however, the key is to have these teams extend beyond design, engineering and R&D and include other organisational functions and in this case, the supply chain department. With the exception of C001, a prospective ENPD organisation, all the other cases have these multi-functional product development teams. As C001 has the least amount of supply chain involvement in the product development process it was decided that it would be examined further and have learnings from other cases can be applied to it to show how an organisation can increase supply chain involvement for ENPD benefits.

During product development within C001, R&D conducts technology market research where they find components that meet their technical requirements and can be used in products. From there, they develop products incorporating these components and when design is complete they specify to procurement exactly what should be purchased and from whom. Procurement then conducts their own research of the suppliers as it aims to procure those components for the best cost, quality and delivery scenarios; they have very little room to influence supplier selection. Occasionally, some suppliers recommend alternative components to the ones that are specified. When this happens, due to the need to fully understand the technical performance of the component, procurement cannot just accept the new components. Instead they have to go back to R&D who then test the components for appropriateness. From there R&D either accepts or rejects the alternative, either way procurement then goes back to the suppliers to try and secure a supply of the chosen components. In other cases when procurement is not able to source the components under the right conditions, they go back to R&D who then have to specify alternative components and adjust the design.

Fundamentally, there are two major problems related to the way that C001's R&D and procurement functions work during product development. The first is that there is a lot of back and forth between C001 and its suppliers as both R&D and procurement have interactions with them and the second is that supplier selection, which underpins supply chain design, is predominantly done by R&D who perform the task solely from the perspective of trying to satisfy technical needs. Both of these issues can be addressed through early and more integrated procurement involvement in the product development process.

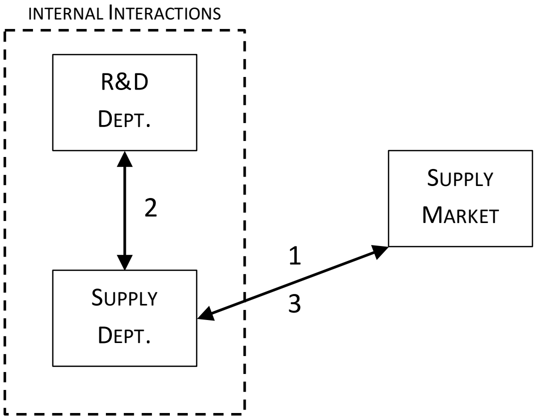
Early Procurement Involvement in New Product Development.

When procurement is involved in the product development process, it can offer more to the process than just managing supplier involvement in the process. Having procurement involved on that level is beneficial. However, for C001, procurement is expected to procure pre-defined components under intense cost pressures while not being involved in the development process. The cost engineering group in C003, an ENPD organisation, manages supplier involvement in NPD but procurement occurs later in the development process where the procurement group finds itself under a lot of time and cost pressures when sourcing components. On the other hand, there is the scenario like that within C004 and C005 (ENPD organisations) where the supply department (including the procurement function) is an integral part of the design process, where the supply considerations are embedded in to the design process and design issues are embedded into the supply process.

Consolidated Supply-Side Interactions

When the procurement function is an active part of the development process, it is possible to cut down product development time by consolidating supply-side interactions. This can be illustrated using C001's supply side interactions. Essentially, there are two sets of supply-side interactions that C001 engages in that occur independent of each other as both R&D and procurement have direct interactions with suppliers. Figure 43 presents three possible scenarios that can manifest within C001 regarding their current interactions with the supply market during NPD. In the first scenario, the most ideal under the conditions, is that the R&D department conducts its own technology-based supply market research. After selecting components to be used in products, they specify the exact component to the procurement department. After conducting their own research and evaluating the suppliers who are capable of meeting their requirements they commence the procurement process. In the second scenario, procurement finds a suitable alternative to R&D's specified product offering supply-related benefits such as cost and delivery. They present R&D with the alternative and R&D tests and accepts the alternative component before procurement procures it. In the last scenario, procurement cannot procure the specified product under the right conditions so R&D has to go back to the market to find an alternative component, procurement then has to do its own research and evaluation before deciding to procure the component. These are just a few of the scenarios that can arise, as it is possible that there is a lot more back-and-forth between the actors. What these scenarios highlight is that if procurement and R&D work separately, with each focusing mainly on meeting their own needs, the development of the product will be costly and drawn out.

If these supply chain interactions are consolidated and managed by the supply chain department, then they will reduce in number and occur over a shorter period of time. If procurement is involved in NPD early, it can take on the role of managing all supplier interactions. They can monitor supplier markets for technological developments, gather new information on products that are being developed, find alternative components that can result in a higher quality of the final product and pre-select suppliers who satisfy supply-related requirements. Following from this, as shown in Figure 43, they would then present R&D with the outputs of this process before R&D selects the components that it deems most appropriate to use, after which procurement returns to the market to procure the components. This way, the procurement can do more to support the product development process beyond just attaining the best cost for specified components. Through the cultivation of relationships that procurement has with the supply market, headway can be made in attaining both supply and design objectives.



1	SD-SM	SD conducts technology and supply based supplier research
2	SD-R&D	SD presents R&D with outputs and R&D uses information to select components
3	SD-SM	SD procures the components

FIGURE 43: CONSOLIDATED SUPPLY-SIDE INTERACTIONS

It is important to note that these are interactions that are related to supplier selection only; different interactions are possible if the objective is to practice supplier collaboration in new product development. This means that within the consolidated scenario there is scope for R&D to interact with the supply chain, the interactions will focus on technical product development issues rather than inherently supply chain related issues.

As procurement takes control of the majority of interactions with the supply chain it is essential that they do not do so at the neglect of product design issues. It is important that they employ cross-functional teams that include engineers to ensure that technical considerations are an integral part of the interactions resulting in outputs that are of great use to R&D. Additionally, procurement can be in a better position to facilitate the integration of suppliers into the product development process and manage any supplier development as they already have contact with the suppliers.

In all the case companies the supply chain departments have relationships with the supply base that they nurture and cultivate for a myriad of reasons. This is the case with C001 who feel that they have relationships which offer benefits that are wasted and not being fully appreciated or utilised during NPD. There is a belief within the supply chain department that they can do more to support the product development process beyond just attaining the best cost for specified components. Additionally, by having supply play a bigger role in the product development process there can be a bit more balance between the departments. The strong focus on R&D's need makes it difficult for the supply team to achieve their objectives and support the product development process.

Through early involvement in NPD, not only can procurement support designers by organising and managing supply-side activities, they also place themselves in the most ideal position to facilitate the flow of information from the supply chain into the product development process. This includes information that can be used to inform environmental considerations during environmental new product development.

Supply Chain Information in Environmental New Product Development

The information coming in from the supply chain can help designers make better decisions during the product development process, especially when integrating environmental considerations into the process. Compared to other organisational functions, the decisions made by the design department have the greatest impact on the environment. This is because they make decisions that impact the environment through all the stages of the lifecycle of the product; Table 36 shows some of the environmental impacts affecting various organisational functions. Due to this, it is important that when designers make their decisions they have as much information as possible including information relating to the considerations and decisions made by the other functions.

TABLE 36: ENVIRONMENT ASSOCIATED IMPACTS AFFECTED BY ORGANISATION FUNCTION DECISIONS

Organisation Function	Environmental Impacts Affected
Design	Whole Product Lifecycle including product development, manufacture, use and disposal
Supply Chain Management	Manufacturing, Supplier Profile and Transport
Manufacturing	Manufacturing including waste, chemicals and processes
Training	Education of Workforce

The designers would especially need to embed considerations that relate to production and the supply chain into their design process. Traditionally, designers only focused on design-related issues and with the rise of concurrent engineering they became competent at simultaneously considering design and process issues. Now, as they look to practice ENPD it becomes necessary that they are able to integrate supply chain considerations. This can be accomplished by having information coming in from both the supply chain department and suppliers enter the design process. The designers need to take into consideration, not only the environmental information relating to the technical performance of components and materials, they also need to consider the environmental and activities of the suppliers of themselves. It is important to make sure that the designers are not overwhelmed by the information and that they can utilise it to its fullest potential.

The role of getting information from the supply chain should be one that is undertaken by the supply department; they are traditionally responsible for and have the most expertise in organisational information sharing. Procurement can collect various types of information from the supply chain and then collate it in databases that can be used by designers; this can be seen in all the case companies with the exception of C001. In most of the case companies, this is already happening as IT solutions are used to facilitate information sharing. And much like how C006 deal with REACH issues, on a need to know basis, it is possible for procurement to do the necessary vetting and analysis of suppliers such that designers are only given outputs from that process which are pertinent to design tasks. One possibility is to have the information that the supply department gathers through it EMS available to designers, this means that along with product technical and environmental information the designers can also consider the environmental profile of suppliers of products. As is evidenced by most of the case companies, organisations are already trying to act in more environmentally conscious ways by adopting EMSs; within these they also assess the impacts and profiles of their suppliers. EMS is an organisational-level tool that can also have benefits in product development.

In the presence of richer supply chain information, designers will be able to make better-informed decisions regarding the products they design and the suppliers they use and as they specify material and component suppliers during product design they start to engage in early supply chain design; not just supply chain design but green supply chain design.

Supply Chain Design in New Product Development

When designers deal directly with suppliers as they attempt to practice preliminary supplier selection, they will likely focus mainly on technical capabilities and overlook other factors that are paramount in supplier selection and supply chain design. The procurement department has expertise not only in managing supplier relationships but in developing suppliers to ensure that the appropriate technical and operational requirements are met; in varying degrees, this is the case across all the case companies. All the case companies practice strategic supply chain management and are involved in supply chain collaborations of varying types.

At this point it is important to differentiate supply chain design in new product development, which is from the SCM perspective, from supplier collaboration in new product development (SCNPD), which is from the product design and development perspective. Through SCNPD, where the product design function takes a lead role, designers incorporate their suppliers into their product development process; the practice has been found to be beneficial with regards to product effectiveness (product quality and cost) and project efficiency (product development time and project cost) (Johnsen, 2009; Fujimoto *et al.*, 1996; Dyer and Singh, 1998).

When product designers practice supply chain design, it is important that they incorporate SCM strategies into their process and that they collaborate with the internal SCM function. Supply chain design is about more than just supplier selection and the make-or-buy decision. It is of strategic importance as it can determine the fate of companies, and of their profit and power. The locus of value chain control can shift in unpredictable ways (Fine, 1998). As a result, it is important that the procurement function has a central role in directing how it happens. When a company's supply chain capabilities are directly aligned with its enterprise strategy, the results tend to be superior performance and a strong market position. The strategic importance of the supply chain is highlighted in most of the case companies, in particular the ENPD companies where it plays a large role in how the companies conduct their activities; it adds value that goes beyond just supplying products and they manage it in a structured manner to ensure that they get the most out of it. It is important to ensure that when supply chain design is moved further forward and designers play a bigger role in selecting suppliers that more than just technical considerations are made. Procurement should be involved as that is where supply chain related expertise lies. When designers practice preliminary supplier selection and early supply chain design, the back and forth between the design department and the supply chain management departments is reduced. The procurement function gets more time to explore and identify opportunities in the supply chain, negotiate with suppliers, finalise supply conditions etc. On the other hand, the designers are able to use supplier-specific information in the environmental assessments they carry out as they integrate environmental considerations into their design process. The collaboration between the two departments is mutually beneficial and improves the company's process of developing products.

Supply Chain Information Sharing

For data to be available during the product development process, it has to be obtained from outside the company thorough organisational information sharing. The sharing of information is an issue that affects all companies for myriad reasons. Essentially, information sharing problems within the case companies could be categorised as related to: willingness to share; availability or information technology.

Willingness to Share

When dealing with a global supply chain, cultural and language barriers are only a fraction of the challenges that companies will encounter. In different forms, all the case companies encounter 'willingness to share' as a barrier to information sharing; reasons for this are varied but mainly centre on non-sharing cultures within companies. As exemplified by C001 and the initial stance of some of C005's suppliers, there can be a sense of mistrust regarding how the information will be utilised. Whatever the reasons, the key to information sharing lies in openness and trust. It is those companies that have open and trust based relationships with their suppliers that seem to be able to obtain information more effectively. Affective trust, trust that is based on emotion and the personality of the entity being trusted, is particularly important in information sharing. When there is trust that the information being shared will be handled accordingly then it is more likely to be shared.

Those companies, such as C004 and C005 (both ENPD organisations), that have high levels of openness and information sharing across their supply chains achieved it by not just requesting that their suppliers share information with them but by also sharing information with their suppliers. They work on cultivating the relationships they have with suppliers for information sharing benefits and attribute the high levels of sharing they have to mutual respect, shared goals, open and honest relationships. For these companies, attaining these levels of trust and openness has not been instantaneous but rather the result of meticulous supply chain management.

In these companies, information sharing is a requirement that is embedded into supplier contracts; suppliers are required to share information not only with the company but also with other suppliers. Due to the importance of keeping costs down, C001 requires a cost breakdown of all the materials that go into PCBs; while this is not information that is typically shared. Due to its importance to C001, it is a must that the suppliers share it. On the opposite end, C002 – the other prospective ENPD organisation – values quality to such an extent that they pay extra to guarantee it. It can be posited that the same tactics can be employed regarding environmental information; you can pay more to get components that are supplied with environmental information or you can specify to suppliers that it is a requirement that they provide environmental information related to the products that you purchase. Using C003 with its bonus-malus evaluation system, and C004 with its use of KPIs for evaluation as examples, it is possible to evaluate suppliers based on their information sharing, with those that share ranked higher than those that do not. And following C005's practices, the results of the evaluations can be shared with the suppliers to encourage them to improve.

Particularly among those companies that engage in ENPD, there is recognition that information sharing is an issue that affects everyone in industry and that it can be tackled at an industry level through collaboration. As many of the companies within an industry share customers and suppliers, by consolidating the information sharing, what may be difficult to do for an individual organisation becomes easier to achieve collectively.

Despite its benefits, the practice of supply chain information sharing poses a number of challenges. Many firms are reluctant to share information with their supply chain partners due to an unequal distribution of risks, costs, and benefits among the partners. The information shared will usually benefit the recipient, yet the provider will incur the majority of costs. Reluctance to share information also arises due to the risk of it being divulged to competitors or used for opportunistic bargaining.

Availability of Information

Even with suppliers willing to share information, they might not be in a position to due to lack of resources to search for information or lack of existence of the information. This is particularly true for SMEs, as they tend to lack the resources that allow them to acquire information and share it, particularly as investment is required. This can be seen in the SMEs within C006's supply chain and also in C001 who primarily share information using data sheets. A common method, employed by C001 and C002, to combat the lack of technical product information is to test components to generate the information. This can be employed for the generation of information that can be fed into the NPD process; for the use-phase of the lifecycle it can be possible to test a component to determine its environmental performance. Such a tactic is best used on critical components that are likely to have a significant impact on the technical or environmental performance of the product.

In some cases, information is not shared outright as it might not be deemed as pertinent and in others it is shared if asked for. Whatever the scenario, it is important to continually make information requests. As suppliers get more requests for information, the more likely they are to take the necessary measures to acquire that information.

Use of Information Technology

Information technology plays a central role in organisational information sharing. With the exception of C001, the case companies employ the use of IT to collate and share information internally and with their suppliers. Issues regarding information sharing using IT extend beyond technology to operational impact. This means that not only is it important to have the necessary technology but it is important to have an understanding of the human element associated with the use of the technology.

With various companies using IT to share information and various types of software being used for the practice, the different types of software that employees have to interact with increases. While large organisations can cope with the resources required, it is increasingly difficult for smaller companies. The more uniformity there is regarding the technology that is used across industries, the less of a burden IT investments become. C001 and suppliers to C006 cited 'lack of resources' as barriers to implementing information technologies, which are only worsened by the ever-changing nature of software required. On the other hand, for C003 the currently available IT infrastructure is not fully supportive of advanced information sharing, the information sharing that they believe is necessary to be able to adapt to ever changing market conditions. As a result, they are looking to tackle information sharing issues on an industry level by collaborating within the automotive industry (including with C004) and a leading enterprise software provider. Beyond its traditional role in facilitating transactions, IT is not only paramount in sharing information with suppliers but also in the management of supply chain relationships.

Supply Chain Mapping

In a world that is increasingly interdependent, what happens to one supplier can have ripple effects onto an entire multinational company. Through supply chain mapping visibility of a multi-tier supply chain can be gained allowing for information to be collected that allows pre-emptive action to be taken to protect against risks. Supply chain mapping is a relatively new concept to most organisations. C001 and C002, the two prospective ENPD companies, do not practice any form of supply chain mapping, while C003 turned to supply chain mapping after failing to detect risks within the supply chain and C004 after unknowingly violating trade restrictions. Due to a need to adhere to REACH requirements, C006 strategically maps its supply chain by focusing on critical points. Not only does supply chain mapping allows risks to be identified early and mitigating action put in place more rapidly - so preserving continuity of supply – also, it is beneficial for: collecting information on sub-suppliers; maintaining accurate supplier data; linking relationships between the different tiers of a supply chain; and increasing the visibility of the chain as a whole to enable all parties involved to understand where and how their goods are sourced. All this can have a positive impact on ENPD efforts as this can be used to drive the sharing of technical and environmental performance information relating to suppliers and the products that they supply.

Supply chain mapping is a very cumbersome and challenging exercise due to the complexity of supply chains. As a result, ENPD companies like C003, C004, C005 and C006 look to collaborating to develop industry solutions to supply chain visibility, as it is an industry-wide issue. Most industries share common suppliers, so what may be difficult to do for an individual organisation becomes easier to achieve collectively. Additionally, C003 and C004 outsource their supply chain mapping to an enterprise software vendor that maps supply chains through the use of cascading invitations that are sent to suppliers and from suppliers' suppliers ad infinitum, helping to gather comprehensive information about the supply chain and supplier compliance within it.

Conclusion

Through early procurement involvement in product development, supply chain design can be introduced earlier in the development process with the procurement function not only interfacing with suppliers but also managing supplier-side interactions and enabling the sharing of information that can be used in ENPD. Adequate relationship management that creates an openness and information sharing culture across the supply chain can mitigate some of the challenges that are associated with information sharing. However, it is important to understand the risks that are inherent in the practice and the consequences of providing accidental but harmful access to corporate information. The use of IT and practicing supply chain mapping also aid in attaining visibility, which is essential to supply chain information sharing. To address information risk in the supply chain, organisations should adopt robust, scalable and repeatable processes. Supply chain information risk management should be embedded within existing procurement processes; it becomes part of regular business operations.

5.6 Outputs of the Multi-Case Study

Insights gained from the multi-case study advocated for the development of the tools described in Table 37; these tools have the potential to be beneficial to supply chain information sharing for ENPD. The first two tools will be discussed further in Chapter 7.

TABLE 37: TOOLS TO AID SUPPLY CHAIN INFORMATION SHARING FOR ENPD

Tool	Description	Use
Procurement Involvement in ENPD Maturity Model	A process maturity model of procurement involvement in ENPD	Serves as an audit tool to assess and guide how procurement is involved in and supports design during ENPD.
Guidelines for Supply chain Mapping Focusing on Information Sharing	A list of issues to consider when practicing supply chain mapping for information sharing	Used to guide the process and as a check to assess if typical requirements have been fulfilled.
Web Based Supply Chain Information Sharing Portal for ENPD	A web based portal that facilitates the sharing of information within the supply chain.	Provides the product designer with a reliable input of accurate data and information central to ENPD.

Chapter Summary

With the intention of answering RQ1(a), RQ2 and RQ3, as well as addressing RO1(a), RO2 and RO5, a multi-case study was undertaken. The aim of the multi-case study was to explain the complex causal links in real-life NPD and SCM interaction and describe and explore the real life context within in which environmental considerations can be introduced into NPD. The study composed of six companies, four that conduct ENPD and can provide valuable understanding and two that are looking to implement ENPD. The data collected and used to inform the multi-case study included interviews, documentation, archival records and direct observation. Following the coding of the interview transcripts and case notes, and an in-depth analysis of the other forms of data, results that inform answers to the research questions (See Section 9.1.1) were isolated and presented in partially ordered descriptive meta-matrices. Case narratives were then written in the form of single case reports; these reports were a condensed version of the results from the coded data enriched with contextual information, the reports ended with inferences and conclusions on each of the cases. All the cases were brought together in a cross-case discussion before the outputs of this phase of the research project were summarised.

6. Controlled Experiments Exploring the Impact of Early Supply Chain Design during Environmental New Product Development

Chapter Overview

This chapter contains details on the controlled experiments that were developed to help fulfil Research Objectives 1(b), 2, 3 and 4. The main aim of the controlled experiments, which take the form of component selection exercises, was to explore the role and impact of early supply chain design and supplier-specific information on the outputs of the ENPD process. It covers how the controlled experiments were formulated, designed and conducted, how the results were analysed, the resultant inferences and their implications.

Highlighted Contents

Taking the form of an empirical investigation under controlled conditions, the component selection exercises are a form of experiment that assess early supply chain design during the ENPD process and aim to examine the properties of, and the relationships between, information available during the ENPD process and its outputs. The component selection exercises were designed and conducted in order to answer the following question:

> *RQ1b: When transitioning to a 3DCE-based approach to ENPD, what changes are required in the way in which designers work?*

They address the following research objectives:

> *RO1b: Establish what is required of design departments when adopting a 3DCE based approach to ENPD.*
>
> *RO3: Critically assess the impact of early supply chain design on environmental new product development outputs.*

The outputs and insights gained from the exercises also partially fed into the fulfilment of the following research objectives:

> *RO2: Develop a method, based on 3DCE and with a supply chain focus, which can be utilised during the environmental new product development process.*
>
> *RO4: Make recommendations to support and improve how the supply chain is utilised during the ENPD process.*

Supply chain design was taken to be represented by the selection of components to incorporate into a product, thus determining the configuration of the product's supply chain, made by making decisions relating to supply chain related factors such as number of suppliers, supplier selection, proximity to suppliers etc.

6.1 The Component Selection Exercises

The component selection exercises were carefully developed as a simplified version of real-life scenarios and a way of simulating them under controlled conditions. The exercises tested the underlying principles of 3DCE, particularly that of the simultaneous design of product and supply chain through early supply chain design, to see if it had synergy with the way designers integrate environmental considerations into their design process. The exercises focus on how designers are able to select components to use in products while simultaneously selection suppliers of the component and thus designing the product's supply chain.

Based on a real-life company and product, with extra elements added to ensure that the aims of the component selection exercises can be met by participants, the backdrop against which the exercises played out was set as follows:

> "One year ago, CleanAir introduced the 1st generation Stylish wall cooker hood. Following its success, CleanAir is looking to launch the next generation Stylish cooker hood. Named the StylishEco, the new cooker hood aims to have an outstanding environmental performance profile.
>
> Located in Milan, Italy, CleanAir has been producing high quality cooker hoods since 1955. With 50% market share, it is the market leader in Italy – a country that values premium kitchen ventilation. CleanAir products show the company-wide commitment to technology, quality and design. Its expertise lies in the design and assembly of cooker hoods. All cooker hoods are designed in house and incorporate a mixture of standard and made to order parts. After parts have been appropriately sourced, CleanAir, in Fabriano, assembles them into the final product. CleanAir does not have any component

manufacturing capabilities; product design is conducted in-house and component manufacturing is outsourced.

CleanAir™ has recently become verified under the Eco-Management and Audit Scheme (EMAS) to reflect its commitment to environmental issues. As part of this, CleanAir conducted an environmental review of its supply base. During the review, CleanAir used key performance indicators (KIPs) to evaluate suppliers and to measure and monitor improvements.

CleanAir™ has the following certifications:

- ISO 9001 – Quality Management
- OHSAS 18001– Occupational Health and Safety Management Systems
- ISO 14001 – Environmental Management

The main aim of the StylishEco project is to update the 1st generation Stylish cooker hood into the StylishEco. The StylishEco will be the first cooker hood to be produced by CleanAir since its EMAS verification. The StylishEco will be characterised by differences that aim to lower environmental impacts during various life cycle stages."

During this scenario the participants assumed the role of the product designer whose responsibility it is to design the new generation cookerhood guided by the following constraints:

- The new cooker hood should have a better environmental profile
- The new cooker hood should not cost too much
- The new cooker hood should be similar to its predecessor style wise

The participants were given up to 60 mins within which to complete the product re-design. The redesign involved replacing pre-specified parts in the Stylish cookerhood with ones that they deemed to be more appropriate for the StylishEco. During the exercise the researcher could answer some questions and offer clarifications where necessary. The researcher also asked questions to capture the participants' thought processes and the basis for their decision making.

The real life company that the component selection exercises are based on is C002, one of the case companies from the multi-case study (See Chapter 5), and the exercise scenario is based on one that C002 found itself in as a prospective ENPD company. In an attempt to trial the implementation of ENPD practices within the company, C002 collaborated on an ENPD project with other prospective ENPD companies (including C001 from the multi-case study) and academic institutions (including the researcher's own – the researcher was part of the project team). The product that C002 put forward during the project is the one the Stylish cooker hood is based on. The formulation of these exercises was informed by the researcher's experience of working on the ENPD project and undertaking the multi-case study as

Through working on the ENPD project and undertaking the multi-case study, the researcher was able to gain an in-depth understanding of the real life context within which environmental considerations are introduced into NPD; this heavily informed the development of the controlled exercises. During the ENPD project the researcher worked experienced how a product can be re-designed based on environmental objectives and gained access to documentation and analysis results relating to a real life product; this resulted in the know-how of how designers could integrate supply chain considerations into the ENPD process through the integration of supplier-specific information (supplying company and product information) and access to materials that could be adapted for use in the exercises. The interviews that were undertaken with SCM, R&D and Production employees from C001 and C002 – two prospective ENPD companies – during the multi-case study provided the researcher with an understanding of the interactions between NPD and SCM. This provided insight into how the procurement function could support the design function by providing them with supplier-specific information.

6.1.1 *Critically Assessing the Outputs*

The 3DCE-based approach incorporated into the component selection exercises (See Section 3.2) gives designers access to supplier-specific information during the ENPD process. It is the impact of the availability of this supplier-specific information on the process outputs that will be assessed; the attributes of the design output that will be assessed are as follows:

- The environmental performance of the product
- The greenness of the product's supply chain
- The product cost

Product environmental performance and cost were selected because the performance of a product is usually defined in either technical or financial terms, often with a strong relationship between the two. Supply chain greenness, related to supply chain design, is the additional attribute that was considered as an output. This relates to the product development trade-off model presented in Section 2.2.2 (See Figure 13). The assessments of these attributes were of a quantitative nature and were guided by the research questions whose resultant working hypotheses are listed in Table 38 and aimed to address Research Objective 3. During the exercises, the participants were given different amounts of information relating to component performance, cost and suppliers – this is what is denoted by 'extra information'.

TABLE 38: RESULTANT WORKING HYPOTHESES

Working Hypothesis	
H_A: The designers will be willing to spend more on components for products with better environmental profiles	H_G: Designers with cost information will design products with lower environmental performance
H_B: The designers that spend more will have products with greener supply chains	H_H: Designers with cost information will design products with lower supply chain greenness
H_C: The designers that have designed products with better environmental performance will have greener supply chains	H_I: Designers with cost information will design products with lower cost
H_D: Extra information will result in improved product environmental performance	H_J: Designers with supplier information will design products with lower environmental performance
H_E: Extra information will result in improved supply chain greenness	H_K: Designers with supplier information will design products with lower supply chain greenness
H_F: Extra information will result in increased cost	H_L: Designers with supplier information will design products with lower cost

6.2 Cause and Effect

In experimental research, the aim is to manipulate an independent variable(s) and then examine the effect that this change has on a dependent variable(s). Since it is possible to manipulate the independent variable(s), experimental research has the advantage of enabling a researcher to identify a cause and effect between variables. Within the context of these controlled experiments, the aim was to manipulate the information that the product designer has access to in order to examine the effect that it has on the outputs of the ENPD process. It was important to explore not only if there was a connection between the two variables but also to, through their manipulation, discover what effects certain types of information have.

6.2.1 *Categorising Variables*

A variable is not only something that can be measured, but also something that can be manipulated and controlled for. It is important to understand the characteristics of the variables and to accurately describe them. Table 39 contains a list of the variables that are related to the 'degree of relationship' hypotheses; no distinction is made between the variables, as the aim is check if there is a relationship as opposed to exploring causes and effects. For those hypotheses that deal with group differences, the independent and dependant variables have been identified and categorised in Table 40.

TABLE 39: DEGREE OF RELATIONSHIP VARIABLES

Hypothesis	Variable 1	Variable 2	Variable Type
H_A	Product Cost	Product Environmental Performance	Continuous
H_B	Product Cost	Supply Chain Greenness	
H_C	Product Environmental Performance	Supply Chain Greenness	

TABLE 40: GROUP DIFFERENCES VARIABLES

Hypothesis	Type of Variable	Variable	Variable Type	Categories			
$H_{D/E/F}$	Independent	Extra Information	Categorical	A	B	C	D
	Dependent	Product Environmental Performance	Continuous				
		Supply Chain Greenness	Continuous				
		Product Cost	Continuous				
$H_{G/H/I}$	Independent	Knowing cost	Dichotomous	No		Yes	
	Dependent	Product Environmental Performance	Continuous				
		Supply Chain Greenness	Continuous				
		Product Cost	Continuous				
$H_{J/K/L}$	Independent	Knowing supplier information	Dichotomous	No		Yes	
	Dependent	Product Environmental Performance	Continuous				
		Supply Chain Greenness	Continuous				
		Product Cost	Continuous				

6.3 Generalising from Samples to Populations

Sampling involves the selection of a number of study units from a defined study population. In the context of this study, the population of interest is product designers. While random sampling is preferable, due to practical reasons such lack of as access to all sampling frame units, non-random purposive sampling was adopted. Additionally, mainly due to pragmatic factors, the study site was selected as the academic institution where the researcher was situated. This set up gave the researcher relatively easy access to a representative sample.

Though the use of inferential statistics, samples can be used to make generalisations about the populations from which the samples were drawn. This means that the research outputs can have broader application than merely being limited to a small group. In this case, the outputs can be applied to product designers within industry that undertake ENPD. It was, therefore, important that the sample accurately represented the population.

6.3.1 Participants in the Sample

The sample for this study was made up of 16 third year Mechanical Engineering students from the University of Bath. All the participants had at least 12 months industrial placement experience working with suppliers in industry and had an understanding of eco-design basics. The group was identified as one that had characteristics that correspond to the population of interest (i.e. product development professionals). Care was taken when determining the traits of participants in the sample, as the disadvantage of purposive sampling is the omission of a vital characteristic or subconscious bias in selecting the sample. The participants were assigned to control and experimental groups randomly; being similar in background to qualities that are relevant to the exercises and the broader population enhances the representativeness of the research subjects. Table 41 contains details on the participants that made up the sample.

TABLE 41: PARTICIPANTS IN THE SAMPLE

CONDITION	PARTICIPANT	PROFILE		
		WORK EXPERIENCE INDUSTRY	SUPPLIER ENGAGEMENT LEVEL	ECO-DESIGN LEVEL
A	P001	AUTOMOTIVE	2	1
	P002	AUTOMOTIVE	2	1
	P003	CONSUMER PRODUCTS	3	1
	P004	CONSUMER PRODUCTS	2	1
B	P005	PRODUCT DESIGN CONSULTANCY	3	1
	P006	AEROSPACE	2	1
	P007	OIL AND GAS	2	1
	P008	CONSUMER PRODUCTS	3	1
C	P009	AUTOMOTIVE	2	1
	P010	OIL AND GAS	3	1
	P011	PRODUCT DESIGN CONSULTANCY	2	1
	P012	AEROSPACE	2	1
D	P013	CONSUMER PRODUCTS	2	1
	P014	AUTOMOTIVE	3	1
	P015	AUTOMOTIVE	2	1
	P016	CONSUMER PRODUCTS	2	1

KEY				
SUPPLIER ENGAGEMENT LEVEL	DEFINITION		ECO DESIGN LEVEL	DEFINITION
1	WORKING WITH CATALOGUES		1	ACADEMIC EXPERIENCE
2	COMMUNICATING WITH SUPPLIERS		2	INDUSTRIAL EXPERIENCE
3	WORKING ON PROJECTS WITH SUPPLIERS			

6.4 EXPERIMENT STRUCTURE DESIGN

The main aim of these exercises was to show how the dependent variables (ENPD outputs) respond to changes in the independent variables (information). To do this, it was important to ensure that it is the information the designers had was responsible for any changes in the design outputs and not some other factor. This was achieved through the control of variables that could perhaps affect the incidence, to ensure that, out of all of them, it was only the one factor that could possibly be linked to the change. McBurney and White (2003) state that there is no such thing as a perfect experiment; nevertheless, the existence of a control group and random allocation of subjects to groups form the basis of sound experiment designs and provide some control over threats to validity.

6.4.1 USE OF CONTROLS

The most straightforward way to isolate the impact of information is to introduce it while keeping all other relevant factors unchanged. In the case of these component selection exercises, Condition A, where the participants were only provided with information regarding the performance of the parts they could choose from, was set up as the control group. Three other groups, which had varying types of information, were the experimental groups. Those in Condition B had cost and performance information, Condition C had cost, performance and supplier information and Condition D has access to performance, cost and supplier information but it would only be supplied if they explicitly asked for it. Condition C is the group that would perform the component selection exercises under the conditions suggested by the approach and process model detailed in the conceptual framework (See Section 3.2). The use of control groups is summarised in Table 42. The pre- and post-tests are designed to evaluate the participants before and after receiving the treatments.

TABLE 42: CONTROLS WITHIN THE EXPERIMENTS

CONDITION	SUBJECTS	ALLOCATION	GROUP	TREATMENT	EXAMPLE INFORMATION	PRE-TEST	POST-TEST
A	4	RANDOM	CONTROL	PERFORMANCE INFORMATION	LIGHT BULB LUMENS	YES	YES
B	4	RANDOM	EXPERIMENTAL	PERFORMANCE AND COST INFORMATION	LIGHT BULB LUMENS AND COST OF LIGHT BULB	YES	YES
C	4	RANDOM	EXPERIMENTAL	PERFORMANCE, COST AND SUPPLIER INFORMATION	LIGHT BULB LUMENS, COST OF LIGHT BULB AND LOCATION OF LIGHT BULB SUPPLIER	YES	YES
D	4	RANDOM	EXPERIMENTAL	OPTIONAL INFORMATION		YES	YES

6.4.2 PRE-TEST AND POST-TEST

To compensate for any non-equivalency within the groups that was likely due to eco-design experience and to eliminate any resultant biases, a pre-test post-test design was adopted. In this case before they undertook the exercises, all the participants will be guided by the researcher through a task that aimed to explore eco-design principles. Through this task, all the participants gained have the same level of understanding of eco-design principles that related to the product that they are redesigning. This exercise took the form of exploring the LCA results of a reference product and identifying environmental hotspots; it was related to the analysis steps in the environmental performance integration method proposed by Nielsen and Wenzel (2002b) (See Section 2.2.2.) Following that, the participants undertook the exercise in accordance with the treatment of the condition they have been placed in. During the post-test, the researcher and participants discussed and analysed the produced designs.

6.5 EXPERIMENT INSTRUMENT DESIGN

For defensible inferences to be made on the basis of the data collected during the experimentation process, the data from the component selection exercises had to be valid and reliable. To achieve external validity, the instruments were designed in a manner that allowed for generalisations to be made from the analysis of the sample data to the population as a whole. Figure 44 shows the stages in the instrumentation process that resulted in the development of materials that were used in the component selection exercises.

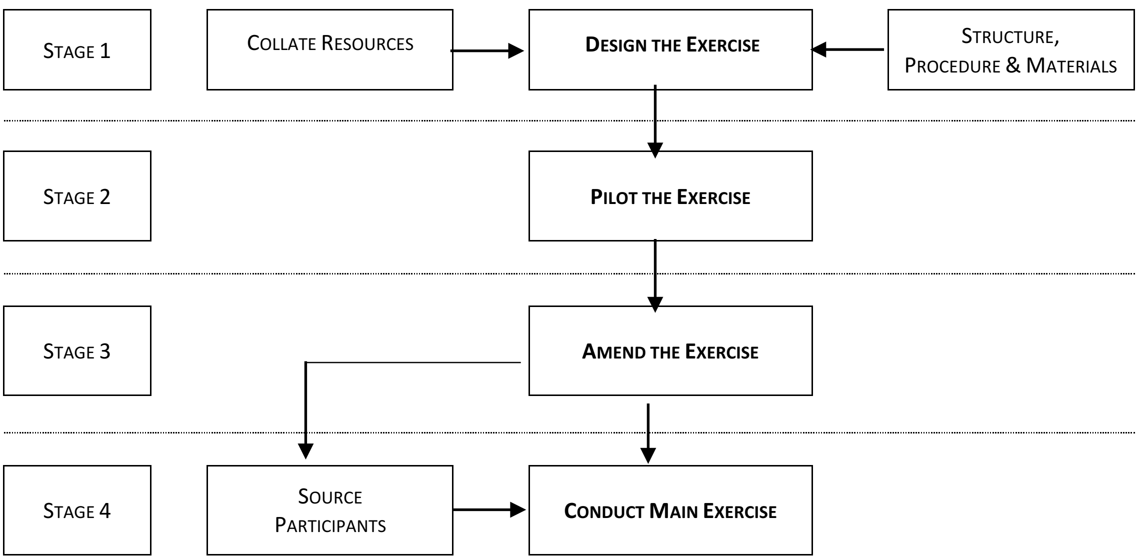


FIGURE 44: STAGES IN THE EXERCISE INSTRUMENTATION PROCESS

6.5.1 *Instrumentation*

The main objective of the instrumentation process was to design an exercise that would simulate ENPD and allow the impacts of the different conditions on the outputs to be investigated.

Structure and Procedure

A time limit was set for the execution of the exercise; this, along with a breakdown of activities that were to be undertaken during each exercise, is detailed in Table 43.

TABLE 43: COMPONENT SELECTION EXERCISES TIMELINE AND ACTIVITIES

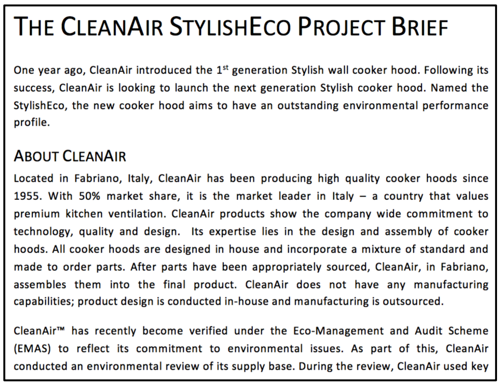
Timeline	**Activity**	**Description**
0 – 5 mins.	Introduction	Brief introduction to the researcher and what the exercise will entail.
5 – 10 mins.	Opening Interview	Getting to know the participants background (in particular, their placement and experience with eco-design and working with suppliers).
10 – 25 mins.	1st Set of Materials	Participants are given the documents related to the Stylish cookerhood and given time to get familiar with them.
25 – 40 mins.	Understanding the Materials and Eco-Design	To ensure that the participants have an understanding of the materials that they are given, they are asked to do the following: - Identify environmental issues related to the product - List design solutions that they could apply to address those issues Through this process the participants are encouraged to talk through their thoughts with the facilitator.
30 – 45 mins.	2nd Set of Materials	Participants are given the rest of the documents that relate to the StylishEco that they will be designing and given time to get familiar with them.
45 – 115 mins.	Component Selection Exercise	The participants carry out the component selection exercise. They are encouraged to think out loud and are required to explain to the investigator how they came to the decision of which components to use.
115 – 120 mins.	Exit Interview	Discuss the produced design and design process with the participants.

Materials

Table 44 lists the materials that were created for the exercises, summarises of the materials contain, and how they were created and Table 45 shows which materials were given in each of the experimental conditions.

TABLE 44: MATERIALS CREATED FOR THE COMPONENT SELECTION EXERCISES

THE CLEANAIR STYLISHECO PROJECT BRIEF


THE CLEANAIR STYLISHECO PROJECT BRIEF

One year ago, CleanAir introduced the 1st generation Stylish wall cooker hood. Following its success, CleanAir is looking to launch the next generation Stylish cooker hood. Named the StylishEco, the new cooker hood aims to have an outstanding environmental performance profile.

ABOUT CLEANAIR

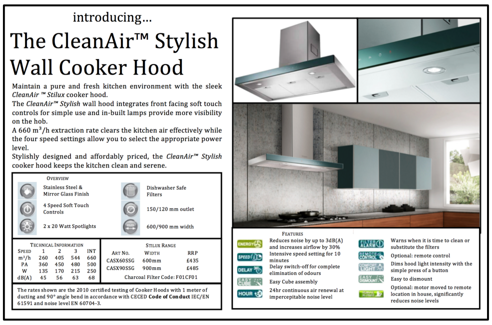
Located in Fabriano, Italy, CleanAir has been producing high quality cooker hoods since 1955. With 50% market share, it is the market leader in Italy – a country that values premium kitchen ventilation. CleanAir products show the company wide commitment to technology, quality and design. Its expertise lies in the design and assembly of cooker hoods. All cooker hoods are designed in house and incorporate a mixture of standard and made to order parts. After parts have been appropriately sourced, CleanAir, in Fabriano, assembles them into the final product. CleanAir does not have any manufacturing capabilities; product design is conducted in-house and manufacturing is outsourced.

CleanAir™ has recently become verified under the Eco-Management and Audit Scheme (EMAS) to reflect its commitment to environmental issues. As part of this, CleanAir conducted an environmental review of its supply base. During the review, CleanAir used key

An outline of the component selection exercise in the form of a project brief for the redesign of the Stylish Cookerhood into the StylishEco Cookerhood. The brief contains information on the company background, project background and what is required of the participant.
The project brief was created especially for the exercise and is based on C002.

Full document in Appendix 6.1: The CleanAir StylishEco Project Brief

STYLISH COOKERHOOD PROMOTIONAL FLYER


introducing...

The CleanAir™ Stylish Wall Cooker Hood

Maintain a pure and fresh kitchen environment with the sleek *CleanAir ™ Stilux* cooker hood.
The *CleanAir™ Stylish* wall hood integrates front facing soft touch controls for simple use and in-built lamps provide more visibility on the hob.
A 660 m³/h extraction rate clears the kitchen air effectively while the four speed settings allow you to select the appropriate power level.
Stylishly designed and affordably priced, the *CleanAir™ Stylish* cooker hood keeps the kitchen clean and serene.

OVERVIEW

- Stainless Steel & Mirror Glass Finish
- Dishwasher Safe Filters
- 4 Speed Soft Touch Controls
- 150/120 mm outlet
- 2 x 20 Watt Spotlights
- 600/900 mm width

TECHNICAL INFORMATION

SPEED	1	2	3	INT
m³/h	260	405	544	660
PA	360	450	480	500
W	135	170	215	250
dB(A)	45	56	63	68

STILUX RANGE

ART NO.	WIDTH	RRP
CASX60SSG	600mm	£435
CASX90SSG	900mm	£485

Charcoal Filter Code: F01CF01

The rates shown are the 2010 certified testing of Cooker Hoods with 1 meter of ducting and 90° angle bend in accordance with CECED **Code of Conduct** IEC/EN 61591 and noise level EN 60704-3.

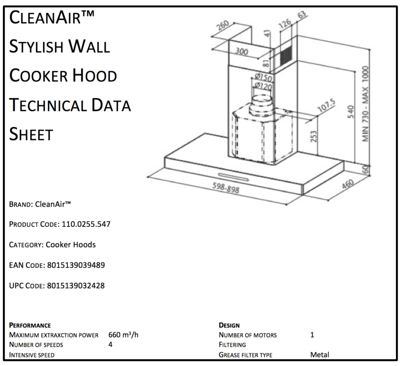
FEATURES

- ENERGY: Reduces noise by up to 3dB(A) and increases airflow by 30%
- SPEED: Intensive speed setting for 10 minutes
- DELAY: Delay switch-off for complete elimination of odours
- EASY CUBE: Easy Cube assembly
- HOUR: 24hr continuous air renewal at impercepitable noise level
- FILTER ALARM: Warns when it is time to clean or substitute the filters
- REMOTE CONTROL: Optional: remote control
- COMFORT LIGHT: Dims hood light intensity with the simple press of a button
- EASY DISMOUNT: Easy to dismount
- Optional: motor moved to remote location in house, significantly reduces noise levels

A promotional flyer that gives details on the Stylish Cookerhood. The flyer contains pictures of the cookerhood, has information on the performance of the cookerhood and highlights the cookerhood's main features.
While the flyer was created especially for the exercise, the information that is contained within it accurately corresponds to the real cookerhood that the exercise is based on.

Full document in Appendix 6.2: Stylish Cookerhood Promotional Flyer

STYLISH COOKERHOOD TECHNICAL DATASHEET


CLEANAIR™ STYLISH WALL COOKER HOOD TECHNICAL DATA SHEET

BRAND: CleanAir™

PRODUCT CODE: 110.0255.547

CATEGORY: Cooker Hoods

EAN CODE: 8015139039489

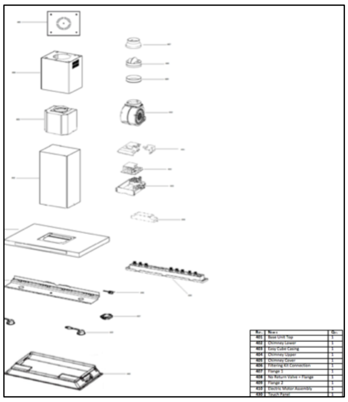
UPC CODE: 8015139032428

PERFORMANCE		DESIGN	
MAXIMUM EXTRAXCTION POWER	660 m³/h	NUMBER OF MOTORS	1
NUMBER OF SPEEDS	4	FILTERING	
INTENSIVE SPEED		GREASE FILTER TYPE	Metal

The technical datasheet for the Stylish Cookerhood. The datasheet contains information on the performance and physical attributes of the cookerhood and also has drawings of the cookerhood.
While the datasheet was created for the purpose of the exercise, the information within it accurately corresponds to the real cookerhood that the exercise is based on.

Full document in Appendix 6.2: Stylish Cookerhood Technical Datasheet

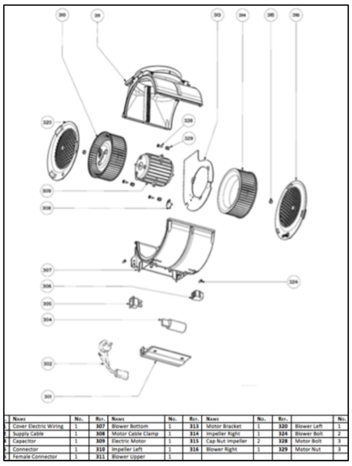
STYLISH COOKERHOOD ASSEMBLY DRAWING



An assembly drawing for the Stylish Cookerhood. The drawing is an exploded view of the cookerhood; a parts list is also included.
The drawing was created especially for this exercise; however, it relates to the real cookerhood that the exercise is based on.

Full document in Appendix 6.3: Stylish Cookerhood Assembly Drawing

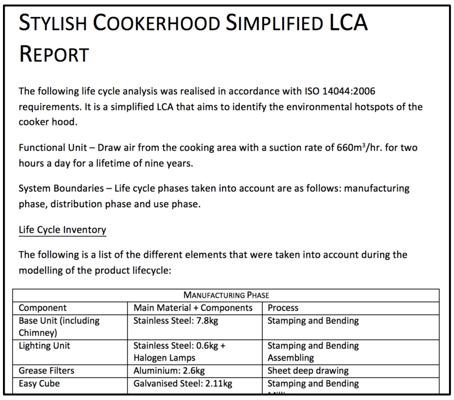
ELECTRIC MOTOR ASSEMBLY DRAWING



A drawing of the electric motor assembly that can be found inside the Stylish cookerhood. The drawing is an exploded view of the motor assembly; a parts list is also included.
While the drawing was created especially for this exercise, it is based on the real life cookerhood that the exercise is based on.

Full document in Appendix 6.4: Electric Motor Assembly Drawing

STYLISH COOKERHOOD SIMPLIFIED LCA REPORT



STYLISH COOKERHOOD SIMPLIFIED LCA REPORT

The following life cycle analysis was realised in accordance with ISO 14044:2006 requirements. It is a simplified LCA that aims to identify the environmental hotspots of the cooker hood.

Functional Unit – Draw air from the cooking area with a suction rate of 660m^3/hr. for two hours a day for a lifetime of nine years.

System Boundaries – Life cycle phases taken into account are as follows: manufacturing phase, distribution phase and use phase.

Life Cycle Inventory

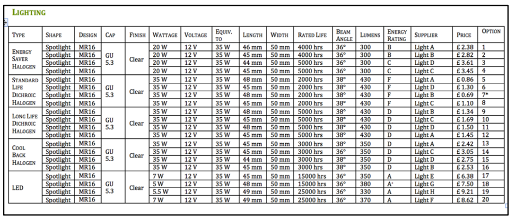
The following is a list of the different elements that were taken into account during the modelling of the product lifecycle:

MANUFACTURING PHASE		
Component	Main Material + Components	Process
Base Unit (including Chimney)	Stainless Steel: 7.8kg	Stamping and Bending
Lighting Unit	Stainless Steel: 0.6kg + Halogen Lamps	Stamping and Bending Assembling
Grease Filters	Aluminium: 2.6kg	Sheet deep drawing
Easy Cube	Galvanised Steel: 2.11kg	Stamping and Bending

A simplified LCA report of the Stylish cookerhood. The LCA report contains an inventory list which details the elements that were taken into consideration during the LCA and the subsequent LCA, which focused on the impact of the cookerhood during the manufacturing, use and transportation phases of its lifecycle.
This simplified LCA report is identical to the one that was created for the real life cookerhood that this exercise is based on.

Full document in
Appendix 6.5: Stylish Cookerhood Simplified LCA Report

COOKERHOOD PARTS CATALOGUE



LIGHTING

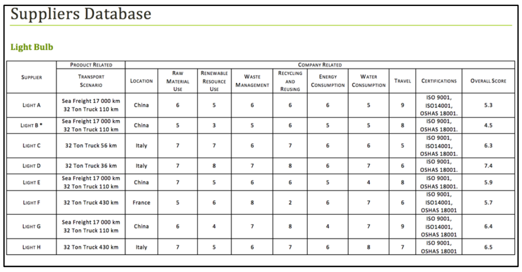
TYPE	SHAPE	DESIGN	CAP	FINISH	WATTAGE	VOLTAGE	EQUIV. TO	LENGTH	WIDTH	RATED LIFE	BEAM ANGLE	LUMENS	ENERGY RATING	SUPPLIER	PRICE	OPTION
ENERGY SAVER HALOGEN	Spotlight	MR16	GU 5.3	Clear	20 W	12 V	35 W	46 mm	50 mm	4000 hrs	36°	300	B	Light A	£ 2.38	1
	Spotlight	MR16			20 W	12 V	35 W	45 mm	50 mm	4000 hrs	36°	300	B	Light B	£ 2.82	2
	Spotlight	MR16			20 W	12 V	35 W	44 mm	50 mm	5000 hrs	36°	300	C	Light D	£ 3.61	3
	Spotlight	MR16			20 W	12 V	35 W	45 mm	50 mm	5000 hrs	36°	300	C	Light C	£ 3.45	4
STANDARD LIFE DICHROIC HALOGEN	Spotlight	MR16	GU 5.3	Clear	35 W	12 V	35 W	48 mm	50 mm	2000 hrs	38°	430	F	Light A	£ 0.86	5
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	2000 hrs	38°	430	F	Light D	£ 1.30	6
	Spotlight	MR16			35 W	12 V	35 W	48 mm	50 mm	2000 hrs	38°	430	F	Light B	£ 0.69	7*
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	2000 hrs	38°	430	F	Light C	£ 1.10	8
LONG LIFE DICHROIC HALOGEN	Spotlight	MR16	GU 5.3	Clear	35 W	12 V	35 W	48 mm	50 mm	5000 hrs	38°	430	D	Light B	£ 1.34	9
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	5000 hrs	38°	430	D	Light C	£ 1.69	10
	Spotlight	MR16			35 W	12 V	35 W	48 mm	50 mm	5000 hrs	38°	430	D	Light D	£ 1.50	11
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	5000 hrs	38°	430	D	Light A	£ 1.45	12
COOL BACK HALOGEN	Spotlight	MR16	GU 5.3	Clear	35 W	12 V	35 W	45 mm	50 mm	3000 hrs	38°	350	D	Light A	£ 2.42	13
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	3000 hrs	36°	350	D	Light C	£ 3.05	14
	Spotlight	MR16			35 W	12 V	35 W	44 mm	50 mm	3000 hrs	38°	350	D	Light D	£ 2.75	15
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	3000 hrs	38°	350	D	Light B	£ 2.53	16
LED	Spotlight	MR16	GU 5.3	Clear	7 W	12 V	35 W	45 mm	50 mm	15000 hrs	36°	350	A	Light E	£ 6.38	17
	Spotlight	MR16			5 W	12 V	35 W	48 mm	50 mm	15000 hrs	36°	380	A+	Light G	£ 7.50	18
	Spotlight	MR16			5.5 W	12 V	35 W	49 mm	50 mm	25000 hrs	36°	330	A	Light H	£ 9.21	19
	Spotlight	MR16			7 W	12 V	35 W	49 mm	50 mm	25000 hrs	36°	370	A	Light F	£ 8.62	20

A cookerhood parts catalogue. The parts catalogue contains information on the different parts that the participants can choose from during the component selection exercise. It contains performance, design and cost information on the parts that is typically found in catalogues.

The parts catalogue contains real components that are available to buy from different vendors. The parts catalogue comes in two varieties, one with cost information and another one without.

Full document in Appendix 6.6: Cookerhood Parts Catalogue

SUPPLIER DATABASE



Suppliers Database

Light Bulb

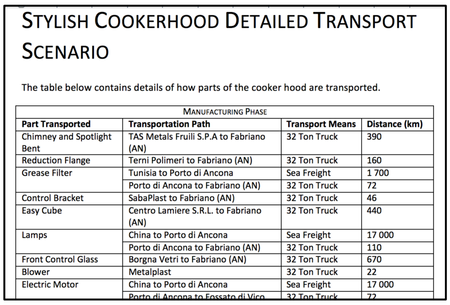
SUPPLIER	PRODUCT RELATED: TRANSPORT SCENARIO	COMPANY RELATED: LOCATION	RAW MATERIAL USE	RENEWABLE RESOURCE USE	WASTE MANAGEMENT	RECYCLING AND REUSING	ENERGY CONSUMPTION	WATER CONSUMPTION	TRAVEL	CERTIFICATIONS	OVERALL SCORE
LIGHT A	Sea Freight 17 000 km 32 Ton Truck 110 km	China	6	5	6	6	6	5	9	ISO 9001, ISO14001, OSHAS 18001.	5.3
LIGHT B *	Sea Freight 17 000 km 32 Ton Truck 110 km	China	5	3	5	6	5	5	8	ISO 9001, OSHAS 18001.	4.5
LIGHT C	32 Ton Truck 56 km	Italy	7	7	6	7	6	6	5	ISO 9001, ISO14001, OSHAS 18001.	6.3
LIGHT D	32 Ton Truck 36 km	Italy	7	8	7	8	6	7	6	ISO 9001, OSHAS 18001.	7.4
LIGHT E	Sea Freight 17 000 km 32 Ton Truck 110 km	China	7	5	6	6	5	4	8	ISO 9001, OSHAS 18001.	5.9
LIGHT F	32 Ton Truck 430 km	France	5	6	8	2	6	7	6	ISO 9001, ISO14001, OSHAS 18001	5.7
LIGHT G	Sea Freight 17 000 km 32 Ton Truck 110 km	China	6	4	7	8	4	7	9	ISO 9001, ISO14001, OSHAS 18001	6.4
LIGHT H	32 Ton Truck 430 km	Italy	7	5	6	7	6	8	7	ISO 9001, OSHAS 18001	6.5

A database of the suppliers that provide the parts that are included in the parts catalogue. The information includes location of the suppliers, results of the Eco-Management and Audit Scheme and certifications that the suppliers have.

The information regarding the locations of the suppliers is based on real life; however, all the other information in the database was created for the exercise. The type of information in the database is based on the information typically found in an EMS database.

Full document in Appendix 6.7: Supplier Database

STYLISH COOKERHOOD DETAILED TRANSPORT SCENARIO



STYLISH COOKERHOOD DETAILED TRANSPORT SCENARIO

The table below contains details of how parts of the cooker hood are transported.

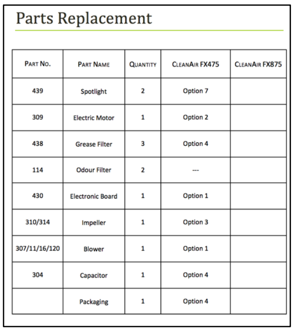
MANUFACTURING PHASE			
Part Transported	**Transportation Path**	**Transport Means**	**Distance (km)**
Chimney and Spotlight Bent	TAS Metals Fruili S.P.A to Fabriano (AN)	32 Ton Truck	390
Reduction Flange	Terni Polimeri to Fabriano (AN)	32 Ton Truck	160
Grease Filter	Tunisia to Porto di Ancona	Sea Freight	1 700
	Porto di Ancona to Fabriano (AN)	32 Ton Truck	72
Control Bracket	SabaPlast to Fabriano (AN)	32 Ton Truck	46
Easy Cube	Centro Lamiere S.R.L. to Fabriano (AN)	32 Ton Truck	440
Lamps	China to Porto di Ancona	Sea Freight	17 000
	Porto di Ancona to Fabriano (AN)	32 Ton Truck	110
Front Control Glass	Borgna Vetri to Fabriano (AN)	32 Ton Truck	670
Blower	Metalplast	32 Ton Truck	22
Electric Motor	China to Porto di Ancona	Sea Freight	17 000
	Porto di Ancona to Fossato di Vico	32 Ton Truck	72

A detailed report of the transport scenario of the Stylish cookerhood. The document includes information on where the parts in the cookerhood were transported from and the means of transportation that was used.

The report is identical to that of the real life cookerhood that the exercise is based on.

Full document in Appendix 6.8: Stylish Cookerhood Detailed Transport Scenario

PARTS REPLACEMENT FILL-IN SHEET



Parts Replacement

PART NO.	PART NAME	QUANTITY	CLEANAIR FX475	CLEANAIR FX875
439	Spotlight	2	Option 7	
309	Electric Motor	1	Option 2	
438	Grease Filter	3	Option 4	
114	Odour Filter	2	---	
430	Electronic Board	1	Option 1	
310/314	Impeller	1	Option 3	
307/11/16/120	Blower	1	Option 1	
304	Capacitor	1	Option 4	
	Packaging	1	Option 4	

A parts replacement fill-in sheet. The sheet contains information on the parts that are in the Stylish cookerhood and has spaces where the participants write down the parts that they would replace them with when they are designing the StylishEco.

Full document in Appendix 6.9: Parts Replacement Fill-in Sheet

TABLE 45: MATERIALS GIVEN TO THE PARTICIPANTS DURING THE EXERCISE

Resources	**Extra Information Classification**	**Condition**			
		A	B	C	D
Clean Air StylishEco Project Brief	-	✔	✔	✔	✔
Stylish Cookerhood Promotional Flyer	-	✔	✔	✔	✔
Stylish Cookerhood Technical Datasheet	-	✔	✔	✔	✔
Stylish Cookerhood Assembly Drawing	-	✔	✔	✔	✔
Electric Motor Assembly Drawing	-	✔	✔	✔	✔
Stylish Cookerhood Simplified LCA Report	-	✔	✔	✔	✔
Parts Catalogue (with Cost)	Cost		✔	✔	(available upon request)
Parts Catalogue (without Cost)	Product	✔			✔
Supplier Database	Supplier			✔	(available upon request)
Stylish Cookerhood Detailed Transport Scenario	Supplier			✔	(available upon request)
Parts Replacement Fill-in Sheet	-	✔	✔	✔	✔

6.5.2 Pilot and Post Pilot

Several drafts of the research instrument were tested until a satisfactory version was reached. Throughout this process Dr. L. Domingo, an eco-design expert, was consulted to help evaluate the overall design of the exercises and validity of associated materials. The component selection exercises were only carried out after necessary amendments were made and the research instrument was thought to be ready. Dr. Domingo was also instrumental in developing the evaluation process with for the outputs of the exercises.

6.6 Data Collection and Results

With the materials for the exercises produced and the necessary resources gathered, the experiments were conducted. During the data collection exercises, the participants were asked to fill in the sheet detailing the options they selected and audio recordings were made of the entire process. The fill-in sheets formed the basis for the quantitative dataset and the audio recordings did the same for the qualitative dataset. The options selected by each participant are listed in Table 46.

TABLE 46: OPTIONS SELECTED BY PARTICIPANTS DURING EXERCISES

Cond.	Part.	Spotlight	Electric Motor	G. Filter	O. Filter	Impeller	Blower	Packaging
Base (Stylish Cookerhood)		Option 7	Option 1	Option 3		Option 1	Option 4	Option 1
		Standard Halogen	Shaded Pole Single Phase Asynchronous	SS Mesh & AL		Galvanized Steel	Polypropylene	Cardboard
A	P001	Option 19	Option 12	Option 3	Option 8	Option 1	Option 4	Option 2
		LED	Brushless Permanent Magnet Motor	SS Mesh & AL	Long Life Filter	Galvanized Steel	Polypropylene	Cardboard
	P002	Option 18	Option 12	Option 5		Option 1	Option 4	Option 2
		LED	Brushless Permanent Magnet Motor	SS Mesh & SS		Galvanized Steel	Polypropylene	Cardboard
	P003	Option 18	Option 8	Option 5	Option 8	Option 1	Option 4	Option 2
		LED	Single Phase with Permanent Capacitor	SS Mesh & SS	Long Life Filter	Galvanized Steel	Polypropylene	Cardboard
	P004	Option 18	Option 10	Option 5		Option 1	Option 1	Option 2
		LED	Brushless Permanent Magnet Motor	SS Mesh & SS		Galvanized Steel	Galvanised Steel	Cardboard
B	P005	Option 9	Option 11	Option 1		Option 6	Option 6	Option 5
		Long Life Dichroic Halogen	Brushless Permanent Magnet Motor	SS Mesh & SS		Polypropylene	Polypropylene	Cardboard
	P006	Option 18	Option 9	Option 7		Option 5	Option 5	Option 1
		LED	Brushless Permanent Magnet Motor	SS Mesh & AL		Polypropylene	Polypropylene	Cardboard
	P007	Option 9	Option 9	Option 3		Option 6	Option 6	Option 5
		Long Life Dichroic Halogen	Brushless Permanent Magnet Motor	SS Mesh & AL		Polypropylene	Polypropylene	Cardboard
	P008	Option 9	Option 9	Option 1		Option 1	Option 1	Option 5
		Long Life Dichroic Halogen	Brushless Permanent Magnet Motor	SS Mesh & SS		Galvanized Steel	Galvanised Steel	Cardboard
C	P009	Option 18	Option 10	Option 3	Option 7	Option 1	Option 4	Option 2
		LED	Brushless Permanent Magnet Motor	SS Mesh & AL	Long Life Filter	Galvanized Steel	Polypropylene	Cardboard
	P010	Option 19	Option 7	Option 3	Option 7	Option 1	Option 4	Option 2
		LED	Single Phase with Permanent Capacitor	SS Mesh & AL	Long Life Filter	Galvanized Steel	Polypropylene	Cardboard
	P011	Option 18	Option 10	Option 3	Option 7	Option 1	Option 4	Option 2
		LED	Brushless Permanent Magnet Motor	SS Mesh & AL	Long Life Filter	Galvanized Steel	Polypropylene	Cardboard
	P012	Option 18	Option 7	Option 5		Option 4	Option 4	Option 1
		LED	Single Phase with Permanent Capacitor	SS Mesh & SS		Galvanized Steel	Polypropylene	Cardboard
D	P013	Option 18	Option 7	Option 1		Option 1	Option 1	Option 1
		LED	Single Phase with Permanent Capacitor	SS Mesh & SS		Galvanized Steel	Galvanized Steel	Cardboard
	P014	Option 1	Option 9	Option 1		Option 6	Option 6	Option 1
		Energy Saver Halogen	Brushless Permanent Magnet Motor	SS Mesh & SS		Polypropylene	Polypropylene	Cardboard
	P015	Option 18	Option 12	Option 3		Option 3	Option 6	Option 2
		LED	Brushless Permanent Magnet Motor	SS Mesh & AL		Galvanized Steel	Polypropylene	Cardboard
	P016	Option 17	Option 7	Option 3		Option 1	Option 1	Option 2
		LED	Single Phase with Permanent Capacitor	SS Mesh & AL		Galvanized Steel	Galvanized Steel	Cardboard

6.7 Data Analysis

The main objective of this stage of the research was to probe the data from the component selection exercises in a way that critically assesses the impact of supply chain design on environmental new product development outputs, with the aim of understanding what information affects ENPD and how it could be improved.

6.7.1 Data Analysis Process

The data analysis of the component selection exercises followed a process composed of three stages. Figure 45 details these stages in relation for both the quantitative and qualitative data. Furthermore, it shows the differences between the quantitative and qualitative data analysis, with the quantitative arm tending to shape the data more consciously and explicitly in the earlier stages of the processes compared to the qualitative.

	Quantitative	Qualitative
Data	Participant's component selections Information on components	Audio recordings of component selection exercise protocols
1. Preparation and Processing (Section 6.7.2)	Calculate PEP, SCG and Cost Determine Optimal designs - Finding combinations - Multi-objective optimisation Categorise data Check data	Transcribe recordings
2. Analysis (Section 6.7.3-6.7.5)	Descriptive Statistics Inferential Statistics Analytic Memoing	Content analysis - Code data - Group codes into categories - Comparisons of categories Textual Analysis - Analytic Memoing
3. Representation and Display (section 6.7-6.9)	Tables Figures Written interpretation of statistical findings	Written interpretation of findings Use of matrices and tables

FIGURE 45: STAGES IN THE DATA ANALYSIS PROCESS

Use of Software

The qualitative data was analysed using Nvivo, while the quantitative data was analysed using Microsoft Excel, SPSS and Matlab. Figure 46 contains details on the data that each software package analysed, along with the actions involved and the outcomes. The use of software saved time, helped to manage large amounts of qualitative data, increased analysis flexibility and improved validity.

	Software			
	Excel	SPSS	Matlab	Nvivo
Data	Participants selections and part information	PEP, SCG and Cost values for all participants	Possibly non-dominated design combinations	Transcriptions of component selection exercises
Action	Data preparation Combination generation	Descriptive and inferential statistics	Linear programming	Holistic and In-vivo Coding
Outputs	All PEP, SCG and Cost values Possibly non-dominated design combinations	Descriptive statistics Hypothesis acceptance or rejection	Non-dominated design combinations	Participants' sourcing strategies

FIGURE 46: SOFTWARE USE DURING DATA ANALYSIS

6.7.2 Data Processing and Preparation

The main aim of this stage of the analysis process is to process the data that was generated during the component selection exercises into data sets that can be carried over into the analysis stage. This meant calculating values for PEP, SCG and Cost for the designs made by the participants and to determine what the most optimal designs that could have been generated were.

Product Environmental Performance Calculations

This section presents the calculations that were made on the collected data. The calculations are based on original metrics and scoring systems that were established and developed for the purpose of this study.

The first step in calculating the product environmental performance was referring back to the contributions highlighted in the LCA report, the electric motor, spotlights and grease filters were shown to have the highest environmental impacts. Their individual contributions are broken down in Table 47; collectively they contribute 80.59% of the cookerhood's total impact.

TABLE 47: COMPONENTS WITH HIGHEST ENVIRONMENTAL IMPACTS

	Use Phase	Manufacturing	Total
Life Cycle Impact	71.7%	27.5%	
Motor	89%	9.1%	66.32%
Lights	9%	8.4%	8.76%
Grease Filter	1%	18%	5.61%
		Contribution	80.59%

As they constitute the parts that the participants could change that have the most impact on the environmental profiles of the designed cookerhoods, the product environmental performance calculation was based solely on these. However, as the parts did not contribute equally, it was necessary to reflect that in the calculation. By treating the 80.59% contribution of the three parts as 100% of the PEP, the weight of each part's contributions was calculated resulting in the individual contributions shown in Table 48.

TABLE 48: PART CONTRIBUTION TO PEP

	CONTRIBUTION
MOTOR	82.2%
LIGHTS	10.9%
GREASE FILTER	7.0%

Resultantly, the product environmental performance is the averaging the totalling of the environmental performance of the individual parts according to the following equation:

$$PEP = \frac{0.822EP_{motor} + 0.109EP_{spotlight} + 0.07EP_{greasefilter}}{3}$$

Electric Motor Environmental Performance

As the efficiency was one of the attributes that the participants could determine by selecting the motor with the efficiency they desired from the parts catalogue, it is what EP_{motor} was based on; the higher the efficiency of the motor the better its environmental profile. The biggest environmental impact contribution of the electric motor in Stylish cookerhood was in the 'use phase', which is linked to the motor's efficiency. The motor's environmental performance value is relative to that of the best option available. Table 49 contains the equations that were used and a worked out example of EP_{motor} being calculated; the results of the evaluation process are outlined in Table 50.

TABLE 49: CALCULATING THE ELECTRIC MOTOR ENVIRONMENTAL PERFORMANCE

	EQUATIONS	EXAMPLE CALCULATION USING OPTION 1
STEP 1	$EF = \frac{1}{highest\ efficiency\ from\ options}$	$EF = \frac{1}{0.66} = 1.52$
STEP 2	$EP_{motor} = E \times EF$	$EP_{motor} = 0.24 \times 1.52 = 0.364$
	KEY EF = Environmental Factor E = Efficiency	EPMOTOR = Motor Environmental Performance

TABLE 50: MOTOR ENVIRONMENTAL PERFORMANCE SCORES

TYPE	OPTION	EFFICIENCY	EP_{MOTOR}
SHADED-POLE SINGLE PHASE ASYNCHRONOUS MOTOR	1	24%	0.364
	2	24%	0.364
	3	28%	0.424
	4	28%	0.424
SINGLE PHASE MOTOR WITH PERMANENT CAPACITOR	5	41%	0.621
	6	41%	0.621
	7	48%	0.727
	8	48%	0.727
BRUSHLESS PERMANENT MAGNET MOTOR	9	50%	0.758
	10	50%	0.758
	11	66%	1.000
	12	66%	1.000

Spotlight Environmental Performance

The biggest spotlight contributions were almost equally in the use and manufacturing phases, relating these to the attributes that the participants had control over resulted in $EP_{spotlight}$ being based on the wattage and the number of lights used through the life of the cookerhood such that the lower in both the better the environmental performance. As with the electric motor the spotlight environmental performance is relative to the best option available and in the event of a tie, the closer of the two would be considered better. Table 51 contains the equations that were used and a worked out example of $EP_{spotlight}$ being calculated; the results of the evaluation process are shown in Table 52.

TABLE 51: CALCULATING THE SPOTLIGHT ENVIRONMENTAL PERFORMANCE

	EQUATIONS	EXAMPLE CALCULATION USING OPTION 1
STEP 1	$EF = \frac{1}{lowest\ wattage\ from\ options}$	$EF = \frac{1}{5} = 0.2$
STEP 2	$E = wattage \times EF$	$E = 20 \times 0.2 = 4$
STEP 3	$BR = \frac{Required\ Bulb\ Hours}{Bulb\ Rated\ Life}$	$BR = \frac{8000}{4000} = 2$
STEP 4	$EP_{spotlight} = \frac{1}{BR \times E}$	$EP_{spotlight} = \frac{1}{2 \times 4} = 0.125$
	KEY EF = Environmental Factor BR = Bulbs Required	E = Efficiency EPSPOTLIGHT = Spotlight Environmental Performance

TABLE 52: SPOTLIGHT ENVIRONMENTAL PERFORMANCE SCORES

TYPE	OPTION	WATTAGE	EFFICIENCY	RATED LIFE	BULBS REQUIRED	$EP_{SPOTLIGHT}$
ENERGY SAVER HALOGEN	1	20	4	4000 HRS	2	0.125
	2	20	4	4000 HRS	2	0.125
	3	20	4	5000 HRS	2	0.125
	4	20	4	5000 HRS	2	0.125
STANDARD LIFE DICHROIC HALOGEN	5	35	7	2000 HRS	3	0.048
	6	35	7	2000 HRS	3	0.048
	7	35	7	2000 HRS	3	0.048
	8	35	7	2000 HRS	3	0.048
LONG LIFE DICHROIC HALOGEN	9	35	7	5000 HRS	2	0.071
	10	35	7	5000 HRS	2	0.071
	11	35	7	5000 HRS	2	0.071
	12	35	7	5000 HRS	2	0.071
COOL BACK HALOGEN	13	35	7	3000 HRS	2	0.071
	14	35	7	3000 HRS	2	0.071
	15	35	7	3000 HRS	2	0.071
	16	35	7	3000 HRS	2	0.071
LED	17	7	1.4	15000 HRS	1	0.714
	18	5	1	15000 HRS	1	1.000
	19	5.5	1.1	25000 HRS	1	0.909
	20	7	1.4	25000 HRS	1	0.714

Grease Filter Environmental Performance

With the grease filter, the biggest impacts were in the manufacturing phase; looking at what the participants had control over, the homogeneity of materials (represented by number of individual materials in the filter) and thickness were selected as the basis of the $EP_{greasefilter}$ calculation. Being made from a single material was more desirable due to its contribution to ease of recycling and the smaller thickness due to the minimisation of materials used. Once again the options were evaluated relative to the best available one. Table 53 contains the equations that were used and a worked out example of $EP_{spotlight}$ being calculated; the results of this evaluation are shown in Table 54.

TABLE 53: CALCULATING THE GREASE FILTER ENVIRONMENTAL PERFORMANCE

	EQUATIONS	EXAMPLE CALCULATION USING OPTION 1
STEP 1	$EF = \frac{1}{lowest(no.of\ materials + thickness)\ from\ options}$	$EF = \frac{1}{1+1} = 0.5$
STEP 2	$EP_{greasefilter} = \left(\frac{EF}{no.of\ materials + thickness}\right)$	$EP_{greasefilter} = \frac{2}{3} = 0.67$
	KEY EF = Environmental Factor	EPGREASEFILTER = Spotlight Environmental Performance

TABLE 54: GREASE FILTER ENVIRONMENTAL PERFORMANCE SCORES

OPTION	NO. OF MATERIALS	THICKNESS	TOTAL	$EP_{GREASEFILTER}$
1	1	2	3	0.67
2	2	2	4	0.50
3	2	2	4	0.50
4	2	2	4	0.50
5	1	1	2	1.00
6	2	1	3	0.67
7	2	1	3	0.67
8	2	1	3	0.67
9	2	2	4	0.50
10	3	2	5	0.40
11	2	2	4	0.50
12	3	2	5	0.40
13	2	1	3	0.67
14	3	1	4	0.50
15	2	1	3	0.67
16	3	1	4	0.50

Participant Cookerhood PEP Scores

The values corresponding to the selections that the participants made were used to determine the appropriate EP values to input into the PEP equation. The results of this, the PEP of the designed cookerhoods, are shown in Table 55. The closer the value of PEP to 1.00 the better.

TABLE 55: COOKERHOOD PEP SCORES

CONDITION	PARTICIPANT	LIGHTS	MOTOR	FILTER	TOTAL
A	P001	0.0987	0.8219	0.0348	0.9554
	P002	0.1085	0.8219	0.0695	1.0000
	P003	0.1085	0.5978	0.0695	0.7758
	P004	0.1085	0.6227	0.0695	0.8007
B	P005	0.0078	0.8219	0.0464	0.8760
	P006	0.1085	0.6227	0.0464	0.7776
	P007	0.0078	0.6227	0.0348	0.6652
	P008	0.0078	0.6227	0.0348	0.6652
C	P009	0.1085	0.6227	0.0348	0.7660
	P010	0.0987	0.5978	0.0348	0.7312
	P011	0.1085	0.6227	0.0348	0.7660
	P012	0.1085	0.5978	0.0695	0.7758
D	P013	0.1085	0.5978	0.0464	0.7527
	P014	0.0136	0.6227	0.0464	0.6826
	P015	0.1085	0.8219	0.0348	0.9652
	P016	0.0775	0.5978	0.0348	0.7101

Supply Chain Greenness Calculations

As with the PEP, the SCG is totalling of the supplier greenness scores of all the suppliers in the designed products supply chain and is calculated according to the following equation:

$$SCG = \frac{SG_{motor} + SG_{spotlight} + SG_{greasefilter} + SG_{impeller} + SG_{blower} + SG_{packaging}}{6}$$

Supplier Greenness

The supplier greenness is calculated based on the information that was supplied in the supplier database, it includes the eco-score, the distance and the certifications and is exclusive of the product being supplied. The eco-score is the score that is assigned to each supplier in CleanAir's Eco-Management and Audit Scheme, the distance is how far away the supplier is from CleanAir's site and the certifications represent the number of environmentally related certifications that each supplier has. The suppliers are evaluated relative to the best out of the group with the lower the distance, the higher the number of certifications and the higher the eco-score resulting in the better supply chain greenness score. The factors are all assigned equal weight because the emphasis is on those three aspects of the suppliers and not what they are supplying. Table 56 contains the equations that were used and a worked out example of SG_{lighta} being calculated; the results of the evaluation of all the suppliers are shown in Table 57.

TABLE 56: CALCULATING THE SUPPLIER GREENESS FOR LIGHT A

	EQUATIONS	EXAMPLE CALCULATION USING LIGHT A
STEP 1	$RD = \frac{Overall\ shortet\ supplier\ distance\ from\ CleanAir}{Supplier\ distance\ from\ CleanAir}$	$RD = \frac{20}{17230} = 0.0012$
STEP 2	$RC = \frac{No.of\ certifcations}{Highest\ no.of\ supplier\ certifications}$	$RC = \frac{3}{3} = 1$
STEP 3	$RES = \frac{Eco - Score}{Highest\ supplier\ eco - score}$	$RES = \frac{5.3}{8.2} = 0.646$
STEP 4	$SG_{supplier} = RD + RC + RES$	$SG_{lighta} = 0.0012 + 1 + 0.646$ = 1.646
KEY	RD = Relative Distance RC = Relative Certifications	RES = Relative Eco-Score SGSUPPLIER = Supplier Greenness Score

TABLE 57: SUPPLIER GREENNESS CALCULATIONS AND SCORES FOR ALL SUPPLIERS

SUPPLIER	DISTANCE	RELATIVE DISTANCE	CERT.	RELATIVE CERT.	ECO-SCORE	RELATIVE ES	SUPPLIER GREENNESS
LIGHT A	17230	0.0012	3	1.000	5.3	0.646	1.6475
LIGHT B	17110	0.0012	2	0.667	4.5	0.549	1.2166
LIGHT C	56	0.3571	3	1.000	6.3	0.768	2.1254
LIGHT D	36	0.5556	2	0.667	7.4	0.902	2.1247
LIGHT E	17070	0.0012	2	0.667	5.9	0.720	1.3874
LIGHT F	430	0.0465	3	1.000	5.7	0.695	1.7416
LIGHT G	17310	0.0012	3	1.000	6.4	0.780	1.7816
LIGHT H	630	0.0317	2	0.667	6.6	0.805	1.5033
MOTOR A	17110	0.0012	2	0.667	5.8	0.707	1.3752
MOTOR B	730	0.0274	2	0.667	6.4	0.780	1.4746
MOTOR C	1900	0.0105	3	1.000	6.9	0.841	1.8520
MOTOR D	2100	0.0095	2	0.667	5.4	0.659	1.3347
MOTOR E	17110	0.0012	3	1.000	6.6	0.805	1.8060
MOTOR F	1500	0.0133	3	1.000	7	0.854	1.8670
FILTER A	1772	0.0113	3	1.000	6.4	0.780	1.7918
FILTER B	256	0.0781	3	1.000	7	0.854	1.9318
CUSTOM A	22	0.9091	2	0.667	7.7	0.939	2.5148
CUSTOM B	440	0.0455	3	1.000	5.8	0.707	1.7528
CUSTOM C	18020	0.0011	3	1.000	7.4	0.902	1.9035
CUSTOM D	90	0.2222	2	0.667	7.2	0.878	1.7669
CUSTOM E	972	0.0206	2	0.667	6	0.732	1.4190
CUSTOM F	15210	0.0013	3	1.000	6.4	0.780	1.7818
BOX A	75	0.2667	3	1.000	7.6	0.927	2.1935
BOX B	20	1.0000	2	0.667	7.4	0.902	2.5691
BOX C	23	0.8696	2	0.667	7	0.854	2.3899
BOX D	720	0.0278	3	1.000	8.2	1.000	2.0278
BOX E	17310	0.0012	2	0.667	6.1	0.744	1.4117

Participant Cookerhood Supply Chain Greenness

The values corresponding to the selections that the participants made were used to determine the appropriate SC values to input into the SCG equation. The results of this, the SCG of the designed cookerhoods, are shown in Table 58; the higher the value of SCG the better.

At this point it is important to note that the odour filter was not included in any of the calculations. The option to add the odour filter was given to the participants to capture how they would react to being given the opportunity to add extra functionality to the product they were designing. Their reactions to this choice are addressed in the qualitative section of the study analysis.

TABLE 58: COOKERHOOD SCG SCORES

Cond.	Part.	Spotlight	Motor	Grease Filter	Impeller	Blower	Packaging	Suppliers
A	P001	Light H	Motor F	Filter A	Custom A	Custom D	Box B	2.0021
		1.5033	1.8670	1.7918	2.5148	1.7669	2.5691	
	P002	Light G	Motor F	Filter A	Custom A	Custom D	Box B	2.0485
		1.7816	1.8670	1.7918	2.5148	1.7669	2.5691	
	P003	Light G	Motor D	Filter A	Custom A	Custom D	Box B	1.9598
		1.7816	1.3347	1.7918	2.5148	1.7669	2.5691	
	P004	Light G	Motor F	Filter A	Custom A	Custom A	Box B	2.1732
		1.7816	1.8670	1.7918	2.5148	2.5148	2.5691	
B	P005	Light B	Motor E	Filter A	Custom F	Custom F	Box E	1.6316
		1.2166	1.8060	1.7918	1.7818	1.7818	1.4117	
	P006	Light G	Motor A	Filter A	Custom E	Custom E	Box A	1.6633
		1.7816	1.3752	1.7918	1.4190	1.4190	2.1935	
	P007	Light B	Motor A	Filter A	Custom F	Custom F	Box B	1.7527
		1.2166	1.3752	1.7918	1.7818	1.7818	2.5691	
	P008	Light B	Motor A	Filter A	Custom F	Custom F	Box E	1.5598
		1.2166	1.3752	1.7918	1.7818	1.7818	1.4117	
C	P009	Light G	Motor C	Filter A	Custom A	Custom D	Box B	2.0460
		1.716	1.8520	1.7918	2.5148	1.7669	2.5691	
	P010	Light H	Motor E	Filter A	Custom A	Custom D	Box B	1.9920
		1.5033	1.8060	1.7918	2.5148	1.7669	2.5691	
	P011	Light H	Motor C	Filter A	Custom C	Custom C	Box B	1.9205
		1.5033	1.8520	1.7918	1.9035	1.9035	2.5691	
	P012	Light G	Motor E	Filter A	Custom D	Custom D	Box B	1.9137
		1.7816	1.8060	1.7918	1.7669	1.7669	2.5691	
D	P013	Light G	Motor E	Filter A	Custom A	Custom A	Box B	2.1630
		1.7816	1.8060	1.7918	2.5148	2.5148	2.5691	
	P014	Light A	Motor A	Filter A	Custom F	Custom F	Box B	1.8245
			1.3752	1.7918	1.7818	1.7818	2.5691	
	P015	Light G	Motor F	Filter A	Custom C	Custom F	Box B	1.9491
		1.7816	1.8670	1.7918	1.9035	1.7818	2.5691	
	P016	Light E	Motor E	Filter A	Custom A	Custom A	Box B	2.0973
		1.3874	1.8060	1.7918	2.5148	2.5148	2.5691	

Cost Calculations

The product cost values were calculated using the simple equation below:

$$total\ cost = sum\ (part\ cost\ x\ quantity)$$

The results of the total cost calculations, based on the options selected by the participants, are shown in Table 59.

TABLE 59: TOTAL COST CALCULATION RESULTS

Cond.	Part.		Spotlight	Motor	Grease Filter	Impeller	Blower	Packaging	Total Cost
A	P001	Selection	Option 19	Option 12	Option 3	Option 8	Option 1	Option 4	£46.96
		Cost/item	£9.21	£15.84	£3.20	£1.30	£1.20	£0.60	
		Quantity	2	1	3	1	1	1	
	P002	Selection	Option 18	Option 12	Option 5	Option 1	Option 4	Option 2	£47.14
		Cost	£7.50	£15.84	£4.40	£1.30	£1.20	£0.60	
		Quantity	2	1	3	1	1	1	
	P003	Selection	Option 18	Option 8	Option 5	Option 1	Option 4	Option 2	£41.50
		Cost	£7.50	£10.20	£4.40	£1.30	£1.20	£0.60	
		Quantity	2	1	3	1	1	1	
	P004	Selection	Option 18	Option 10	Option 5	Option 1	Option 1	Option 2	£47.63
		Cost	£7.50	£15.84	£4.40	£1.30	£1.69	£0.60	
		Quantity	2	1	3	1	1	1	
B	P005	Selection	Option 9	Option 11	Option 1	Option 6	Option 6	Option 5	£27.96
		Cost/item	£1.34	£14.40	£3.20	£0.40	£0.58	£0.30	
		Quantity	2	1	3	1	1	1	
	P006	Selection	Option 18	Option 9	Option 7	Option 5	Option 5	Option 1	£40.95
		Cost	£7.50	£11.25	£4.40	£0.45	£0.40	£0.65	
		Quantity	2	1	3	1	1	1	
	P007	Selection	Option 9	Option 9	Option 3	Option 6	Option 6	Option 5	£25.11
		Cost	£1.34	£11.25	£3.20	£0.40	£0.58	£0.60	
		Quantity	2	1	3	1	1	1	
	P008	Selection	Option 9	Option 9	Option 1	Option 1	Option 1	Option 5	£33.94
		Cost	£1.34	£11.25	£3.20	£0.40	£0.58	£0.30	
		Quantity	2	1	3	1	1	1	
C	P009	Selection	Option 18	Option 10	Option 3	Option 1	Option 4	Option 2	£39.83
		Cost	£7.50	£12.13	£3.20	£1.30	£1.20	£0.60	
		Quantity	2	1	3	1	1	1	
	P010	Selection	Option 19	Option 7	Option 3	Option 1	Option 4	Option 2	£40.64
		Cost	£9.21	£10.12	£3.20	£1.30	£1.20	£0.60	
		Quantity	2	1	3	1	1	1	
	P011	Selection	Option 18	Option 10	Option 3	Option 1	Option 4	Option 2	£43.25
		Cost	£9.21	£12.13	£3.20	£1.15	£1.35	£0.60	
		Quantity	2	1	3	1	1	1	
	P012	Selection	Option 18	Option 7	Option 5	Option 4	Option 4	Option 1	£41.02
		Cost	£7.50	£10.12	£4.40	£0.90	£1.20	£0.60	
		Quantity	2	1	3	1	1	1	
D	P013	Selection	Option 18	Option 7	Option 1	Option 1	Option 1	Option 1	£38.31
		Cost	£7.50	£10.12	£3.20	£1.30	£1.69	£0.60	
		Quantity	2	1	3	1	1	1	
	P014	Selection	Option 1	Option 9	Option 1	Option 6	Option 6	Option 1	£27.19
		Cost	£2.38	£11.25	£3.20	£0.40	£0.58	£0.60	
		Quantity	2	1	3	1	1	1	
	P015	Selection	Option 18	Option 12	Option 3	Option 3	Option 6	Option 2	£42.77
		Cost	£7.50	£15.84	£3.20	£1.15	£0.58	£0.60	
		Quantity	2	1	3	1	1	1	
	P016	Selection	Option 17	Option 7	Option 3	Option 1	Option 1	Option 2	£36.07
		Cost	£6.38	£10.12	£3.20	£1.30	£1.69	£0.60	
		Quantity	2	1	3	1	1	1	

Finding the Non-Dominated Design Solutions

The component selection exercises were about making trade-offs, where the participants had to try to improve the environmental performance of the cookerhood while simultaneously trying to keep the cost down and have a green supply chain. Resultantly, it was a multi-objective optimization problem that had many solutions in the feasible region. Therefore, it could be described as a mathematical optimisation problem involving three objective functions to be optimised simultaneously. As a non-trivial multi-objective optimisation problem, there did not exist a single solution that that simultaneously optimised all the objectives; the objectives functions were conflicting. Resultantly, with equal weight being given to increasing PEP, keeping costs down and increasing SCG, a number of Pareto optimal, or non-dominated, solutions existed. A solution is non-dominated if none of the objective functions can be improved in value without degrading some of the other objective values.

Generating a set of solutions to this multi-objective optimisation problem, allows for the computation of an approximation of the entire Pareto front. However, the Pareto optimality of the solutions cannot be guaranteed, meaning that it will only be known that none of the generated solutions dominates the others. By finding these non-dominated solutions, a list of product designs will be created where none of the designs dominate the others, without more input these represent the most optimal designs. The designs produced by the participants can be compared with the designs on the Pareto front to establish which of the participants were best able to optimise the three objectives, low cost, high SGC and high PEP.

To start off the process of finding the non-dominated designs, it was necessary to generate all possible designs from the options available. This was achieved in excel by generating a list of all the different component combinations possible based on the component options in the parts catalogue; Table 60 contains an equation for determining the different combinations and examples of combinations.

TABLE 60: EQUATION FOR AND EXAMPLES OF POSSIBLE COMBINATIONS

COMBINATION EQUATION	$Combo\ y = \ spotlightx\ motorxfilterx\ customx\ customx\ packagingx$
EXAMPLE COMBINATIONS	$Combo\ 1 = spotlight1\ motor1\ filter1\ custom1\ custom1\ packaging\ 1$ $Combo\ 2 = spotlight1\ motor1\ filter1\ custom1\ custom1\ packaging\ 2$ $\vdots$ $Combo\ 691199\ = spotlight19\ motor12\ filter16\ custom6\ custom6\ packaging\ 5$ $Combo\ 691200 = spotlight20\ motor12\ filter16\ custom6\ custom6\ packaging\ 5$
	KEY y = combination no. x = component option no.

691 200 combinations were generated and to reduce this data component options that were dominated were eliminated leaving behind those that potentially could be combined with other non-dominated ones to produce non-dominated designs. This means that all the components that could be outdone in terms of cost, supplier greenness or environmental performance were eliminated. Table 61 shows how non-dominated packaging options were determined. Table 62 lists all the non-dominated components; this list was then used to create a new set of cookerhood designs.

TABLE 61: DETERMINING NON-DOMINATED OPTIONS FOR PACKAGING

PACKAGING	SUPPLIER GREENNESS	COST	DOMINATED BY	EXPLANATION
OPTION 1	2.1935	£0.65	OPTION 2	Option 2 is cheaper and has better supplier greenness
OPTION 2	2.5691	£0.60	NONE	Highest supplier greenness score
OPTION 3	2.3899	£0.66	OPTION 2	Option 2 is cheaper
OPTION 4	2.0278	£0.96	OPTION 2	Option 2 has better supplier greenness
OPTION 5	1.4117	£0.30	NONE	Lowest cost

TABLE 62: NON-DOMINATED PART OPTIONS

LIGHTS	MOTOR	GREASE FILTER	IMPELLER	BLOWER	PACKAGING
Spotlight 1	Motor 1	Filter 1	Custom 1	Custom 1	Packaging 2
Spotlight 4	Motor 2	Filter 5	Custom 3	Custom 3	Packaging 5
Spotlight 5	Motor 3		Custom 6	Custom 6	
Spotlight 7	Motor 4				
Spotlight 8	Motor 5				
Spotlight 9	Motor 7				
Spotlight 10	Motor 9				
Spotlight 11	Motor 10				
Spotlight 12	Motor 11				
Spotlight 17	Motor 12				
Spotlight 18					

Using the condensed list of options resulted in the creation of 3960 unique cookerhood designs. Much like the designs made by the participants, the values for PEP, Cost and SCG for the generated designs were then calculated. Table 63 shows a sample of the generated designs and their values for PEP, SCG and cost.

TABLE 63: SAMPLE OF GENERATED DESIGNS AND THEIR CALCULATED ATTRIBUTES

COMBINATION	SELECTION	PEP	SCG	COST
DESIGN 1	Spotlight 1Motor 1Filter 1Custom 1Custom 1Packaging 2	0.359	2.069	£22.64
DESIGN 2	Spotlight 1Motor 1Filter 1Custom 1Custom 1Packaging 5	0.359	1.876	£22.34
DESIGN 3	Spotlight 1Motor 1Filter 1Custom 1Custom 3Packaging 2	0.359	1.967	£22.30
DESIGN 4	Spotlight 1Motor 1Filter 1Custom 1Custom 3Packaging 5	0.359	1.774	£22.00
DESIGN 5	Spotlight 1Motor 1Filter 1Custom 1Custom 6Packaging 2	0.359	1.947	£21.53
DESIGN 6	Spotlight 1Motor 1Filter 1Custom 1Custom 6Packaging 5	0.359	1.754	£21.23
DESIGN 7	Spotlight 1Motor 1Filter 1Custom 3Custom 1Packaging 2	0.359	1.967	£22.49
DESIGN 8	Spotlight 1Motor 1Filter 1Custom 3Custom 1Packaging 5	0.359	1.774	£22.19
DESIGN 9	Spotlight 1Motor 1Filter 1Custom 3Custom 3Packaging 2	0.359	1.865	£22.15

By formulating it as a multi objective non-linear programming problem, code was written to solve the optimisation task. The written code can be found in Appendix 6.10: Code for 3-D Multi-Objective . Using the cost, PEP and SCG data associated with the potentially non-dominated designs as variables, this code was run in Matlab. The outcome resulted in a list of 179 designs that were non-dominated. The red points in Figure 47 show the non-dominated, or Pareto optimal designs, in the form of a Pareto front and the blue points inside the front represent the dominated designs. The Pareto front can be seen more clearly in Figure 48.

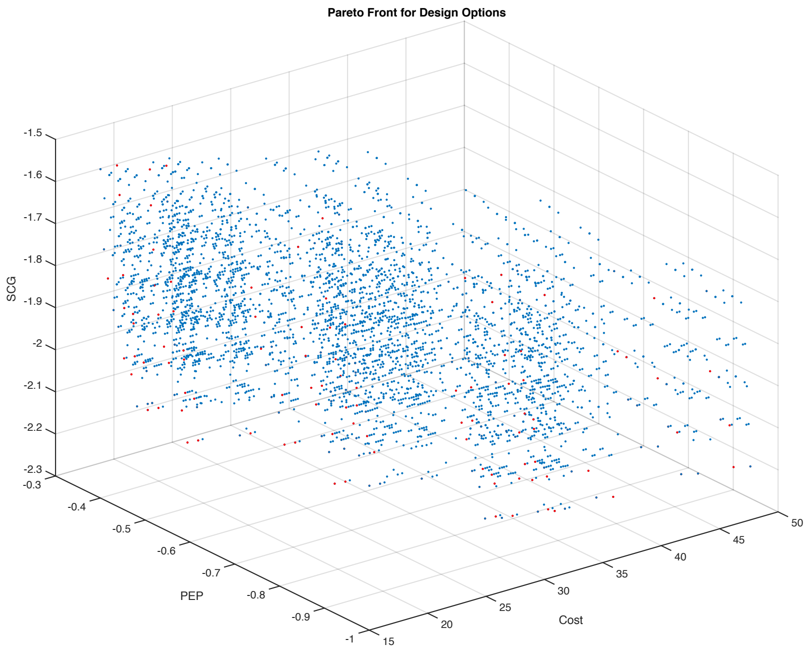


FIGURE 47: PARETO FRONT WITH NON-PARETO POINTS

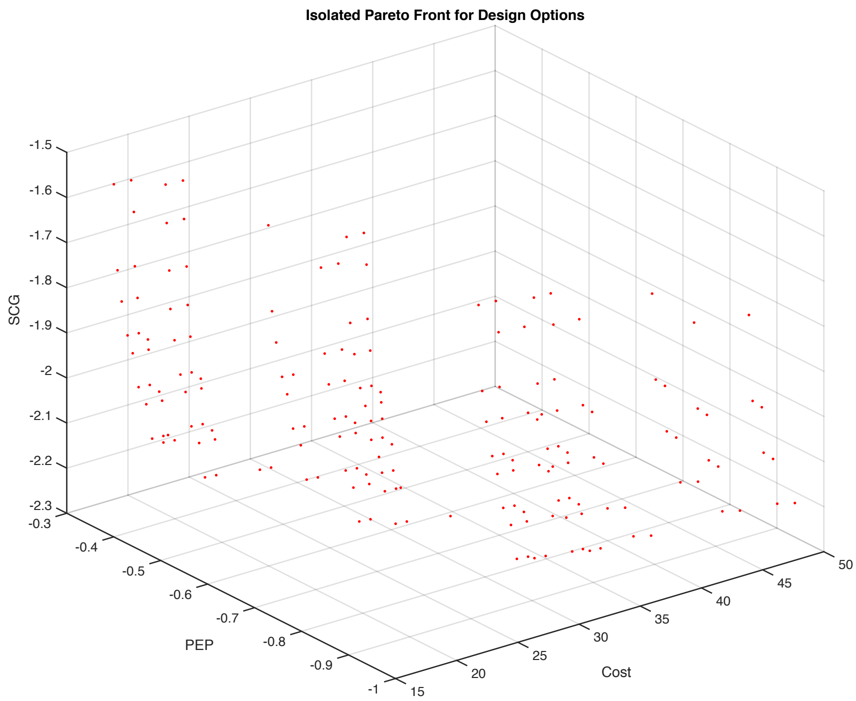


FIGURE 48: ISOLATED PARETO FRONT

Outputs

This section highlights the data that was carried over from the preparation stage into the analysis stage.

Attributes of the Participants' Cookerhoods

The first data set, shown in Table 64, contains the values of PEP, SCG and Cost that were calculated for the StylishEco cookerhoods designed by the participants. In addition, it also includes the same values for the original Stylish cookerhood and one of the Pareto solutions (the one with the highest possible PEP and SCG); these are respectively referred to as base and optimal. These two designs represent where the design started and the best it could have become based on the available options; they are used to put into context the designs that the participants came up with.

TABLE 64: PREPARED DATASET 1

CONDITION	PARTICIPANT	PRODUCT ENVIRONMENTAL PERFORMANCE	SUPPLY CHAIN GREENNESS	COST
	BASE	0.339	1.8098	£18.80
	OPTIMAL	1.000	2.1732	£47.63
A (PERFORMANCE INFORMATION)	P001	0.955	2.0021	£46.96
	P002	1.000	2.0485	£47.14
	P003	0.776	1.9598	£41.50
	P004	0.801	2.1732	£47.63
B (PERFORMANCE AND COST INFORMATION)	P005	0.876	1.6316	£27.96
	P006	0.778	1.6633	£40.95
	P007	0.665	1.7527	£25.11
	P008	0.665	1.5598	£33.94
C (PERFORMANCE, COST AND SUPPLIER INFORMATION)	P009	0.766	2.0460	£39.83
	P010	0.731	1.9920	£40.64
	P011	0.766	1.9205	£43.25
	P012	0.776	1.9137	£41.02
D (OPTIONAL INFORMATION)	P013	0.753	2.1630	£38.31
	P014	0.683	1.8245	£27.19
	P015	0.965	1.9491	£42.77
	P016	0.710	2.0973	£36.07

Pareto Optimal Designs

The second dataset is made up of a list of the 179 design combinations that were deemed to be non-dominated and on the Pareto front; Table 65 is a sample of that dataset. The designs created by the participants were to be compared to the designs in this dataset to see if any of the participants created designs that are non-dominated. The results of this comparison are presented at the end of Section 6.7.4.

TABLE 65: SAMPLE OF PREPARED DATASET 2

COMBINATION	SELECTION	PEP	SCG	COST
DESIGN 289	Spotlight 1Motor 11Filter 1Custom 1Custom 1Packaging 2	0.882	2.141	£32.37
DESIGN 291	Spotlight 1Motor 11Filter 1Custom 1Custom 3Packaging 2	0.882	2.039	£32.03
DESIGN 293	Spotlight 1Motor 11Filter 1Custom 1Custom 6Packaging 2	0.882	2.019	£31.26
DESIGN 299	Spotlight 1Motor 11Filter 1Custom 3Custom 6Packaging 2	0.882	1.917	£31.11
DESIGN 305	Spotlight 1Motor 11Filter 1Custom 6Custom 6Packaging 2	0.882	1.896	£30.36
DESIGN 306	Spotlight 1Motor 11Filter 1Custom 6Custom 6Packaging 5	0.882	1.703	£30.06
DESIGN 307	Spotlight 1Motor 11Filter 5Custom 1Custom 1Packaging 2	0.905	2.141	£35.97
DESIGN 309	Spotlight 1Motor 11Filter 5Custom 1Custom 3Packaging 2	0.905	2.039	£35.63
DESIGN 311	Spotlight 1Motor 11Filter 5Custom 1Custom 6Packaging 2	0.905	2.019	£34.86
DESIGN 317	Spotlight 1Motor 11Filter 5Custom 3Custom 6Packaging 2	0.905	1.917	£34.71

6.7.3 *Qualitative Analysis*

The main objective of this phase of the research project was to analyse the transcripts in order to explore:

1. How participants decide on which components to select
2. How participants work with supplier-specific information when incorporating environmental considerations in to their design process

Content Analysis

The qualitative analysis of the outputs of the component selection exercises took on the form of content analysis, a means of categorising verbal or behavioural data for the purposes of classification, summarisation and tabulation. A bespoke method of identifying and coding data was developed to account for the fact that no system for pre-coding exists. Through coding, the content was analysed on the following two levels:

- Basic/manifest level – a descriptive account of the data i.e. this is what was said, but no comments or theories as to why or how.
- Higher or latent level – interpretive analysis that is concerned with the response as well as what may have been inferred or implied.

Coding

The categorising and indexing of the transcripts took on the form of holistic coding and pattern coding. Making up the first coding cycle, holistic coding refers a method that applies a single code to a large piece unit of data in the corpus, rather than line by line coding, to capture a sense of the overall contents. In this case the code was 'decision process' and it used to highlight when the participant was talking through how they decided on which component to choose. Pattern codes, defined as explanatory or inferential codes that identify an emergent theme, configuration or explanation, were identified during the second coding cycle. This is where the factors that influenced the decisions that were made were isolated.

Outputs

The coding based content analysis produced the outputs listed in Table 66.

TABLE 66: CODING AND OUTPUTS

Cycle	Level	Coding	Outputs	Description
First	Higher or Latent	Holistic	Sourcing Strategies	The sourcing strategies adopted by the participants, individually and as groups
Second	Basic or Manifest	Pattern	Decision Matrix	Determining the product related factors that influenced decision making

Participant Sourcing Strategies

The process that each participant took was condensed into a short paragraph that represents the strategy embedded within it. The sourcing strategies of the participants are also summarised by the condition they were in; these highlight where there were patterns amongst the strategies adopted by the participants. These sourcing strategies are presented in Table 67 and they make up one of the outputs of the analysis.

TABLE 67: PARTICIPANT SOURCING STRATEGIES

		SOURCING STRATEGY
PERFORMANCE INFORMATION	P001	When they surmised that they had all the information they needed to make an informed choice they selected what they thought was the most efficient component option, however when they surmised that they were not well-informed they left the components same as in the original.
	P002	When they surmised that they had all the information they needed to make an informed choice they selected what they thought was the most efficient component option, however but when they surmised that they were not well-informed they left the components same as in the original.
	P003	When they surmised that had all the information they needed to make an informed choice they selected what they thought was the most efficient component option or what they deemed to be a 'good enough' efficiency improvement, however when they surmised that they were not well informed they left the components the same as in the original.
	P004	When they surmised that had all the information they need to make an informed choice they selected what they thought was the most efficient component option or what they deemed to be a good enough efficiency improvement, however when they surmised that they were not well informed they left the components the same as in the original.
	CONDITION A SUMMARY	When they surmised that had all the information they need to make an informed choice they selected what they thought was the most efficient component option or what they deemed to be a good enough efficiency improvement but when they surmised that they were not well informed they left the components the same as in the original.
PERFORMANCE AND COST INFORMATION	P005	For components with high impacts, decided what performance improvements they thought were sufficient enough and then selected the cheapest appropriate component. For low impact components, disregarded any environmental benefits and selected for the cheapest component.
	P006	When there was a clear environmental advantage to be gained, they made sure they made an improvement. The choice was a balance between technical performance and cost but always with an improvement in environmental performance. For other components, either stayed the same or made a cost saving.
	P007	For components with high impacts, selected the supplier that they wanted based on using the same supplier as in the original product. They then selected what they thought was the best component that supplier offered when cost and technical performance were balanced. For components with negligible impacts, selected cheapest options.
	P008	Decided on what was a good performance improvement on environmental profile then selected the cheapest components. In the case of the impeller and blower went against this, claiming the cost savings were not worth switching suppliers.
	CONDITION B SUMMARY	Mostly decided on the technical performance improvements that they wanted and then went for the cheapest component option. For the low impact components, they all disregarded any environmental benefits. Instead they decided based on cost savings or on sticking with the same supplier.

TABLE 68 CNTD.: PARTICIPANT SOURCING STRATEGIES

PERFORMANCE, COST AND SUPPLIER INFORMATION	P009	Prioritised technical performance and supplier profile and then tried to get it for the best price possible. Participant spent time to calculating cost per x.
	P010	Either decided on the performance that they wanted and chose the best supplier or they chose the suppliers that they wanted and selected the best performing component option from them.
	P011	Decided on the performance that they wanted and then selected the component option with the better supplier.
	P012	Decided on the performance that they wanted and then selected the component option with the better supplier. Did not consider cost at all.
	CONDITION C SUMMARY	They all seemed to have an idea of what they want technical performance wise and selected components that came from the supplier with the best profile. Sometimes they wouldn't let cost be a barrier and other times they would consider cost but not at a large sacrifice of performance and supplier.
OPTIONAL INFORMATION	P013	Decided on the technical performance improvement that they wanted and tried to balance out the cost and supplier profile.
	P014	Tried to go for the cheapest option wherever possible. For the components with high impacts they improved the performance but for the low impact ones, they did not.
	P015	Tried to save money on the components with low impacts. For the high impact components they tried to balance out cost, supplier and the best possible technical performance.
	P016	Tried to go for the cheapest component option that met the performance standards that they determined.
	CONDITION D SUMMARY	Some of the participants would try to balance out all the factors and find the best solution that way, in some cases aiming for the best technical performance. Others decided on performance that was good enough and they tried to get it as cheap as possible – these were the ones that had neglected the suppliers. This mainly happened for the high impact components, for the low impact ones they either kept the components the same as in the original or tried to save money. There was no discernible pattern to this group as their approaches varied.

Decision Making Matrices.

Through the use of matrices, the factors that formed the basis of the decisions that the participants made were quantified. For each participant Table 69 shows factors that made up the basis of the decision of which component to select; all the factors could be classified into groups as defined in Table 68. The decision factors that influenced the participants' selections throughout the whole redesign process were then grouped and quantified in Table 70. This table highlights how some of the participants in Condition B, although they did not have supplier information except supplier named, did take into account not wanting to switch suppliers due to perceived supplier switching costs. Explaining why 'S' does appear in table 74 under condition B. Finally, Table 71 groups the decision factors by condition. The matrix shows that those in Condition A considered the least number of factors when selecting parts

Although the differences between conditions were not large, the number of factors considered increased as the conditions moved from B to D. Participants in Condition B based most of their decisions on performance and cost factors and those in Condition C seemed to have neglected cost in favour of considering performance and supplier information. The group that appeared to be the most balanced is Condition D where there was an almost identical consideration of cost and suppliers and only a slightly higher consideration of performance, even though the individual approaches of the participants varied a lot.

TABLE 68: DEFINITION OF DECISION FACTORS

Decision Factor	Description	Explanation
P	Component Performance e.g. Rated Life, Filter thickness	Participant made decision after considering the technical performance of the component.
C	Component Cost	Participant made decision after considering the cost of the component.
S	Supplier Attributes e.g. Distance, Eco-Score	Participant made decision after considering the attributes of the component supplier.
U	Lack of Understanding	Participant made a decision based on a mistaken assumption or misunderstanding on their part e.g. surmising that all the grease filter options had the same environmental performance.
I	Lack of Requested Information	Participant requested information that was not available to them and made a decision without that information e.g. manufacturing process information

TABLE 69: DECISION FACTORS FOR STYLISHECO COMPONENT SELECTION

		Decision Basis					
Condition	Part.	Spotlight	Motor	Grease Filter	Impeller	Blower	Packaging
A (Performance Information)	P001	P	P	P	I	I	I
	P002	P	P	P	U	U	I
	P003	P	P	P	U	U	I
	P004	P	P	P	P	P	I
B (Performance and Cost Information)	P005	P C	P C	P C	C	C	C
	P006	P	P C	P	C	C	I
	P007	P C S	P S	P	P C	P C	C
	P008	P C	P C	P C	P S	P S	C
C (Performance, Cost and Supplier Information)	P009	P C S	P C S	U	U I	U I	C S
	P010	P S	P C S	U	P S	P C S	C
	P011	P S	P S	U	S	S	C S
	P012	P S	P S	P	S	S	S
D (Optional Information)	P013	P S	P S	P	P C S	P C S	C S
	P014	P C	P C S	P C	C	C	S
	P015	P C S	P S	P	P C	C	C S
	P016	P C	P C	U	P S	P S	C S

TABLE 70: CATEGORISING AND QUANTIFYING INDIVIDUAL DECISION FACTORS

Condition	Part.	Component Performance	Component Cost	Supplier Attributes	Lack of Understanding	Lack of Requested Information	Total
A (Performance Information)	P001	3	-	-	-	3	6
	P002	3	-	-	2	1	6
	P003	3	-	-	2	1	6
	P004	5	-	-	-	1	6
B (Performance and Cost Information)	P005	3	6	-	-	-	9
	P006	3	3	-	-	1	7
	P007	5	4	2	-	-	11
	P008	5	4	2	-	-	11
C (Performance, Cost and Supplier Information)	P009	2	1	3	3	2	11
	P010	4	3	4	1	-	12
	P011	2	1	5	1	-	9
	P012	3		5	-	-	8
D (Optional Information)	P013	5	3	5	-	-	13
	P014	3	5	2	-	-	10
	P015	4	3	3	-	-	10
	P016	5	3	3	1	-	12

TABLE 71: QUANTIFYING CONDITION DECISION FACTORS

Condition	Component Performance	Component Cost	Supplier Attributes	Lack of Understanding	Lack of Requested Information	Total
A	14	-	-	6	4	24
B	16	4	17	1	-	38
C	11	17	5	2	5	40
D	17	13	14	-	1	45
Total	58	34	36	9	10	147

Views on Information.

Some of the participants' informative opinions on the component selection exercises were in the comments that were based around information. These comments were grouped by condition and are listed in Table 72.

TABLE 72: VIEWS ON INFORMATION

CONDITION	COMMENTS
A (PERFORMANCE INFORMATION)	All said that they would have liked more information and that having cost information particularly would have made it easier to make decisions. There were remarks made about having more information on the impacts of manufacturing with various materials.
B (PERFORMANCE AND COST INFORMATION)	They all remarked that they would have liked more information on the suppliers that they were using. They said that this was the thing that was missing which would allow them to make better environmental decisions.
C (PERFORMANCE, COST AND SUPPLIER INFORMATION)	They all noted that there was a lot of information to get their head around but realised that it was important to have that information as it allowed them to make informed decisions. In some cases they asked for detailed manufacturing and materials information.
D (OPTIONAL INFORMATION)	The group was varied in terms of the information that they requested. Two of the group's members asked only for cost and performance information while the other two requested all the extra information. When those that had requested the least amount of information were told what else they could have had they were frustrated and concluded that having that information would have made it so much better in terms of the environmental decisions they made.

6.7.4 QUANTITATIVE ANALYSIS

The main aim of the quantitative analysis was to critically assess the outputs of the component selection exercise and was carried out on the dataset that comprised of the PEP, SCG and Cost values for the designs created by the participants.

Descriptive Statistics

To help describe the data and to show and summarise it in a meaningful way, descriptive statistical analysis was carried out.

Extreme Values

Assessing the outputs of each of the participants separately and ranking them, Table 73 shows the designs with the highest and lowest values of product environmental performance (PEP), supply chain greenness (SCG) and Cost. Three out of 5 of the designs with the best PEP scores were by those in Condition A, these are the participants who only had access to performance information. The same designs were also three of the most expensive of all the designs; two of them also featured in the list of highest SCG.

At first glance, those with the lowest PEP seem to be spread across Conditions B, C and D, however since P014 and P016 did not ask for any supplier information and undertook the exercise as though they were in Condition B then 4 out of the 5 designs with the lowest PEP values were created by those who only had cost and performance information.

Two of each from Conditions A and D made an appearance on the highest SCG list. If there is a connection between SCG and PEP, then this could be explained by the fact that the participants in Condition A focused mainly on improving the environmental performance of their cookerhoods. Those in Condition D that appear on the list are the ones that asked for supplier information and took great care in designing products with parts from suppliers with good environmental profiles.

Mostly participants from Condition B populate the lowest SCG list, four out of five. These are the participants who mostly decided on the performance they required and went for the cheapest option. If there are connections between PEP & SCG and Cost & PEP, then it could be said that they appear on the list because they limited the PEP of their products due to cost and that in turn limited the SCG. Coincidentally, three of the four designs also appear in the lowest Cost list and two out of four in the lowest PEP list; one design however does appear in the highest PEP list.

Condition A participants make up three out of five of those in the highest Cost list, as alluded to earlier. On the opposite end, the lowest Cost list is made up of three participants from Conditions B and two from Condition D, essentially participants with only performance and cost information. Four out of five of these are the ones that also appear on the list of lowest PEP, suggesting that it is likely that there is a connection between Cost and PEP. None of the participants managed to appear on the highest PEP, highest SCG and lowest Cost lists or on the opposite, the lowest PEP, lowest SCG and highest Cost lists. This shows that all the participants were able to handle the trade-offs to improve at least one of three aspects.

TABLE 73: EXTREME PEP, SCG AND COST VALUES

		Ranking	Case Number	Condition	Value
PEP	Highest	1	2	Condition A	1.000
		2	15	Condition D	0.965
		3	1	Condition A	0.955
		4	5	Condition B	0.876
		5	4	Condition A	0.801
	Lowest	1	8	Condition B	0.665
		2	7	Condition B	0.665
		3	14	Condition D (like condition B)	0.683
		4	16	Condition D (like condition B)	0.710
		5	10	Condition C	0.731
SCG	Highest	1	4	Condition A	2.173
		2	13	Condition D	2.163
		3	16	Condition D (like condition B)	2.097
		4	2	Condition A	2.049
		5	9	Condition C	2.046
	Lowest	1	8	Condition B	1.560
		2	5	Condition B	1.632
		3	6	Condition B	1.663
		4	7	Condition B	1.753
		5	14	Condition D (like condition B)	1.825
Cost	Highest	1	4	Condition A	£47.63
		2	2	Condition A	£47.14
		3	1	Condition A	£46.96
		4	11	Condition C	£43.25
		5	15	Condition D	£42.77
	Lowest	1	7	Condition B	£25.11
		2	14	Condition D (like condition B)	£27.19
		3	5	Condition B	£27.96
		4	8	Condition B	£33.94
		5	16	Condition D (like condition B)	£36.07

Relationships

Figure 49 is a scatter plot that shows PEP vs. Cost, the plot suggests a correlation between the two where the participants increase the cost as they increase the PEP scores of their solutions. When categorised by Condition, those in A generally have higher costs and PEP; these are the participants that only had performance information to go by. Condition B participants mainly occupy the bottom end of the plot with relatively low PEP and low cost. Condition C, those with all the information seem to mainly be in the middle of the pack; while Condition D, which is essentially a split between Conditions C and B spreads itself amongst the results from those two groups.

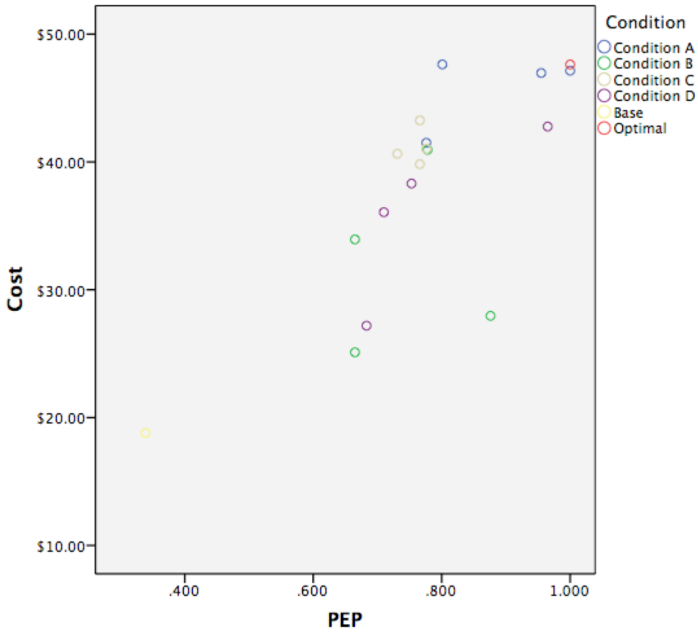


FIGURE 49: COST VS. PEP CLASSIFIED BY CONDITION

When Cost is plotted against SCG as shown in Figure 50, the plot suggests a weak relationship with the cost of the participants' solutions going up as the associated SCG goes up. The plot shows that there is a considerable gap between the SCG of the designs in Condition B compared to the other conditions, with those in Condition B having worse off SCG scores. With the exception of one Condition D result (Participant 14), where the participant only requested Cost data and was therefore effectively in Condition B, all the other results occupy the top right corner with high Cost and high SCG. Once again, the results from Condition C seem to be in the middle and all grouped together; they are less spread out compared to the other conditions. Condition D designs generally occupy the top left corner, sitting higher than Condition C in Cost and lower in SCG.

The last of the scatter plots, Figure 51, shows SCG vs. PEP. Much like the previous plot, this one suggests a weak relationship between SCG and PEP. Looking at the graph, it is difficult to make any concrete observations except perhaps that Condition C results once again seem to be concentrated in one area.

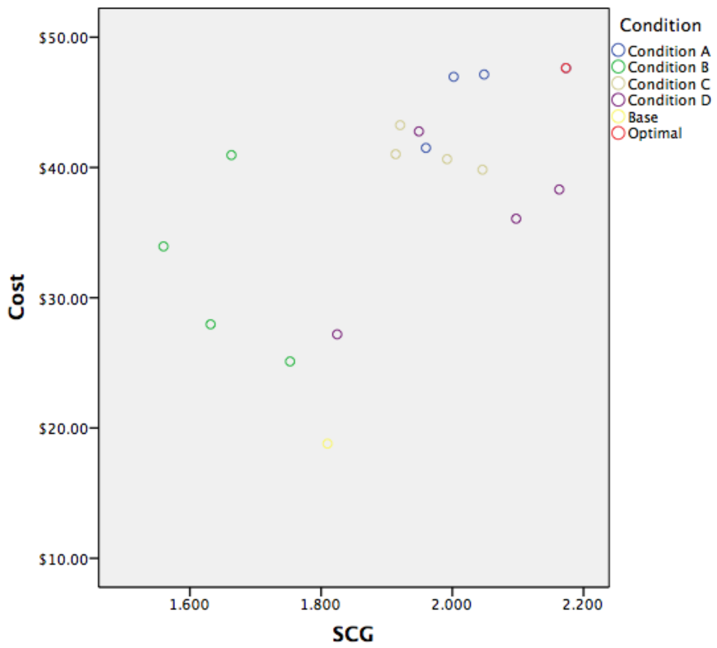


FIGURE 50: COST VS. SCG CLASSIFIED BY CONDITION

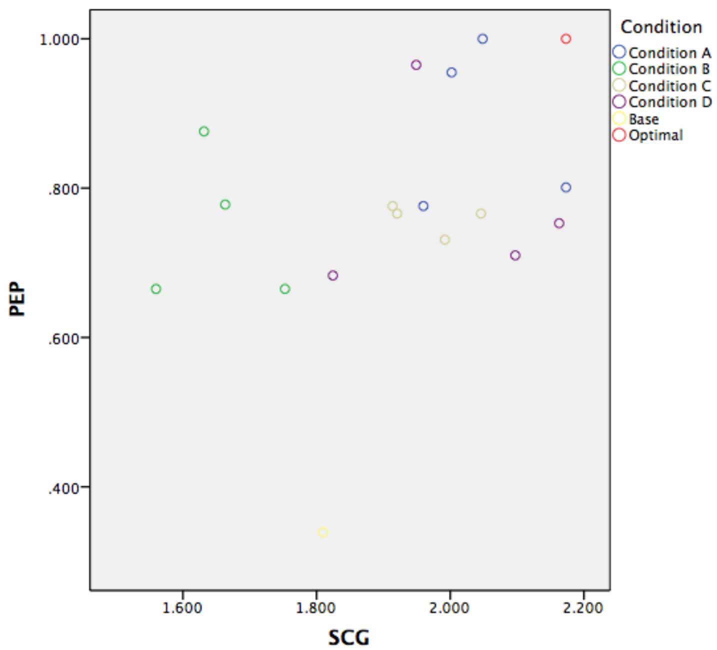


FIGURE 51: PEP VS. COST CATEGORISED BY CONDITION

Measures of Central Tendency

Analysed together, the designs made by the group had a mean PEP of 0.79, a mean SCG of 1.92 and a mean Cost of £38.77. Table 74 groups the participant results by condition and mean values for PEP, SCG and Cost for the conditions; it also shows the same values for the Base and Optimal designs. The table also shows values for Cost per % PEP and relative SCG. The Cost per % PEP was calculated by dividing the PEP by the cost, it shows you how much you are paying for the performance that you get; while the relative SCG shows how the supply chains compare to the best possible supply chain, which would have a value of 3. These results are ranked from best to worst in Table 75.

TABLE 74: NUMERICAL GROUP RESULTS BY CONDITION

	Base	Optimal	Condition A	Condition B	Condition C	Condition D	All Cond
PEP	0.339	1.000	0.883	0.746	0.760	0.778	0.791
SCG	1.810	2.173	2.046	1.652	1.968	2.008	1.912
Cost	£18.80	£47.63	£45.81	£31.99	£41.19	£36.09	£38.77
Cost per % PEP	£0.55	£0.48	£0.52	£0.43	£0.54	£0.46	£0.49
Relative SCG	60%	72%	68%	55%	66%	67%	64%

TABLE 75: DESCRIPTIVE GROUP RESULTS BY CONDITION

Ranking (Best to Worst)	1st	2nd	3rd	4th	5th	6th
PEP	Optimal	Condition A	Condition D	Condition C	Condition B	Base
SCG	Optimal	Condition A	Condition D	Condition C	Base	Condition B
Cost	Base	Condition B	Condition D	Condition C	Condition A	Optimal
Cost per % PEP	Condition B	Condition D	Optimal	Condition A	Condition C	Base
Relative SCG	Optimal	Condition A	Condition D	Condition C	Base	Condition B

As expected, the Optimal and Base designs topped and tailed the PEP rankings and unsurprisingly, Condition A produced the highest PEP amongst the participants. Condition D, which turned out to be a mix between Conditions B and C ranked higher than both those conditions; Condition C scored higher than Condition B. The Optimal design came out on top again for the SCG with a score of 72%, followed by Condition A at 68%. Once again, Condition D was the second best performing condition at 67%. Condition C came in third and Condition B was last with values of 66% and 55% respectively. The differences between Conditions A, C and D are only 1% each but Condition B is separated from the rest by at least 10%. The presence of relationships between Cost and SCG and PEP and SCG, if they exist, they could explain this result.

Looking at how much each of the participants were willing to increase the product's cost in order to achieve a more environmentally-friendly product (high PEP), those in Condition B came out on top paying only £0.43 per % PEP, followed by Condition D at £0.46 and the Optimal design at £0.48. This shows that it is those with cost and performance information that were able to get the most PEP for their money. Condition D being in second place can be explained by the fact that half of its participants were under conditions similar to Condition B. Although it was the cheapest product overall, the Base design proved to be the most expensive in terms of cost per % PEP at £0.55. Condition A, where they only had performance information came in at £0.52 and took fourth place. Due to the performance focus of the manner in which the participants undertook the exercise it makes sense that they had a relatively high value. However, what is particularly surprising is how Condition C was the worst performing condition coming in at £0.54 per % PEP, only just better than the Base design. The participants in Condition C were the ones that had the most amount of information, factors to balance out and objectives to optimise. This is likely to be the reason why they scored so badly. Again, the presence of relationships between Cost and SCG, if they exist, they could explain this.

Measures of Spread

To get a better idea of how the designs compared to each, the standard deviations for the conditions were calculated and ranked; the results are shown in Figure 52 and Figure 53 respectively. One thing that is clear is that those in Condition C created the most consistent designs in terms of Cost, PEP and SCG. On the other hand, the participants in Condition B - despite having the same information, unlike those in Condition D - produced design solutions with the most varied Cost values at £7.02. Due to the way those in Condition D undertook the exercise, it is unsurprising that there is such disparity in Cost of solutions. While not as grouped together as those for Condition C, results for Condition A seem to be reasonably grouped.

Standard Deviation	Condition A	Condition B	Condition C	Condition D
PEP	0.11	0.10	0.02	0.12
SCG	0.09	0.08	0.06	0.15
Cost	£2.89	£7.02	£1.46	£6.55

FIGURE 52: STANDARD DEVIATION OF CATEGORISED BY CONDITION

Standard Deviation	1	2	3	4
PEP	Condition C	Condition B	Condition A	Condition D
SCG	Condition C	Condition B	Condition A	Condition D
Cost	Condition C	Condition A	Condition D	Condition B

FIGURE 53: CONDITION RANKING OF STANDARD DEVIATION

The descriptive statistics presented in this section resulted in the data being presented in a meaningful way and allowed for a simple interpretation of the data. They describe the data and do not allow for conclusions to be made regarding the hypotheses. It is worth mentioning that in the above interpretations of the data, connections were made to the qualitative analysis results and some suppositions were made that will either be confirmed or rejected by inferential statistics.

Inferential Statistics

Inferential statistical analysis techniques are used to make generalisations about the population from which the samples were drawn and include testing hypotheses and deriving estimates. The population is assumed to be larger than the observed data set; in other words, the observed data is assumed to be sampled from a larger population. In this case, the population of interest is larger than the 16 participants and the participants are assumed to be sampled from the larger pool of product designers.

Hypothesis Testing

Hypothesis testing was used to understand whether any differences or effects discovered in the study exist in the population and to establish whether the hypotheses extend beyond those individuals that were examined. The focus of the hypothesis testing was to find ways to structure the results of the controlled experiments in such a way that they could be tested effectively. This process was comprised of the steps listed below:

Step 1: Define the research hypothesis.

Step 2: Explain operationalization of what is being studied and set out variables.

Step 3: Set out the null and alternative hypotheses.

Step 4: Set the significant level α.

Step 5: Determine whether the distribution being studied is normal.

Step 6: Select appropriate statistical tests based on variables and data distribution.

Step 7: Run statistical tests and interpret outputs.

Step 8: Reject or fail to reject the null hypotheses.

Steps 1 and 2 are presented in sections 5.1.3, 5.7.2 and 5.2 and the rest are presented in sections to follow.

Hypotheses Setting

When undertaking hypothesis testing, the working hypotheses must be expressed as null and alternative hypotheses; these are statements regarding the differences or effects that occur in the population. The sample will be used to test which statement (i.e., the null hypothesis or alternative hypothesis) is most likely. Table 76 contains the working hypotheses, how they can be classified and their associated null and alternative hypotheses.

TABLE 76: VARIOUS HYPOTHESES ASSOCIATED WITH THE STUDY

WORKING HYPOTHESIS	HYPOTHESIS TYPE	NULL HYPOTHESIS	ALTERNATIVE HYPOTHESIS
H_A: THE DESIGNERS WILL BE WILLING TO SPEND MORE ON COMPONENTS FOR PRODUCTS WITH BETTER ENVIRONMENTAL PROFILES	DIRECTIONAL CAUSAL	H_{A0}: ENVIRONMENTAL PERFORMANCE WILL NOT AFFECT HOW MUCH DESIGNERS ARE WILLING TO SPEND	H_{A1}: ENVIRONMENTAL PERFORMANCE INCREASES HOW MUCH DESIGNERS ARE WILLING SPEND
H_B: THE DESIGNERS THAT SPEND MORE WILL HAVE PRODUCTS WITH GREENER SUPPLY CHAINS	DIRECTIONAL RELATIONAL	H_{B0}: SPENDING MORE WILL NOT AFFECT THE GREENNESS OF THE DESIGNED PRODUCT'S SUPPLY CHAIN	H_{B1}: SPENDING MORE WILL INCREASE THE GREENNESS OF THE DESIGNED PRODUCT'S SUPPLY CHAIN
H_C: THE DESIGNERS THAT HAVE DESIGNED PRODUCTS WITH BETTER ENVIRONMENTAL PERFORMANCE WILL HAVE GREENER SUPPLY CHAINS	DIRECTIONAL RELATIONAL	H_{C0}: ENVIRONMENTAL PERFORMANCE WILL NOT AFFECT SUPPLY CHAIN GREENNESS	H_{C1}: ENVIRONMENTAL PERFORMANCE WILL INCREASE SUPPLY CHAIN GREENNESS
H_D: EXTRA INFORMATION WILL RESULT IN IMPROVED PRODUCT ENVIRONMENTAL PERFORMANCE	RELATIONAL	H_{D0}: EXTRA INFORMATION HAS NO IMPACT ON PRODUCT ENVIRONMENTAL PERFORMANCE	H_{D1}: EXTRA INFORMATION HAS AN IMPACT PRODUCT ENVIRONMENTAL PERFORMANCE
H_E: EXTRA INFORMATION WILL RESULT IN IMPROVED SUPPLY CHAIN GREENNESS	RELATIONAL	H_{E0}: EXTRA INFORMATION HAS NO IMPACT ON SUPPLY CHAIN GREENNESS	H_{E1}: EXTRA INFORMATION HAS AN IMPACT ON SUPPLY CHAIN GREENNESS
H_F: EXTRA INFORMATION WILL RESULT IN INCREASED COST	RELATIONAL	H_{F0}: EXTRA INFORMATION HAS NO IMPACT ON COST	H_{F1}: EXTRA INFORMATION HAS AN IMPACT ON COST
H_G: DESIGNERS WITH COST INFORMATION WILL DESIGN PRODUCTS WITH LOWER ENVIRONMENTAL PERFORMANCE	DIRECTIONAL CAUSAL	H_{G0}: HAVING COST INFORMATION WILL NOT IMPACT PRODUCT ENVIRONMENTAL PERFORMANCE	H_{G1}: HAVING COST INFORMATION WILL DECREASE PRODUCT ENVIRONMENTAL PERFORMANCE
H_H: DESIGNERS WITH COST INFORMATION WILL DESIGN PRODUCTS WITH LOWER SUPPLY CHAIN GREENNESS	DIRECTIONAL CAUSAL	H_{H0}: HAVING COST INFORMATION WILL NOT IMPACT SUPPLY CHAIN GREENNESS	H_{H1}: HAVING COST INFORMATION WILL DECREASE SUPPLY CHAIN GREENNESS
H_I: DESIGNERS WITH COST INFORMATION WILL DESIGN PRODUCTS WITH LOWER COST	DIRECTIONAL CAUSAL	H_{I0}: HAVING COST INFORMATION WILL NOT IMPACT COST	H_{I1}: HAVING COST INFORMATION WILL DECREASE COST
H_J: DESIGNERS WITH SUPPLIER INFORMATION WILL DESIGN PRODUCTS WITH LOWER ENVIRONMENTAL PERFORMANCE	DIRECTIONAL CAUSAL	H_{J0}: HAVING SUPPLIER INFORMATION WILL NOT IMPACT PRODUCT ENVIRONMENTAL PERFORMANCE	H_{J1}: HAVING SUPPLIER INFORMATION WILL DECREASE PRODUCT ENVIRONMENTAL PERFORMANCE
H_K: DESIGNERS WITH SUPPLIER INFORMATION WILL DESIGN PRODUCTS WITH LOWER SUPPLY CHAIN GREENNESS	DIRECTIONAL CAUSAL	H_{K0}: HAVING SUPPLIER INFORMATION WILL NOT IMPACT SUPPLY CHAIN GREENNESS	H_{K1}: HAVING SUPPLIER INFORMATION WILL DECREASE SUPPLY CHAIN GREENNESS
H_L: DESIGNERS WITH SUPPLIER INFORMATION WILL DESIGN PRODUCTS WITH LOWER COST	DIRECTIONAL CAUSAL	H_{L0}: HAVING SUPPLIER INFORMATION WILL NOT IMPACT COST	H_{JL}: HAVING SUPPLIER WILL INFORMATION DECREASE COST

Significance Levels

Level of statistical significance, often expressed as a p-value, will determine the probability of the observed sample results given that the null hypothesis is true; it considers the probability that a difference could have arisen based on the assumption that there really is no difference.

Whilst there is relatively little justification as to why a significance level of 0.05 is used, it is widely used in academic research and will be adopted for this study. α was set before the data collection (a-priori). Adopting the typical value of α as 0.05, a 95% confidence level was established. Table 77 outlines the criteria used to accept or reject the null hypotheses.

TABLE 77: CRITERIA FOR ACCEPTING OR REJECTING THE NULL HYPOTHESIS

	IN REALITY	
DECISION	H_0 IS TRUE	H_0 IS FALSE
ACCEPT H_0	OK	TYPE II ERROR (FAILURE TO REJECT OF A FALSE NULL HYPOTHESIS I.E. A FALSE NEGATIVE) β = PROBABILITY OF TYPE II ERROR
REJECT H_0	TYPE I ERROR (THE INCORRECT REJECTION OF A TRUE NULL HYPOTHESIS I.E. A FALSE POSITIVE) α = PROBABILITY OF TYPE I ERROR	OK

Testing for Normality

An assessment of the normality of data is a prerequisite for many statistical tests because normal data is an underlying assumption in parametric testing. There are two main methods of assessing normality, graphically and numerically. Numerical methods rely on statistical tests and take advantage of making an objective judgement of normality, however they are sometimes disadvantaged by not being sensitive enough at low sample sizes, such as the one in this study. Graphic methods rely on visual inspections; graphical interpretations have the advantage of allowing good judgement to assess normality in situations when numerical tests might be over or under sensitive however, they lack objectivity. To counter the disadvantages inherent in each method, they were both used to test the data for normality.

Shapiro-Wilk's Test

Table 78 presents the results from the Shapiro-Wilk test; the Shapiro-Wilk test was used to test for normality because it is more appropriate for small sample sizes (<50 samples). SCG and Cost were deemed as normal with p values above 0.05. PEP came out as non-normal, however as the value is so close to 0.05 this outcome could be due to the sample size.

TABLE 78: SHAPIRO WILK'S TEST RESULTS

	STATISTIC	P	NORMAL
PEP	0.885	0.047	NO
SCG	0.939	0.343	YES
COST	0.905	0.096	YES

Normal Q-Q Plots

In order to determine normality graphically, the outputs of normal Q-Q Plots were used. If the data are normally distributed, the data points will be close to the diagonal line. If the data points stray from the line in an obvious non-linear fashion, the data are not normally distributed. The normal Q-Q plots represented in Figure 54, Figure 55 and Figure 56 show that data points are relatively close to the diagonal line and that the data is, at the least approximately, normally distributed. Due to these plots, the negative result for the PEP from the Shapiro-Wilk test will be discarded and all three variables will be treated as normal.

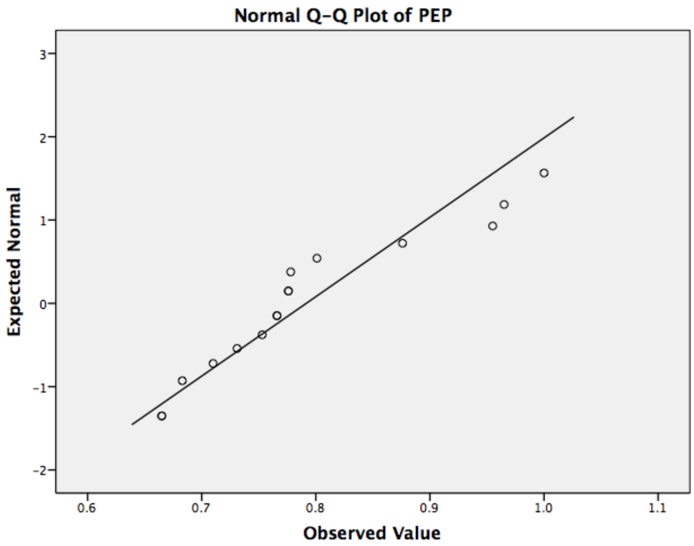


FIGURE 54: NORMAL Q-Q PLOT FOR PEP

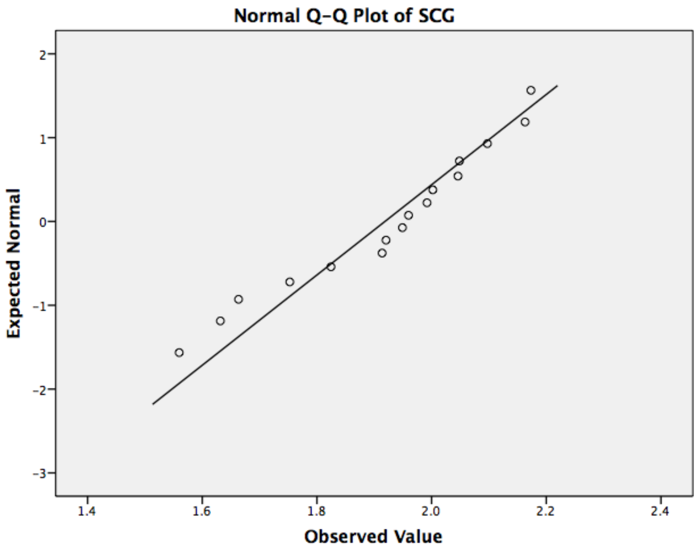


FIGURE 55: NORMAL Q-Q PLOT FOR SCG

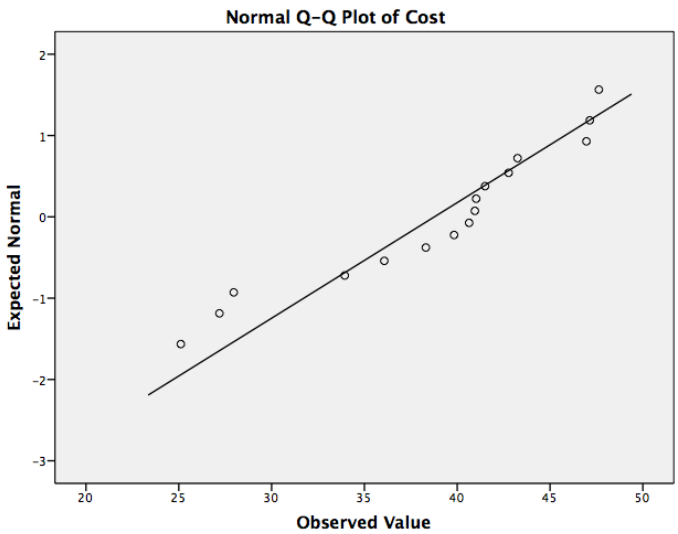


FIGURE 56: NORMAL Q-Q PLOT FOR COST

Skewness and Kurtosis

The skewness and kurtosis of the data were also calculated. The skewness is a measure of symmetry, or more precisely, the lack of symmetry and the kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. The Z values, calculated by dividing the statistic by the standard error, should be as close to 0 as possible and be between +1.96 and -1.96 to signify normality; the results for the data are in Table 79 and they show normality in the data.

After performing these various tests, it can be assumed that the data are at least approximately normally distributed.

TABLE 79: SKEWNESS AND KURTOSIS Z VALUES

		Statistic	Stand. Error	Z	Normal
PEP	Mean	0.792	0.026		
	Skewness	0.859	0.564	1.523	Yes
	Kurtosis	-0.198	1.091	-0.181	Yes
SCG	Mean	1.919	0.046		
	Skewness	-0.591	0.564	-1.048	Yes
	Kurtosis	-0.537	1.091	-0.492	Yes
Cost	Mean	£38.77	£1.76		
	Skewness	-0.757	0.564	-1.342	Yes
	Kurtosis	-0.315	1.091	-0.289	Yes

Testing for Outliers

Another prerequisite for many statistical tests, due to being an underlying assumption in parametric testing, is that there are no outliers in the data. An outlier is a data point that does not fit the general trend of the data. Outliers were checked for using the outlier-labelling rule using a g value of 2.2 (Hoaglin and Iglewicz, 1987). As none of the calculated values of PEP, SCG and Cost for the participants' solutions lie outside of the upper and lower limits, there are no outliers in the data; the results are shown in Table 80.

TABLE 80: OUTLIER LABELLING RULE RESULTS

	PEP	SCG	Cost
Lower Quartile (Q1)	0.715	1.771	£34.47
Upper Quartile (Q3)	0.857	2.048	£43.13
Inter-quartile Range = Q3-Q1	0.142	0.277	£8.66
g	2.2		
g' = (Q3-Q1)g	0.3124	0.610	£19.05
Upper Limit = (Q3 +g')	1.170	2.658	£62.18
Lower Limit = (Q1-g')	0.403	1.161	£15.43
Outliers	No	No	No

Statistical Tests

Based on the types of analyses required, the most appropriate statistical tests were selected for each of the hypotheses; these are detailed in Table 81, along with the goals of the tests.

TABLE 81: HYPOTHESES AND STATISTICAL TESTS

<table>
<tr><th>HYPOTHESIS</th><th>STATISTICAL TEST</th><th>GOAL</th><th>ANALYSIS TYPE</th></tr>
<tr><td>H_A</td><td rowspan="3">PEARSON'S PRODUCT CORRELATION COEFFICIENT</td><td rowspan="3">DETERMINE THE STRENGTH OF THE RELATIONSHIP BETWEEN TWO LINEAR VARIABLES</td><td rowspan="3">DEGREE OF RELATIONSHIPS</td></tr>
<tr><td>H_B</td></tr>
<tr><td>H_C</td></tr>
<tr><td>H_D</td><td rowspan="2">ONE WAY ANOVA</td><td rowspan="2">DETERMINE IF THREE OR MORE GROUPS ARE STATISTICALLY RELATED</td><td rowspan="10">GROUP DIFFERENCES</td></tr>
<tr><td rowspan="2">H_E</td></tr>
<tr><td rowspan="2">POST-HOC TUKEY HONEST SIGNIFICANT DIFFERENCE (HSD)</td><td rowspan="2">DETERMINE THE NATURE RELATION BETWEEN THE GROUPS</td></tr>
<tr><td>H_F</td></tr>
<tr><td>H_G</td><td rowspan="6">T-TESTS</td><td rowspan="6">DETERMINE IF TWO GROUPS ARE STATISTICALLY RELATED</td></tr>
<tr><td>H_H</td></tr>
<tr><td>H_I</td></tr>
<tr><td>H_J</td></tr>
<tr><td>H_K</td></tr>
<tr><td>H_L</td></tr>
</table>

Degree of Relationships

The first three hypotheses to be tested were those centred on finding degree of relationships between the pairs of variables specified in Table 82.

TABLE 82: DEGREE OF RELATIONSHIPS VARIABLES

<table>
<tr><th>WORKING HYPOTHESIS</th><th>VARIABLES</th><th>STATISTICAL TEST</th><th>DATA TYPE</th></tr>
<tr><td>H_A: THE DESIGNERS WILL BE WILLING TO SPEND MORE ON COMPONENTS FOR PRODUCTS WITH BETTER ENVIRONMENTAL PROFILES</td><td>PEP AND COST</td><td rowspan="3">PEARSON'S PRODUCT CORRELATION COEFFICIENT SPEARMAN'S RHO</td><td rowspan="3">CONTINUOUS</td></tr>
<tr><td>H_B: THE DESIGNERS THAT SPEND MORE WILL HAVE PRODUCTS WITH GREENER SUPPLY CHAINS</td><td>COST AND SCG</td></tr>
<tr><td>H_C: THE DESIGNERS THAT HAVE DESIGNED PRODUCTS WITH BETTER ENVIRONMENTAL PERFORMANCE WILL HAVE GREENER SUPPLY CHAINS</td><td>PEP AND SCG</td></tr>
</table>

Pearson's Product Correlation Coefficient

The Pearson product-moment correlation was used to measure the strength and direction of association between the variables of interest. It is important to note that it can only establish the strength of the association between two variables and cannot determine a cause-and-effect relationship.

Assumptions

Part of the process of using Pearson's correlation involves checking to make sure that the data to be analysed can actually be analysed using Pearson's correlation. This is because it is only appropriate to use Pearson's correlation if the data passes the following assumptions that are required for the test to give valid results:

> Assumption #1: The two variables are measured at the interval or ratio level (i.e. they are continuous)
>
> Assumption #2: There is a linear relationship between the two variables
>
> Assumption #3: Outliers are either kept to a minimum or are removed entirely
>
> Assumption #4: Variables are approximately normally distributed

The variables in the hypotheses being tested met these assumptions and as a result Pearson's product correlation coefficient was used on them.

Outputs

Table 83 shows the results that were produced after running a 2-tailed Pearson's product correlation coefficient test. The outputs of the analysis show that the significance level is below the cut off value of 0.05 that was set for α for H_A and H_B, therefore the null hypotheses are rejected and the alternative hypotheses accepted. The significance level for H_C is above the cut off value so the null hypothesis cannot be rejected and the alternative hypothesis cannot be accepted; all the conclusions are summarised in Table 84.

TABLE 83: RESULTS OF PEARSON'S PRODUCT CORRELATION COEFFICIENT TEST

	Variables	N	Correlation Coefficient	p
Pair 1	PEP & Cost	16	0.58	0.018
Pair 2	Cost & SCG	16	0.591	0.016
Pair 3	SCG & PEP	16	0.246	0.358

TABLE 84: IMPLICATIONS OF PEARSON'S PRODUCT CORRELATION COEFFICIENT TEST RESULTS

Null Hypothesis	Alternative Hypothesis	Results	Conclusion
H_{A0}: Environmental performance will not affect how much designers are willing to spend	H_{A1}: Environmental performance increases how much designers are willing spend	Positive correlation	Reject H_{A0} and Accept H_{A1}
H_{B0}: Spending more will not affect the greenness of the designed product's supply chain	H_{B1}: Spending more will increase the greenness of the designed product's supply chain	Positive correlation	Reject H_{B0} and Accept H_{B1}
H_{C0}: Environmental performance will not affect supply chain greenness	H_{C1}: Environmental performance will increase supply chain greenness	No correlation	Can't Reject H_{B0} or accept H_{B1}

Group Differences

The remaining hypotheses were concerned with testing to see if groups were similar or different and to explore the nature of their relationship; the details of the variables within those hypotheses are in Table 85.

TABLE 85: GROUP DIFFERENCES VARIABLES

Hypothesis	Variable Type	Variable	Type of Data	Categories	Test
$H_{D/E/F}$: Extra information will have an impact on PEP/SCG/Cost	Independent	Extra Information	Categorical	A	One way ANOVA
				B	
				C	
				D	
	Dependent	PEP/SCG/Cost	Continuous		
$H_{G/H/I}$: Designers with cost information will design products with lower PEP/SCG/Cost	Independent	Knowing cost	Dichotomous	No	Independent sample t-test
				Yes	
	Dependent	PEP/SCG/Cost	Continuous		
$H_{EJ/K/L}$: Designers with supplier information will design products with lower PEP/SCG/Cost	Independent	Knowing supplier information	Dichotomous	No	
				Yes	
	Dependent	PEP/SCG/Cost	Continuous		

One Way ANOVA

The one-way analysis of variance (ANOVA) was used to determine whether there were any significant differences between the means of SCG and PEP for the 4 different conditions. At this point, it is important to note that the one-way ANOVA is an omnibus test statistic and will not be able to tell which specific conditions are significantly different from each other, only that at least two groups are. To determine which specific groups differ from each other, a *post hoc* test needs to be done.

Assumptions

Before using the one-way ANOVA to analyse data, checks should be done to ensure that the data could actually be analysed using the one-way ANOVA. If the data meets the following assumptions performing a one-way ANOVA will produce a valid result:

> Assumption #1: The dependent variable is normally distributed in each group that is being compared in the one-way ANOVA.
>
> Assumption #2: There is homogeneity of variances. This means that the population variances in each group are equal.
>
> Assumption #3: There is independence of observations.

The data met assumptions 1 and 3 but needed to be tested for assumption 2 before the test could be carried out.

Homogeneity of Variances

Levene's Test for Homogeneity of Variances was used to test the data; the results of the test are shown in Table 86. For all three cases p>0.05 therefore the null hypothesis cannot be rejected, this increases confidence that the variances are equal thus homogeneity of variance assumption has been met.

TABLE 86: LEVENE'S TEST FOR HOMOGENEITY

	Levene Statistic	df1	df2	p
PEP	3.386	3	12	0.054
SCG	1.924	3	12	0.18
Cost	2.297	3	12	0.13

Outputs

The results of the one-way ANOVA showed that there were no statistically significant differences between the condition means for PEP (F(3,12) = 1.572, p = 0.48); however, statistically significant differences were found for the means of SCG (F(3,12) = 12.456, p = 0.001) and Cost (F(3,12) = 5.641, p = 0.012). These results are shown in Table 87 and their implications are detailed in Table 88.

TABLE 87: RESULTS OF ONE-WAY ANOVA TEST

		SUM OF SQUARES	df	MEAN SQUARE	f	SIG.
PEP	BETWEEN GROUPS	0.047	3	0.016	1.572	0.248
	WITHIN GROUPS	0.119	12	0.01		
	TOTAL	0.165	15			
SCG	BETWEEN GROUPS	0.392	3	0.131	12.456	0.001
	WITHIN GROUPS	0.126	12	0.01		
	TOTAL	0.517	15			
COST	BETWEEN GROUPS	434.145	3	144.715	5.641	0.012
	WITHIN GROUPS	307.825	12	25.652		
	TOTAL	741.97	15			

TABLE 88: IMPLICATIONS OF ONE-WAY ANOVA RESULTS

NULL HYPOTHESIS	ALTERNATIVE HYPOTHESIS	CONCLUSION
H_{D0}: EXTRA INFORMATION HAS NO IMPACT PRODUCT ENVIRONMENTAL PERFORMANCE	H_{D1}: EXTRA INFORMATION HAS AN IMPACT PRODUCT ENVIRONMENTAL PERFORMANCE	CAN'T REJECT H_{D0} OR ACCEPT H_{D1}
H_{E0}: EXTRA INFORMATION HAS NO IMPACT SUPPLY CHAIN GREENNESS	H_{E1}: EXTRA INFORMATION HAS AN IMPACT ON SUPPLY CHAIN GREENNESS	REJECT H_{E0} AND ACCEPT H_{E1}
H_{F0}: EXTRA INFORMATION HAS NO IMPACT COST	H_{F1}: EXTRA INFORMATION HAS AN IMPACT ON COST	REJECT H_{F0} AND ACCEPT H_{F1}

Post-Hoc Test Tukey's HSD

Going beyond the questions and hypotheses being tested, a post-hoc test was be used to examine where the differences in the conditions lie for the SCG and Cost. As the data being tested met the assumption of homogeneity of variances, Tukey's HSD test was selected for the post-hoc testing.

The Tukey post-hoc test revealed the following statistically significant findings:

- SCG was lower for those in Condition B (1.651 ± 0.07, p = 0.001) when compared to those in Condition A (2.04 ± 0.09)
- SCG was higher for those in Condition C (1.96 ± 0.06, p = 0.004) when compared to those in Condition B (1.651 ± 0.07)
- SCG was lower for those in Condition B (1.651 ± 0.07, p = 0.002) when compared to those in Condition D (2.00 ± 0.15)
- Cost was higher for those in Condition A (£45.80 ± £2.88, p = 0.011) when compared to those in Condition B (£31.99 ± £7.01)

There were no statistically significant differences between any of the other groups.

Independent-sample t-test.

The independent sample t-test was used to compare the means of PEP, SCG and Cost of those that had cost information and those that didn't and also of those who had supplier information against those that did not.

Assumptions.

To ensure that the results of the independent sample t-test are valid, the data that is to be analysed should pass the following assumptions that test its appropriateness:

Assumption #1: Dependent variables are measured at the interval or ratio level (i.e., they are continuous).

Assumption #2: Independent variable consists of two or more categorical, independent groups.

Assumption #3: There is independence of observations, which means that there is no relationship between the observations in each group or between the groups themselves.

Assumption #4: There are no significant outliers.

Assumption #5: Dependent variable is approximately normally distributed for each category of the independent variable.

Assumption #6: There is homogeneity of variances.

The data being considered met all the assumptions so the tests were carried out.

Outputs

The results of the independent sample t-tests showed that those who knew the cost of parts produced products that had statistically significantly lower overall cost (£36.42 ± £6.41) compared to those that did not have any cost information (£45.81 ± £2.89), $t(14) = -2.784$, $p = 0.015$. They also showed that those who knew the cost of parts produced products that had statistically significantly lower PEP (0.76 ± 0.09) compared to those that did not have any cost information (0.88 ± 0.11), $t(14) = -2.274$, $p = 0.039$. The rest of the tests produced results that showed no statistical significance; the implications of the test results are shown in Table 89.

TABLE 89: IMPLICATIONS OF INDEPENDENT SAMPLE T-TEST RESULTS

Null Hypothesis	Alternative Hypothesis	Conclusion
H_{G0}: Having cost information will not impact product environmental performance	H_{G1}: Having cost information will decrease product environmental performance	Reject H_{G0} and Accept H_{G1}
H_{H0}: Having cost information will not impact supply chain greenness	H_{H1}: Having cost information will decrease supply chain greenness	Can't Reject H_{H0} or accept H_{H1}
H_{I0}: Having cost information will not impact cost	H_{I1}: Having cost information will decrease cost	Reject H_{I0} and Accept H_{I1}
H_{J0}: Having supplier information will not impact product environmental performance	H_{J1}: Having supplier information will decrease product environmental performance	Can't Reject J_{D0} or accept H_{J1}
H_{K0}: Having supplier information will not impact supply chain greenness	H_{K1}: Having supplier information will decrease supply chain greenness	Can't Reject H_{K0} or accept H_{K1}
H_{L0}: Having supplier information will not impact cost	H_{JL}: Having supplier will information decrease cost	Can't Reject H_{L0} or accept H_{L1}

Comparison of Participant Designs to Pareto Efficient Designs

When the participants' generated designs were compared to the list of Pareto optimal designs, it was found that none of them were Pareto optimal; this meant that the participants were not able to effectively optimise the objectives that were embedded within the exercises. However, two designs appeared on the condensed list of options (179 designs) that were deemed to be potentially optimal before the multi objective optimisation was computed in Matlab. These were designs by P004 from Condition A and P008 from Condition B; this suggests that these two participants were better than the others at managing trade-offs.

6.7.5 *Analytic Memoing*

Defined as brief or extended narratives that document the researcher's reflections and thinking process about the data, analytic memos are not just descriptive summaries of data but attempts to synthesise them into higher-level analytic meanings. Table 90 contains a random selection of some of the memos that were written during both the qualitative and quantitative analysis phases. Appendix 6.12: Analytic Memos Created during Analysis, shows all the memos that were written totalling 27. When reading the sample of memos it is worth noting that some of them are written in the earliest stages of analysis and so reflect first impressions prior to the detail analysis that has been presented above.

TABLE 90: SAMPLE OF MEMOS WRITTEN DURING THE QUANTITATIVE ANALYSIS PROCESS

When making decisions designers need more than one factor to consider. Two factors seem to be the ideal number because once you have three, balancing them out becomes harder.	The grease filter option seemed to trip a number of participants up. All they had to do was carefully look through options to note the difference in materials but a significant number failed to do so.	In some of the cases, contrary to what most of the participants assumed, more expensive options did not translate to better environmental performance i.e. some grease filters
Knowing supplier information does not seem to have much of an impact on the environmental performance of your product – this is because the impact of the transport phase is miniscule compared to use and manufacturing.	Participants expressed an overarching assumption that people do not want to buy something that is expensive. Participants seemed to not consider the value that comes with having a better performing product.	When the environmental performance is the same, then knowing supplier information becomes important because it will have an impact. This way those with supplier information will have greener supply chains attached to their products.
Designers are encouraged to adopt lifecycle thinking, to really put that into practice you need information relating to the different lifecycle stages and some of that information is supplier dependant.	While cost comes in as a constraint and is viewed as something that has to be adhered to, when people add supplier considerations they always view them as desirables that they are in charge of determining.	Designers need understandable constraints otherwise they will self-impose constraints and usually they impose cost constraints even when not required or detrimental to other things.

6.8 Discussion

In the following section, comments are made on the results of the eco-component selection exercises. Triangulation brings together the qualitative and quantitative results and explores how they relate to each other; through inferences the results are explained in terms of what they mean and by discussing their implications, the results are interpreted in a wider context.

6.8.1 Triangulation

After the qualitative and quantitative data analysis was carried out, through triangulation (see section 4.4). Data triangulation was carried out as the quantitative and qualitative parts of the component selection exercises were brought together. Some of the outputs were collated and are presented here in the form of vignettes which detail each participant's experience with the exercises and the results they got.

Participants' and Condition Process Vignettes

The vignettes presented here were created as a way of capturing, with added meaning and contextual richness, the process that the participants went through when undertaking the component selection exercises. They aim to capture the mind-set of the participants and to also combine that process with its quantitative outputs. Condition vignettes are also presented, through them the implications of the processes that the participants adopted are discussed. The vignette for P001 is presented here in full; for the rest of the participants summaries are presented with the full vignettes available in Appendix 6.13: Participant Process Vignettes.

P001 (Condition A)

P001 started off by remarking that not having the cost of the parts was a good thing, they felt that knowing the cost usually derails you; cost becomes the factor you consider the most at the sacrifice of environmental performance.

By referring to the LCA report, they came to the conclusion that the spotlights have the second highest environmental impact in the use phase. Resultantly, for the StylishEco they wanted to replace the standard life dichroic halogen spotlights with a very efficient alternative. With particular focus on improving rated life and energy rating, they ultimately settled on LED spotlights that have a rated life of 25k hours and an A energy rating. In their opinion this was the best possible option as there was a significant improvement in energy rating (from F to A) and the rated life had increased over twelve-fold. What P001 did not seem to discern from the information they had been provided was that the life of the cooker hood was approx. 6.5k hours. Given that there were LEDs available that had 15k hours rated life and A/A+ energy ratings, in this instance they had selected an over performing option. This is particularly noteworthy because as the exercise carried on it became clear that P001 assumed that the products with better environmental performance were more expensive. This means that even without knowing the cost of the options, by choosing an over-performing product, they had unwittingly increased the total cost of the cookerhood they were designing.

As with the spotlights, they were able to refer back to the LCA report and deduce that the motor contributed the most during the use phase, making improving its environmental performance paramount. By focusing on the performance they chose to upgrade from a 24% efficient shaded-pole single phase asynchronous motor to a 66% brushless permanent magnet motor, which also represents the best performing motor on offer. While P001 had previously stated that having cost would derail you, as the exercise went on, they expressed how only knowing performance attributes was posing some particular challenges. They remarked that making decisions based on performance only, made it difficult to compare the various options and make compromises. For example, you could not actively save costs on Y, which has lower environmental impacts, so that you can select X, which increased the product cost but vastly improves its environmental performance.

After referring back to the LCA report and noting that the grease filter has high impacts in the manufacturing phase, when faced with replacement options P001 considered the environmental impacts of the materials that the filters were made from. They alluded to aluminium being more recyclable but ultimately decided that they could not really discern any major differences that would impact the environmental performance between the choices given. Resultantly, they decided to carry over the 20mm thick stainless steel-aluminium grease filter that was in the Stylish into the StylishEco; they also remarked that this choice was advantageous as it meant they would not need to switch to a different supplier. While P001 seemed somewhat confident in their choice, it is important to note that they overlooked a couple of things and made certain assumptions that might not have been correct. Initially, they did not notice the differences between the grease filter options and how those would relate to improvements in the overall product's environmental performance. After that, they made the assumption that changing grease filters meant changing supplier when it was highly probable that the same supplier would have different grease filters on offer as the filters only differed in size and or materials used.

When given the choice to add the odour filter to the StylishEco, P001 jumped at the opportunity. They felt that it could be argued that cooker hoods need odour filters and that it would also be way of differentiating the StylishEco from the Stylish in terms of functionality. For the cookerhood, they chose the thinnest available long life carbon filter; this represented the option with the best environmental profile.

Looking at the blower, impeller and packaging options, they decided that they did not have enough information to make any decisions and as a result stuck to the options being currently used. While this is true for the packaging, they could have considered the merits of having the blower and impeller made from steel vs. polypropylene. The designed cookerhood had a PEP score of 0.955; this represents the third highest score amongst all the participants and is 0.164 above the group average. With the average cost for the group coming in at £38.77, P001's total cost of £46.93 was the third highest. However, this translated to £0.49 per % PEP, which is identical to the average that the group paid as a whole. For the environmental cost that this participant got, they did not pay more than average when compared to the rest of the group. The supply chain associated with their product was comprised of 6 different suppliers and had greenness score of 2.001 (66%) this was 2% above the group average. Considering all these factors, P001's design ranked at least average and mostly above their group. Table 91 compares P001 results to the average Condition A results and average group results (all conditions).

TABLE 91: P001 VS. CONDITION A AND GROUP AVERAGE

	P001	Cond. Average		All Cond. Average	
Product Environmental Performance (PEP)	0.955	0.883	Better	0.792	Better
Product Cost (Cost)	£46.96	£45.81	Worse	£38.77	Worse
How much each % of PEP cost (Cost per % PEP)	£0.49	£0.52	Better	£0.49	Same
Supply Chain Greenness (SCG)	2.002	2.046	Worse	1.919	Better
Comparison to best possible supply chain greenness (Relative SCG)	67%	68%	Worse	64%	Better

Upon the conclusion of the exercise, P001 remarked that although they were initially happy that they were not given part costs, they soon realised that not knowing the cost did not mean that they had free reign to select any replacement parts that they wanted without worrying about the cost. In fact, they found themselves in a scenario where they did worry about how much the parts they were selecting cost as they assumed that better environmental performance meant higher cost. They felt that while having cost would have been a potential barrier to selecting the product with the best environmental profile, having that constraint would make decision-making, compromise and justification easier.

To summarise P001's decision making throughout the exercise, when they were satisfied that they had the information and understanding they required to make an informed decision, they selected the options that they felt offered the best performance; however, when they felt they were not well informed they carried over the options from the Stylish cookerhood. All in all, six decision factors were considered, three of which were performance based while the remaining three were information based.

P002 (Condition A)

During the entire exercise, P002 did not refer back to the LCA report's section on the impacts of the cookerhood. This could mean that they blindly decided to change the parts purely because they could and did not consider the impacts that the different parts had; however, it is also equally possible that though the initial run though of the problem, they mentally retained the information regarding impacts and knew that they had to make improvements.

Upon completion of the exercise, P002 remarked that not knowing anything beyond the performance of the parts and not having more stringent specifications regarding what was acceptable and what wasn't made making decisions harder. The exercise was designed such that a lot is left to the participant to decide e.g. there were no specifications as to how the new product had to perform environmentally beyond being better than the last one, how much it was better by was left to the participant's discretion. It is this that seemed to make the participant uncomfortable and less sure about the decisions they were making. They also commented that more information would have eased their discomfort, such as cost and manufacturing information. In the end, they acknowledged that ENPD is about more than just the product that you are designing so you need a vast amount of information to ensure you make informed decisions.

When looking at the way P002 approached and undertook the exercise, a strategy emerges; where they felt they had all the information required to make an informed choice, they went for the option that promised to deliver the best environmental performance, otherwise they kept the choices the same as in the predecessor cookerhood.

Table 92 compares P002 results to the average Condition A results and average group results.

TABLE 92: P002 VS. CONDITION A AND GROUP AVERAGE

	P002	Condition Average		All Cond. Average	
PEP	1.00	0.883	Better	0.792	Better
Cost	£47.14	£45.81	Worse	£38.77	Worse
Cost per % PEP	£0.47	£0.52	Better	£0.49	Better
SCG	2.049	2.046	Better	1.919	Better
Relative SCG	68%	68%	Same	64%	Better

P003 (Condition A)

During the exercise P003 seemed to adopt a view that extended beyond the product that they were designing, they were very conscious of the how the product they were designing would be marketed and how the users would interact with it. Although they acknowledged that they needed to have market research to be sure, they figured that they could make improvements to the new product and it would be possible offset those costs through good product marketing that justified selling the new product at a higher price; it would be easy to justify the increased cost to the end users by highlighting how much lower the running costs of the StylishEco would be compared to the Stylish.

Upon completion of the exercise, along with market needs information, P003 mentioned that they felt they also needed information regarding how much the various options cost to help them make more informed decisions. The impact of not having the cost information manifested itself though P003 assuming that all the options with better environmental profiles would cost more; while this is usually the truth it is not always the case. For example various grease filters have similar costs but environmentally some are better than others and it is a case of understanding what makes some better than others.

When they felt that they had enough information to make a decision, P003 chose either the option with what they perceived would be the best environmental performance or one that they deemed to offer good enough improvements on the predecessor; otherwise they did not change anything.

Table 93 compares P003 results to the average Condition A results and average group results.

TABLE 93: P003 VS. CONDITION A AND GROUP AVERAGE

	P003	Condition Average		All Cond. Average	
PEP	0.776	0.883	Worse	0.792	Worse
Cost	£41.50	£45.81	Better	£38.77	Worse
Cost per % PEP	£0.53	£0.52	Worse	£0.49	Worse
SCG	1.960	2.046	Worse	1.919	Better
Relative SCG	65%	68%	Worse	64%	Worse

P004 (Condition A)

P004 started off by referring to the LCA report and calculating the impacts that the various parts had but somehow, did not seem to translate it well when participant started selecting options. It seemed that when faced with making the biggest improvement (the motor) they were also faced with the potential to include massive costs so they decided to go for a reasonable increase instead of the best on offer; without access to cost information there was no way for them to decide if the performance improvements would be worth it. This ties in with how they expressed that they would have liked to have had cost information during the exercise to help them make better decisions.

Reflecting upon how P004 conducted the exercise, they seemed to recognise the benefits that material homogeneity would have in when dealing with end-of-life issues such as disassembly for recycling. The strategy they adopted can be said to be one where they selected the option with the best performance, or performance they deemed 'good enough', when they felt they had sufficient information; when they were not well informed they kept the previous options. They made more changes than the other participants in their condition.

Table 94 compares P004 results to the average Condition A results and average group results.

TABLE 94: P004 VS. CONDITION A AND GROUP AVERAGE

	P004	Condition Average		All Cond. Average	
PEP	0.801	0.883	Worse	0.792	Better
Cost	£47.63	£45.81	Worse	£38.77	Worse
Cost per % PEP	£0.59	£0.52	Worse	£0.49	Worse
SCG	2.1732	2.046	Better	1.919	Better
Relative SCG	72%	68%	Better	64%	Better

Condition A: Performance Information

The participants that were in Condition A were required to transform the Stylish cookerhood into the StylishEco by replacing certain components. To make these decisions, they were given a parts catalogue that contained parts; all the parts in the catalogue would work well in the new cookerhood however, they were given the mandate to make a new product with a better environmental profile. The challenge was for them to look through the options and decide which ones offered would be included in the new product.

When given the exercise, they all remarked that they would have like to have more information; Condition A participants had only been given information regarding the technical performance of the products and every single one of them expressed that they would also have liked to have cost information. They found that with just one factor to consider (technical performance), it was hard to truly compare and quantify the benefits of one option vs. another. Some of the participants also made comments about how they would have liked to have more information regarding the manufacturing of the different parts, this again would serve a factor that would aid them in comparing options and making informed decisions.

In terms of tackling the challenge, the group was split into two camps. One half of the group took the logical approach where they consulted the LCA report, broke down the impacts of the various components and used that to guide their decision-making. The other half was happy to ignore the contributions of the components and to work through the set of components that they had been told that they could change. Overall, the group seemed to make the assumption that the better performing products would cost more. While they could not come to this conclusion during the experiment because they did not have any cost information, there are industrial examples where a product with a better environmental profile has a lower cost than an alternative product. The cost assumption had two different impacts on the group, half of the group members adopted a strategy where they would go for the option that they deemed to have a 'good enough' performance improvement when they felt that improving the product further would have had major cost ramifications; the other half, regardless of acknowledging that they were likely increasing their product's cost by big margins, was happy to go with the best performance they could get mainly because they reasoned that the benefits would be worth it.

It can be said that as a group, when they felt they had all the information they need to make an informed choice they went for what they thought had the best technical performance or what they deemed to be a 'good enough' technical performance improvement. When they felt they were not well-informed they kept choices the same as the predecessor.

In a sentence, the group's decision-making can be defined as follows: technical performance-based or 'no change'.

The following proved to be the most popular choices within the group:

- A+ energy rating, 15k rated life LED spotlight
- 66% efficient brushless permanent magnet motor
- 20mm all stainless steel grease filter
- 30mm Long life odour filter or no odour filter included
- Galvanised steel impeller
- Polypropylene blower
- Cardboard packaging

Table 95 compares average Condition A results to average group results.

TABLE 95: CONDITION A VS. GROUP AVERAGE CONDITIONS

	CONDITION A	ALL CONDITIONS	
PRODUCT ENVIRONMENTAL PERFORMANCE (PEP)	0.883	0.791	BETTER
SUPPLY CHAIN GREENNESS (SCG)	2.046	1.912	BETTER
PRODUCT COST (COST)	£45.81	£38.77	WORSE
HOW MUCH EACH % OF PEP COST (COST PER % PEP)	£0.52	£0.49	WORSE
COMPARISON TO BEST POSSIBLE SUPPLY CHAIN GREENNESS (RELATIVE SCG)	68%	64%	BETTER

P005 (Condition B)

During the exercise, P005 seemed to have a good grasp on the information that was in the LCA report and used it to inform the decisions that they made. These decisions did not however always result in being environmentally beneficial. This is to say they did not always make decisions to improve the environmental performance of the product, rather, in some cases they made choices based solely on cost.

When reflecting on the exercise, they remarked that while they used cost as a tie breaker in making decisions but to truly make environmentally conscious decisions they would have liked to have more information on the suppliers, transport, locations and manufacturing relating to the different products on offer. They also commented on how having the cost information made them more conscious of keeping costs down especially when they did not know the value of the product; they just could not tell if certain improvements were worth the money or not. As a result, when they were not sure if a certain improvement was worth it or not, they would just not have it.

Looking at how P001 tackled the exercise it can be said that when they came to the components with the highest environmental impacts they decided on performance improvements that they deemed to be appropriate and then selected the cheapest option that met the performance requirements. For the low impact parts, they completely disregarded any environmental benefits and went for the cheapest offering.

Table 96 compares P005 results to the average Condition B results and average group results.

TABLE 96: P005 VS. CONDITION B AND GROUP AVERAGE

	P005	Condition Average		All Cond. Average	
PEP	0.876	0.746	Better	0.792	Better
Cost	£27.96	£31.99	Better	£38.77	Better
Cost per % PEP	£0.32	£0.43	Better	£0.49	Better
SCG	1.6316	1.652	Worse	1.919	Worse
Relative SCG	54%	55%	Worse	64%	Worse

P006 (Condition B)

P006 proved to be very suspicious of the cheapest options that were on offer; without any other information to discern any differences between the suppliers, they seemed to assume that the suppliers who delivered the cheaper products were worse in some kind of way. When reflecting upon the exercise, they noted that they would have liked to have more information regarding the suppliers particularly their location. One can only surmise that had they had this information then maybe P006 would not have been so distrusting of the cheaper offering and instead would have evaluated the suppliers differently.

When tackling the exercise, where there was a clear environmental improvement to be made, P006 made sure they made an improvement; the choice was a balance between performance and cost but always with an improvement. However, for parts where they could not detect a clear environmental gain they either stayed with the same option as in the predecessor or they made a cost saving.

Table 97 compares P006 results to the average Condition B results and average group results.

TABLE 97: P006 VS. CONDITION B AND GROUP AVERAGE

	P006	Condition Average		All Cond. Average	
PEP	0.778	0.746	Better	0.792	Worse
Cost	£40.95	£31.99	Worse	£38.77	Worse
Cost per % PEP	£0.53	£0.43	Worse	£0.49	Worse
SCG	1.6633	1.652	Better	1.919	Worse
Relative SCG	55%	55%	Same	64%	Worse

P007 (Condition B)

Although they did adopt the 'same-supplier-first' approach, throughout most of the design process P007 kept referring back to the LCA report, which means they had a firm understanding on the impacts that various components had throughout the life of the Stylish cookerhood.

Reflecting upon the exercise, P007 stated that they would have liked to have more information regarding the suppliers of the products including their environmental impacts and manufacturing processes, as it was they had gone by the notion that if we used them before then they must be good so stick to them.

Looking at how P007 undertook this exercise, the same-supplier preference is evident. When faced with making decisions on parts that had substantial environmental implications, they looked at the suppliers that they wanted and then picked out what they thought was the best component on offer by balancing out cost and performance. For those parts that were deemed to have negligible impacts, the cheapest option was selected.

Table 98 compares P007 results to the average Condition B results and average group results.

TABLE 98: P007 VS. CONDITION B AND GROUP AVERAGE

	P007	CONDITION AVERAGE		ALL COND. AVERAGE	
PEP	0.665	0.746	WORSE	0.792	BETTER
COST	£25.11	£31.99	BETTER	£38.77	BETTER
COST PER % PEP	£0.38	£0.43	BETTER	£0.49	BETTER
SCG	1.7527	1.652	BETTER	1.919	WORSE
RELATIVE SCG	58%	55%	BETTER	64%	WORSE

P008 (Condition B)

Throughout the design process, P008 seemed to put a lot of emphasis on keeping suppliers constant. After the exercise was completed, they commented that they would have liked more information on the suppliers to know what their environmental profiles were like because that would also have an impact on whether they insisted on staying with them or not. Additionally, they expressed a wish to have had information relating to the locations of the suppliers. While they expressly stated that cost was important but didn't want to fall into the trap on being too blinded by it, they seemed to fall back on it repeatedly.

When undertaking the exercise, P008 seemed to decide on what they classed as a good performance improvement and sought the cheapest way to implement that improvement. They went against this in the case of the blower and the impeller when they claimed that the cost savings were not worth switching suppliers.

Table 99 compares P008 results to the average Condition B results and average group results.

TABLE 99: P008 VS. CONDITION B AND GROUP AVERAGE

	P008	CONDITION AVERAGE		ALL COND. AVERAGE	
PEP	0.665	0.746	WORSE	0.792	WORSE
COST	£33.94	£31.99	WORSE	£38.77	BETTER
COST PER % PEP	£0.51	£0.43	WORSE	£0.49	WORSE
SCG	1.5598	1.652	WORSE	1.919	WORSE
RELATIVE SCG	52%	55%	WORSE	64%	WORSE

Condition B: Performance and Cost Information

When given the challenge of designing the StylishEco, based on the Stylish cookerhood, participants in Condition B were also given a parts catalogue that contained cost and performance information of the parts that they could select from. They all remarked that that they would have like more information, in particular information relating to the suppliers of the products in the catalogue. They remarked that it is this information that would allow them to make better environmental decisions. Regardless of the lack of information relating to the suppliers, the participants all seemed to make a point of trying to stick to the suppliers that were currently being used. The main reason for this was citing as the ease of buying if you have to purchase from someone you already have a history with. Some did remark that with more supplier information they would be able to discern if staying with the same supplier was actually a worthwhile thing to focus on.

As a group, they seemed to put the LCA report and other pieces of supporting information to good use. They seemed to take a logical approach to the design process as they looked at the factors that contributed to the environmental profile of the cookerhood in detail. However, despite this, most of them failed to select the better lighting options as they were not able realise that the rated life improvements they settled on where not enough to negate the need to replace the lights throughout the life of the cookerhood.

While they put the cost information that they had to good use and used it to influence the decisions that they made, they also seemed to find it harder to make those decisions, as they had no concrete concept of how much an increase in cost was worth it environmentally. This is where they felt having more information would help them. There were also comments made that alluded to the participants making the assumption that the cheaper parts were less environmentally friendly and located further away.

As a group they mostly decided on the improvements that they wanted and then went for the cheapest option. For the low-impact components, they all disregarded any environmental benefits. They instead decided based on cost savings or on sticking with the same supplier.

In a sentence, the group's decision-making can be defined as follows: when there was a clear benefit, balanced cost and performance otherwise cut costs or stayed the same.

The following proved to be the most popular choices within the group:

- D energy rating, 5k rated life long life dichroic halogen spotlight @ 1.34
- 50% efficient brushless permanent magnet motor @ £11.25
- 20mm all stainless steel grease filter @ £3.20
- No odour filter
- Polypropylene impeller @ £0.40
- Polypropylene blower @ £0.58
- Cardboard packaging @ £0.30

Table 100 compares average Condition B results to average group results.

TABLE 100: CONDITION B VS. GROUP AVERAGE

	CONDITION B	ALL COND	
PRODUCT ENVIRONMENTAL PERFORMANCE (PEP)	0.746	0.791	WORSE
SUPPLY CHAIN GREENNESS (SCG)	1.652	1.912	WORSE
PRODUCT COST (COST)	£31.99	£38.77	BETTER
HOW MUCH EACH % OF PEP COST (COST PER % PEP)	£0.43	£0.49	BETTER
COMPARISON TO BEST POSSIBLE SUPPLY CHAIN GREENNESS (RELATIVE SCG)	55%	64%	WORSE

P009 (Condition C)

As they undertook the exercise, P009 seemed to like calculating the cost per unit performance; this is how they balanced out cost and performance. They remarked early on that it was very important to be weary of slight cost increases as they do add up very easily. Through their choices, it seemed they prioritised performance and supplier profile and then tried to get what they wanted for the best price possible.

Reflecting on the exercise as a whole, they felt that while they would have like more information on materials, the information depth of information that they had made it easier to make decisions. They cited the lighting decision as the easiest one to make as they felt they had all the information that they needed to make an informed choice.

As someone with a limited working knowledge of eco-design they remarked, "Instinctively you have an idea of things that you can do to improve the environmental profile of a product, this is reinforced when you get more information, like in the LCA report" and confessed that they as they got more information they felt more comfortable and confident. Whenever they were not confident, they decided that they would not change anything and stick to the original component.

In terms of the information they were given, they thought that they did have a lot to consider but by taking their time they were able to gain more confidence in their decisions. While in some cases they would have liked more performance-related information to guide them, they felt the supplier certifications that they were given were very important as they showed you which suppliers cared and had high standards.

Table 101 compares P009 results to the average Condition C results and average group results.

TABLE 101: P009 VS. CONDITION C AND GROUP AVERAGE

	P009	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.766	0.760	Better	0.792	Worse
Cost	£39.83	£41.19	Better	£38.77	Worse
Cost per % PEP	£0.52	£0.54	Better	£0.49	Better
SCG	2.046	1.968	Better	1.919	Better
Relative SCG	68%	66%	Better	64%	Better

P010 (Condition C)

As they were working through the exercise, they did note that they realised that were not really utilising the LCA report that much. They did refer back to it here and there but its contents did not seem to influence the decisions that they were making. They also claimed that wherever possible they were trying to stick to Italian suppliers, as their closer proximity would lead to improved product environmental profile.

Upon completion of the exercise, they stated that overall they were happy with the information that they had been given. They remarked that since there was a lot for them to consider was easy to get overwhelmed or forget things, which meant that it was important concentrate.

Throughout the exercise, P010 asked a lot of questions and bounced their ideas off the facilitator, they said that this process of talking though their thoughts really helped them think about what they were doing in a bit more detail. P010 mainly selected parts by deciding which performance that they wanted and then choosing the best supplier or choosing the supplier that they wanted first and then going for the best performing option that they offered.

Table 102 compares P010 results to the average Condition C results and average group results.

TABLE 102: P010 VS. CONDITION C AND GROUP AVERAGE

	P010	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.731	0.760	Worse	0.792	Better
Cost	£40.64	£41.19	Better	£38.77	Worse
Cost per % PEP	£0.56	£0.54	Worse	£0.49	Worse
SCG	1.992	1.968	Better	1.919	Better
Relative SCG	66%	66%	Same	64%	Worse

P011 (Condition C)

Throughout the exercise P011 was conscious of being limited by price, to counter this they decided that they would decide on the performance that they wanted and would select it regardless of price. Throughout the exercise, the referred back to the LCA report and used it to inform their decisions.

When reflecting upon the exercise, P011 remarked that they were given a lot of information and things to consider but this was good because this reflected the real life scenario that surrounds design and eco-design. For them, cost did not seem to be a major deciding factor. They liked to decide on the performance that they wanted and then select the option from the supplier with the better profile.

Table 103 compares P011 results to the average Condition C results and average group results.

TABLE 103: P011 VS. CONDITION C AND GROUP AVERAGE

	P011	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.766	0.760	Better	0.792	Worse
Cost	£43.25	£41.19	Worse	£38.77	Worse
Cost per % PEP	£0.56	£0.54	Worse	£0.49	Worse
SCG	1.9205	1.968	Worse	1.919	Better
Relative SCG	64%	66%	Worse	64%	Same

P012 (Condition C)

While they did not seem to utilise the LCA report as much, they did seem to always think about the environmental impacts of the choices that they were making and tried to ensure that they made at least an improvement with each component selection.

Throughout the exercise, P012 did not seem to consider cost very much; they were more inclined to choose the product that they wanted and then accept the cost. They did remark that there was a lot of information and things to get their head round during the exercise, things that are not usually thought about. For example, usually it only matters where you get your component from because it affects the cost, but now the implications extended beyond that.

Table 104 compares P012 results to the average Condition C results and average group results.

TABLE 104: P012 VS. CONDITION C AND GROUP AVERAGE

	P012	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.776	0.760	Better	0.792	Worse
Cost	£41.02	£41.19	Better	£38.77	Worse
Cost per % PEP	£0.53	£0.54	Better	£0.49	Worse
SCG	1.914	1.968	Worse	1.919	Worse
Relative SCG	64%	66%	Worse	64%	Same

Condition C: Performance, Cost and Supplier Information

During the component selection exercises, the participants in Condition C were given information on the cost, performance and suppliers of the parts that they could choose to include in their design of the StylishEco. This meant that they were the group that was given the most information. Resultantly, they all made comments about how they had a lot of information to digest; all of them did realise the importance of having all this information as it was vital to ensure that they made informed decisions. Although they had a lot of information, in some cases they felt that access to manufacturing and materials information would have help them as well.

This group did not seem to utilise the LCA report that much, it seemed once they started selecting parts they formed ideas in their heads of the performance that they were looking for and would be happy with; they decided to implement those performance improvements regardless of the impact that they would have or how much they would cost. Cost was definitely not a major deciding factor as they all went for the performance and supplier profile that they wanted and seemed to not let cost get in the way of making the best environmental decisions. There were times when cost was part of their decision making process however it was never at the sacrifice of performance or supplier profile.

In a sentence, the group's decision-making can be defined as follows: decided on the performance they wanted, selected the best supplier profile and placed a low priority on keeping the cost down.

The following proved to be the most popular choices within the group:

- A+ energy rating, 15k rated life LED @ £7.50 from Light G

- 50% efficient brushless permanent magnet motor @ £12.13 from Motor C or 48% efficient single phase motor with permanent capacitor at £10.12 from Motor E
- 20mm stainless steel + aluminium grease filter @ £3.20 from Filter A
- 15mm long life carbon odour filter @ £6.70 from Filter B
- Galvanised steel impeller @ £1.30 from Custom A
- Polypropylene blower @ £0.90 from Custom D
- Cardboard packaging @ £0.60 from Box 2

Table 105 compares average Condition C results to average group results.

TABLE 105: CONDITION C VS. GROUP AVERAGE

	Condition C	All Cond	
Product Environmental Performance (PEP)	0.760	0.791	Better
Supply Chain Greenness (SCG)	1.968	1.912	Better
Product Cost (Cost)	£41.19	£38.77	Worse
How much each % of PEP cost (Cost per % PEP)	£0.54	£0.49	Worse
Comparison to best possible supply chain greenness (Relative SCG)	66%	64%	Better

P013 (Condition D)

When reflecting on the exercise, P013 commented that there was a lot of information that they had to consider but it was nice having the option to ask for more information when they felt that they needed it; it made making informed decisions easier. They did express that they would have liked to have more information regarding materials and manufacturing processes. They felt that there was quite a lot of balancing out that had to be done to ensure that the best choice was made.

Overall, P013 selected components for their StylishEco cookerhood by deciding on the performance improvement that they wanted and selecting and option that fulfilled that while balancing supplier profile and cost.

Table 106 compares P013 results to the average Condition D results and average group results.

TABLE 106: P013 VS. CONDITION D AND GROUP AVERAGE

	P013	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.753	0.778	Worse	0.792	Worse
Cost	£38.31	£38.09	Worse	£38.77	Better
Cost per % PEP	£0.51	£0.46	Worse	£0.49	Worse
SCG	2.163	2.008	Better	1.919	Better
Relative SCG	72%	67%	Better	64%	Better

P014 (Condition D)

P014 summed up their experiences with the exercise by saying “There is a lot of stuff to think about, I just wasn’t thinking about it. I didn’t know what I could and could not ask for. I would have liked to know what things I can ask for then I will ask for them. So I missed the most interesting part of this then. There are too many things to weigh up. I’m more in design mode than looking at the whole picture mode. If I knew you had this, it would have affected the choices that I made. If you do not know that you can get something, then it is hard to ask for it.” They also expressed how having manufacturing information would also have allowed them to make more informed decisions.

In terms of how they tackled the exercise, they tried to go for the cheapest option wherever possible; for the more important parts they went for improved performance but for the other ones they were not concerned about that.

Table 107 compares P014 results to the average Condition D results and average group results.

TABLE 107: P014 VS. CONDITION D AND GROUP AVERAGE

	P014	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.683	0.778	Worse	0.792	Worse
Cost	£27.19	£38.09	Better	£38.77	Better
Cost per % PEP	£0.40	£0.46	Better	£0.49	Better
SCG	1.8245	2.008	Worse	1.919	Worse
Relative SCG	61%	67%	Worse	64%	Worse

P015 (Condition D)

Upon completing the exercise they stated that the aim was to try and optimise your choice and that meant trying to find a balance between improving the environmental performance and the cost. They found it interesting that it was left up to them to decide what information they wanted, in such a case they felt that they would have liked to have had commercial information like sales numbers. They also made a comment that sometimes when all you are faced with are numbers to help you compare items, it is hard to know how they actually translate in the real world; for example what would a 0.2 difference in EMS scores actually look like. To summarise, P0015 tried to save money on the less crucial components and for the crucial ones tried to balance out cost, supplier profile and the best possible performance.

Table 108 compares P015 results to the average Condition D results and average group results.

TABLE 108: P015 VS. CONDITION D AND GROUP AVERAGE

	P015	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.965	0.778	Better	0.792	Better
Cost	£42.77	£38.09	Worse	£38.77	Worse
Cost per % PEP	£0.44	£0.46	Better	£0.49	Better
SCG	1.949	2.008	Worse	1.919	Better
Relative SCG	65%	67%	Worse	64%	Better

P016 (Condition D)

Throughout the whole process, cost was a significant influencing factor for P016; they made several comments about going for the cheapest possible option. It is interesting to note that they never seemed to consider more than two factors at a time. Usually it would be performance and cost and in the one instance where performance was not a differentiator they turned to cost and supplier location. Overall, they tried to go for the cheapest option that met the performance standards that they determined.

After they completed the exercise, they commented that they did not really feel like they had made any environmental decisions and that they didn't really feel like they had the information that would have allowed them to do that (even though they could have asked for it). They would have liked to have manufacturing information and more information regarding the suppliers; more than transport information as that did not really have such a big impact. When asked why they didn't ask for all that extra information that they just had mentioned that would have allowed them to make better-informed environmental decisions, they said that they were not really sure what they could have asked for so they didn't bother doing it.

Table 109 compares P016 results to the average Condition D results and average group results.

TABLE 109: P016 VS. CONDITION D AND GROUP AVERAGE

	P016	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.71	0.778	Better	0.792	Better
Cost	£36.07	£38.09	Worse	£38.77	Worse
Cost per % PEP	£0.51	£0.46	Worse	£0.49	Better
SCG	2.0973	2.008	Better	1.919	Worse
Relative SCG	70%	67%	Better	64%	Better

Condition D: Optional Information

Condition D is the condition where the participants were given performance information only to begin with and told that they could request any extra information that they felt they needed to help them make informed decisions. Under these conditions, the participants all asked for different pieces and levels of information to help them make better environmental decisions. Two of the participants did not request anything beyond cost information and supplier name while the other two asked for all the information that was available to them. They expressly asked for any information that was available that was related to the outputs of the EMS that the company had recently put into practice. All of the participants in the condition did ask for information on manufacturing as they also thought that this would help them make informed decisions. P014 and P016 conducted the exercises in conditions that were similar to Condition B and P013 and P015 those similar to Condition C.

At the end of the exercises, when those that requested the least amount of information, similar to Condition B, were told of what else they could have had access to they remarked that they did not realise that they could have asked for that kind of information. When they were asked why they did not ask anyway, they claimed that they assumed that it would just be a waste of time as that information would not be available; they felt that access to such information would have made it so much better in terms of the environmental decisions that they made.

Across all participants, cost considerations were a prevalent thing; they all tried to go cheap or balance out costs for the performance that they were getting. Through the experiment, some of the participants would try to balance out all the factors that they had information on and find the best solution that way, in some cases aiming for the best performance. Others decided on performance that was good enough and they tried to get it as cheap as possible – these were the ones that neglected the suppliers. This mainly happened for the high impact parts, for the low impact ones they either kept them the same or tried to save money.

In a sentence, the group's decision-making can be defined as follows: either tried to balance out cost, performance and supplier or went for the cheapest option for the performance they deemed adequate.

The following proved to be the most popular choices within the group:

- A+ energy rating, 15k rated life LED @ £7.50 from Light G
- 48% efficient single phase motor with permanent capacitor at £10.12 from Motor E
- 20mm stainless steel grease filter @ £3.20 from Filter A
- No odour filter
- Galvanised steel impeller @ £1.69 from Custom A
- Galvanised steel blower @ £1.30 from Custom A
- Cardboard packaging@ £0.65 from Box 1 @ £0.60 from Box 2

Table 110 compares average Condition D results to average group results.

TABLE 110: CONDITION D VS. GROUP AVERAGE

	CONDITION D	ALL COND	
PRODUCT ENVIRONMENTAL PERFORMANCE (PEP)	0.778	0.791	WORSE
SUPPLY CHAIN GREENNESS (SCG)	2.008	1.912	BETTER
PRODUCT COST (COST)	£36.09	£38.77	BETTER
HOW MUCH EACH % OF PEP COST (COST PER % PEP)	£0.46	£0.49	BETTER
COMPARISON TO BEST POSSIBLE SUPPLY CHAIN GREENNESS (RELATIVE SCG)	67%	64%	BETTER

6.8.2 INFERENCES

The incorporation of both the qualitative and quantitative results into a coherent framework was also achieved through the process of inference, where sense is made out of the results of the data analysis. As inferences are conclusions and interpretations that are made on the basis of collected data, it is essential to distinguish them from the data from which they were derived. Inferences during this phase were made with the guidance of the *Rules of Integration* as outlined in *Foundations of Mixed Method Research* (Teddlie and Tashakkori, 2009); prevalence of themes in the data can be used to identify the most important inferences. It is also important to note that inferences are not limited to addressing the hypotheses or to answers to the research questions; they also develop new understandings and explanations for events, phenomenon and relationships.

Observer Impression

Observer impression is the process where the researcher interprets coded data via the formation of an impression which is then reported in a structured form (Punch, 2005). Table 111 categorises and details the inferences that were made as the final combined data set was analysed; these inferences were deemed as important due to their prevalence.

TABLE 111: INFERENCES MADE FROM DATA ANALYSIS

INFERENCES
DECISION MAKING DURING ENPD
- To make informed decisions designers need more than one factor to consider; they are comfortable with considering two factors. However, they find considering three factors at the same time considerably more challenging. - When told to improve the environmental performance and not given any other stringent constraints or a value to aim for, designers find it difficult to make decisions confidently. - Designers make decisions based on what they have in front of them or they make assumptions to fill in any gaps if they feel something is missing, making it important to manage the assumptions that they have and to ensure that they are not detrimental to ENPD objectives.
QUANTIFYING PEP
- It is important to quantify the improvements that you want. A good way of looking at it is '£x per % unit environmental performance' or 'best possible EP for any cost' or 'best EP for this max cost' or '50% increase in EP' etc. - Designers that only have cost will want something else to help them decide if what they were paying for a certain level of performance is worth it.
CONSTRAINTS
- Understandable constraints are needed otherwise designers will self-impose constraints and usually this means cost constraints even when not required or detrimental performance. - Cost comes in as a constraint and is viewed as something that has to be adhered to, however supplier considerations are always viewed by designer as desirable.
ENPD PROCESS
- When designers integrate environmental considerations into their design process, they require some supplier-specific information.

- Not only do designers need information, they also need to be able to accurately interpret the information they have, allowing them to make informed decisions. An understanding of eco-design principles and utilisation of eco-design support tools help them to achieve this.
AVAILABILITY OF INFORMATION
- When there is no cost information, better performing parts will be assumed to be more expensive and vice versa. - When there is no information on suppliers at all, not having to switch suppliers will count as a merit to sticking to the same supplier option and cheaper products will be assumed to be from worse performing suppliers and vice versa.
SUPPLIER INFORMATION
- Knowing supplier information did not seem to have much of an impact on the product's environmental performance, probably because in the product that was designed here the impact of the transport phase was miniscule compared to the use and manufacturing phases. - When environmental performance cannot be a differentiator, then knowing supplier information becomes important, as it will have an impact. In this case those with supplier information were able to select products with suppliers who have better overall profile resulting in greener supply chains being attached to their products.
COST INFORMATION
- When given cost information designers tend to design cheaper products. - When it is not provided, designers will ask for cost information.
CONDITION COMPARISONS
- Condition C produced the most consistent results. Condition D was very varied but on average they performed well. Condition B did not have enough information to go by and focused a lot on cost reduction. - While Condition D performed well on average, there was a distinct split in the group. Two of the participants vastly outperformed the other two. This highlighted the danger inherent in a situation where the designers are required to pull out information that they require, they can fail to adequately do so and resultantly put themselves at a disadvantage.

6.8.3 IMPLICATIONS

Cost plays a vital role in ENPD, within the component selection exercises, there were statistically significant positive correlations between cost and PEP, and cost and SCG. Additionally, compared to not knowing component costs, knowing component costs helps designers keep overall cost down but with an adverse impact on the PEP of the designed product. As the integration of environmental considerations into product design take the form of a multi-objective optimisation problem, it is essential that the designers are able to adequately balance the trade-offs that have to be made. Due to its impact on overall cost, it is important that designers have access to cost information, at the same time measures have to be put in place that ensure that designers are capable of accurately evaluating the value of PEP so that it is not compromised as they focus solely on cost. This is to say, it is vital to ensure that designers are able to accurately appraise environmental performance in relation to cost.

It is also important to understand the dynamics that surround the type of information that designers have access to during ENPD. When given just technical performance related information, designers express a need to have cost information to help them make more informed decisions and when supplied with cost and technical performance information they typically request supplier information. Even though they state that they can feel overwhelmed at times, it is only those that are supplied with all three types of information that feel that they are in a position to make informed decisions that aim to tackle environmental objectives. One way to mitigate this sense of feeling overwhelmed is to inform designers about the types of information available to them and giving them the option of attaining the information that they think they need at their own behest. This goes some way to addressing the information push/pull paradox where pushing information to the designers could result in oversaturation and having the designers pull the information they require, could result in them not adequately requesting the most beneficial type of information. It is important to note that, as was evident in the exercises, the designers will typically request manufacturing- and materials-related information before they ask for supplier-related information. The request for manufacturing- and materials-related information is testament to how traditional concurrent engineering principles (simultaneous design of process and product) are already embedded into the designer's processes and the need to bring supply chain design to the same level through 3DCE based approaches.

The information that designers have impacts the factors that they consider when making decisions; generally speaking, designers mainly tend to consider two factors at once. Depending on what information they have, they will either try to balance performance vs. cost or performance vs. supplier profile. Designers that are given cost, performance and supplier information note it is a lot to consider but realise that it is vital information to have as it allows them to make informed decisions. It is important to note that not only is it important to ensure that designers have the information they require, but to also make sure that they know how to utilise it once they have it.

Whenever designers feel that they do not have enough information to make an informed performance-based decision, they will not change anything or will opt to cut down costs. In some cases when they have incomplete information they will fill in the gaps with their own assumptions, sometimes their assumptions are correct and other times they are not. To ensure the best possible results, it might be beneficial for designers to have eco-design guidelines so that when they are forced to make assumptions they make ones that are not counter-productive.

Looking at the process outputs in terms of cost per % PEP and SCG, Condition D had the best results as the condition's average was above the group average in both instances. Conditions A and C performed better in terms of SCG but had worse average cost per % PEP, whilst Condition B performed better than average in terms of cost per % PEP and worse for SCG. It is impossible to categorically say that Condition D is the best to perform ENPD under as it represents the best of Condition B and the best of Condition C. While its results were not particularly remarkable or terrible, Condition C was the most consistent condition. The participants in this condition had the most information and as a result made the least assumptions and carried out the redesign process in consistent manner in terms of how they made decisions and the results that they got.

By introducing supplier-specific information into the ENPD process, not only are designers able to make more informed environmental decisions as they focus on making products with improved environmental profiles but one of the process outputs becomes a design of the product's supply chain. During the exercises participants were not explicitly asked to design the supply chain of the products they were designing, however they were able to select suppliers and evaluate them based on the information they had, and thereby effectively design the supply chain.

6.9 Outputs of Controlled Experiments

Moving beyond critically assessing the impacts of early supply chain design on ENPD outputs and providing insight into how designers work, the insights from the component selection exercises also advocate for the development of the tools that have the potential to be beneficial to 3DCE-based approaches to ENPD. The following tools are proposed:

- ENPD Designer Decision Model: a visual graphic that outlines the decisions made during a flow of actions embedded in a range of actions governed by ENPD. The decision model is based on composite decision modelling, and through composite sequence analysis that integrates multiple participants' journeys into a single diagram the model would map out specific choices and actions that designers take when they conduct product design with environmental objectives. This tool can help researchers understand how designers behave when confronted with decisions to make during environmental product development; capturing decisions and rationale is helpful for organisational learning.
- Cost per % product environmental performance (PEP) derived unit: a way of quantifying the environmental performance of a set of alternative design solutions and relating it to

cost. The cost per % PEP was developed and used during the analysis of the component selection exercises and was shown to useful in evaluating PEP improvements. If developed as a tool is would allow designers to evaluate various designs in terms of how much they cost per unit of environmental performance.

- Design Optimisation: a comparison of design solutions to the Pareto front, showing how close or far the solutions are to optimised solutions. Through the use of design optimisation, researchers would be able to gain insight into how designers handle multi-objective optimisation challenges that are embedded within ENPD. This process was adopted during the analysis of the exercises to compare the participates proposed solutions to optimised solutions, which lead to the idea that it could be developed as a useful tool in its own right.
- Supplier-Specific Information Database: an information database that gives designers access to supplier-specific information regarding components and materials that can be used during the design and development process. This tool is based on a combination of the supplier database and parts catalogues that were given to some of the participants of the exercises. Ideas for this tool were further investigated as part of the G.EN.ESI project (described in section 8.4). Designers are able to set the variables they want to see regarding the components they are considering (e.g. cost, performance, materials etc.) and the results they are presented with are specific to different suppliers allowing them to take supplier-specific factors into account when deciding on which component to use in their products.

From the tools proposed above, the Cost per % PEP derived unit was further developed and is elaborated in Section 7.2.1.

Chapter Summary

The impact of early supply chain design on ENPD outputs was assessed through eco-component selection exercises in the form of controlled experiments. Based on an existent company and product, the exercises were developed specifically for this purpose; 16 carefully selected participants assumed the role of product designer and undertook the exercises. During the exercises, the participants were required to utilise varying degrees of information to make informed decisions regarding the integration of environmental consideration in to the product design. Of particular interest was the impact that supplier-specific information had on product cost, product environmental performance and supply chain greenness. Qualitative data related to the processes the designers adopted and quantitative data relating to the produced product designs was collected and analysed through content analysis, and descriptive and inferential statistics respectively. After process vignettes were used to discuss the results of the exercises, inferences were made and implications of the exercises results were outlined. The chapter concludes with a presentation of the outputs of the exercises and details on how they answer and address relevant research questions and objectives.

The impact of early supply chain design on ENPD outputs was assessed through controlled experiments in the form of component selection exercises. Based on an existent company and product, the exercises were developed specifically for this purpose; 16 carefully selected participants assumed the role of product designer and undertook the exercises. During the exercises, the participants were required to utilise varying degrees of information to make informed decisions regarding the integration of environmental consideration in the selection of components for the re-design of a cookerhood. Of particular interest was the impact that knowing supplier-specific information had on the final product's cost, environmental performance and supply chain greenness. Qualitative data related to the processes the designers' adopted and quantitative data relating to the final components selected for the re-design of the product was collected and analysed through content analysis, and descriptive and inferential statistics respectively. Process vignettes were used to discuss the results of the exercises, inferences were made and implications results were outlined. The chapter concludes a list of proposed tools that have the potential to be beneficial to 3DCE-based approaches to ENPD.

7. Discussion of Research Findings, Research Outputs and Project Evaluation

Chapter Overview

This chapter opens with a discussion of the findings of the research project and their implications on practice which culminates with the presentation of a matrix based on the levels within the study which contains the main research findings. Following that, various support mechanisms for 3DCE-based approaches to ENPD and a method to ENPD based on the 3DCE approach are presented. The support mechanisms are in the form of tools and recommendations that aim to provide assistance and support when 3DCE-based approaches are adopted for the implementation of ENPD. The 3DCE-based method for ENPD is presented the form of a framework, and is based on the use and availability of supplier-specific information during the ENPD process. The chapter concludes with an evaluation of the research methods used in the project. The aim of this section is to make a case for the quality and validity of the research findings, outputs and conclusions that have been presented and to address assumptions, limitations and delimitations of the project.

Highlighted Contents

After adopting the new product development process as the unit of analysis, through the multi-case study (Chapter 5) and controlled experiments (Chapter 6), a wide range of findings and insights were gleaned. These are discussed in this section, along with their implications and where appropriate, they are reviewed in the context of the literature and existing knowledge on the subject. These findings were combined in an attempt to fulfil the following research objectives:

> *RO2: Develop a method, based on 3DCE and with a supply chain focus, which can be utilised during the environmental new product development process.*
>
> *RO4: Make recommendations to support and improve how the supply chain is utilised during the ENPD process.*

7.1 Key Findings and Insights from Multi-Case Study and Controlled Experiments their Implications

Insights and outputs from the multi-case study (Chapter 5) and the controlled experiments (Chapter 6) are presented in this section, along with their implications and where appropriate, they are reviewed in the context of the literature and existing knowledge on the subject.

7.1.1 Product Designers' use of Information

The participants, who had limited knowledge of eco-design, felt more comfortable and confident when they felt they had all the information they required to make informed environmental decisions. When they did not, they opted not to change anything. A 'normal designer' might be able to get the same result as an eco-designer as long as they are provided with all the relevant information. In some cases, this might negate the need to understand and complex eco-design principles and tools. Tools for eco-design typically do not achieve industry penetration because they are too qualitative/subjective to be used by designers with limited experience, or too quantitative, costly and time consuming and do not allow for easy integration with traditional design tools (Sakao *et al.*, 2008; Boks, 2006). Using supplier-specific information could be a practical solution for day-to-day in design and engineering departments by 'normal designers' looking to integrate environmental considerations into their ENPD process.

However, it is important to ensure that they have the relevant information otherwise they will be reluctant to make a decision. Participants' reluctance to make decisions when they perceived that they lacked information is in line with research findings from business intelligence firm QlikTech. They found that 42% of global business leaders don't have confidence in decisions made due to a lack of information (Green, 2013). Even if they knew that they could ask for extra information, participants did not ask for information that they thought would have allowed them to make better-informed environmental decisions because they were not sure what would be available to them, so they didn't bother asking.

In the current industry practice, information is not pushed to designers. This means that to fully utilise the potential that lies within using supplier-specific information during the ENPD process designers need to proactively pull out the information that they require. Lack of information leads to poor decision making. To pull out information, designers need to know what information is available to them. The use of a supplier-specific information database mitigates this need to pull out information.

7.1.2 Product Designers' use of Supplier-Specific Information

Supplier-specific information (product performance, product cost and supplier information, where supplier information details attributes particular to the supplier such as location, transport details, EMS results etc.) allows designers to consider not just the environmental attributes of the product but also of the suppliers of its components. Participants who were given the most amount of information (performance, cost and supplier information), made the least assumptions and carried out the component selection exercises in a consistent manner in terms of how they made decisions and the results they got.

Typically within ENPD, the three key objectives that are typically used for decision making are product performance, product cost, development cost, development speed, and product environmental performance (Kaebernick *et al.*, 2003). However, it is important to ensure that the product environmental performance includes not only the environmental aspects of the product but also of its supply chain. This can be achieved through the use of supplier-specific information. To do this, designers need to effectively take into consideration, not only the environmental information relating to the technical performance of components and materials, they also need to consider the profiles and environmental activities of the suppliers of themselves when they determine the environmental performance. This adds a new level of complexity to the environmental performance objective.

With the added information that designers have to work with, it is important to make sure that the designers are not overwhelmed by the information and that they can utilise it to its fullest potential by effectively handling trade-offs. Trade-offs are necessary when choices have to be made between different alternatives, however, it is difficult to foresee potential winners or losers in trade-off situations. Participants with the supplier-specific information (cost, performance and supplier information) found having to consider more than two factors (cost and performance) at a time challenging. The Cost per % PEP derived unit was developed to help designers determine how the product's environmental performance affects the cost. Cost per % PEP is calculated by taking into consideration the cost, performance (technical and environmental) and supplier information (technical and environmental) and is a way of relating all the objectives of interest to each other (See Section 7.2.1).

In their study on environmental information, Elarndsson and Tillman (2009) make two main distinctions regarding the use of EI: (1) whether the information is for internal or external use and (2) whether the information pertains to the company and production or to products and services. By using supplier-specific information, the product designers have to evaluate both product related information and company related information; this means that they evaluate information that pertains to both the company and internal production, and to products and services. However, because of the supplier focus, they are using considering information that is typically internal to the suppliers. In the presence of richer supply chain information, product designers will be able to make better-informed decisions regarding the products they design and the suppliers they use. As they specify material and component suppliers during the product design and development phase of the product development process they start to engage in early supply chain design, not just supply chain design but green supply chain design.

For a while, mainly through the use of standardised questionnaires (Andersen and Choong, 1997; Brink *et al.*, 1998), supply chain management has been seen as a vehicle for moving environmental information through the supply chain to product designers (Sarkis *et al.*, 1995; Nagel, 1998). This utilisation of supply chain management practices can be extended through the use of EMSs. The information that is typically found in a EMS system (e.g. location, waste management, raw material use etc.) is the type of supplier-specific information that can enhance the ENPD process. Supply chain departments that practice green supply chain management typically evaluate their suppliers based on environmental criteria and have a requirement that suppliers develop and maintain some form of EMS (Zhu *et al.*, 2012; Zhu *et al.*, 2005; Large and Thomsen, 2011; Min and Galle, 2001). Within the case companies, C005 had exemplary green supply chain management practices. It not only aims to have all eighty of its production bases adopt EMSs but also to have its suppliers do the same and encourage their suppliers to do the same as well. Additionally, it has a number of internal and external guidelines that are support various environmental initiatives.

Supply chain departments that practice green supply chain management can make the information in their EMS available to product designers. This information can be synchronised with the supplier-specific information databases, allowing product designers to use that information during the design and development phase of the ENPD process. Through this, along with technical and environmental product information, the product designers can also consider the environmental profile of suppliers of products. As is evidenced by most of the case companies, organisations are already trying to act in more environmentally conscious ways by adopting EMSs; within these they also assess the impacts and profiles of their suppliers. EMS can be more than an organisational-level tool, it can also be applied to the product design and development phase of the ENPD process. While its use is not without its challenges, the controlled experiments showed that product designers are able to exploit supplier-specific information for the benefit of ENPD objectives.

7.1.3 *Roles of Supply Chain and Design Functions during ENPD*

The procurement function can actively support the design function during the design and development phase by consolidating the company's product design- and supply-based supply-side interactions (See Figure 43). In this case 'supply-side interactions' is used to denote interactions with suppliers. If procurement is involved in NPD early, it can take on the role of managing all supplier interactions. In addition to their typical role that includes sourcing activities, negotiation and strategic selection of goods and services that are usually of importance to an organisation (Chopra and Meindl, 2007), procurement can monitor supplier markets for technological developments, gather new information on products that are being developed, find alternative components that can result in a higher quality of the final product and pre-select suppliers who satisfy supply-related requirements. It is through this these latter activities that the procurement function can support the design function during ENPD. Through the cultivation of relationships that procurement has with the supply market, headway can be made in attaining both supply and design objectives. As procurement takes control of the majority of interactions with the supply chain it is essential that they do not do so at the neglect of product design issues. It is important that they employ cross-functional teams that include engineers to ensure that technical considerations are an integral part of the interactions resulting in outputs that are of great use to R&D. Additionally, procurement can be in a better position to facilitate the integration of suppliers into the product development process and manage any supplier development as they already have contact with the suppliers.

If they are provided with supplier-specific information, through preliminary supplier selection designers are capable of early supply chain design during the product design and development phase of the product development process. When product designers undertake early supply chain design, the procurement function gets more time to explore and identify opportunities in the supply chain, negotiate with suppliers, finalise supply conditions etc. On the other hand, the product designers are able to use supplier-specific information in the environmental assessments they carry out as they integrate environmental considerations into the design process. The collaboration between the two departments is mutually beneficial and improves the company's process of developing products.

7.1.4 *Dynamics of Supply Chain Information Sharing and Supply Chain Mapping*

In a world that is increasingly interdependent, what happens to one supplier can have ripple effects onto an entire multinational company. Through supply chain mapping visibility of a multi-tier supply chain can be gained allowing for information to be collected. Requesting information directly from the source for ENPD can have the added benefit of fostering improved environmental awareness on the part of the supplier. Additionally, direct source information enables comparison of suppliers based on their environmental performance, and the environmental performance of the products they provide. Information sharing is not without its challenges; these can be categorised as related to: willingness to share; availability or information technology. The type of environmental information from suppliers that is beneficial to ENPD is one that is classed as typically being for internal use (Erlandsson and Tillman, 2009); this is information such as LCA results and documented processes in environmental management systems. Requesting information that is typically for internal use as an external party is a barrier to attaining the information. Just because a company understands the value of information sharing, and wants its suppliers to share information more freely, does not mean that it would be open to sharing information their own information. While C001 expressed a desire to have its suppliers share more environmental information, it was reticent to do the same unless if the environmental information showed that their products were competitive compared to other offerings on the competitors.

Information sharing behaviours surrounding environmental sustainability can be split into two. Large enterprises openly publish more information regarding the environmental performance of their products. While SME's are typically reluctant to disclose too much information regarding the environmental performance of their products. Companies are typically reluctant to share information with their supply chain partners due to an unequal distribution of risks, costs, and benefits among the partners. The information shared will usually benefit the recipient, yet the provider will incur the majority of costs. Reluctance to share information also arises due to the risk of it being divulged to competitors or used for opportunistic bargaining. These are all factors that were encountered relating to information sharing across the cases. For example, despite being a large organisation C006, find that their size does not always put them in the position of power. Typically, the power distribution is determined by influence as suggested by Erlandsson and Tillman (2009). By understanding the buyer-supplier relationships they have, C006 can anticipate what the attitude of the supplier will be and how best to deal with them.

Even with suppliers willing to share information, they might not be in a position to due to lack of resources to search for information or lack of existence of the information. This is particularly true for SMEs, as they tend to lack the resources that allow them to acquire information and share it, particularly as investment is required. This can be seen in the SMEs within C006's supply chain and also in C001 who primarily share information using data sheets. In some cases, information is not shared outright as it might not be deemed as pertinent and in others it is shared if asked for. Whatever the scenario, it is important to continually make information requests. As suppliers get more requests for information, the more likely they are to take the necessary measures to acquire that information. With companies like C002 willing to pay more for quality, it can be posited that the same tactics can be employed regarding environmental information; companies can pay more to get components that are supplied with environmental information or they can specify to suppliers that it is a requirement that they provide environmental information related to the products that they purchase. If consumers are expected to be willing to pay more for sustainable products, notion still under debate, then companies too should be willing to pay more. While there is evidence that consumers are willing to pay more for green products up to a point (Miremadi et al, 2012, Nielsen, 2015), some studies have found that it is all an illusion and when it comes down to it, consumers are not willing to pay (Uhur, 2011).

Supply chain mapping is not a new process, however it is not thought to be as widely understood or developed as perhaps it could be (Roy, 2011). Supply chain mapping was a relatively new concept to most of the case companies. C001 and C002 do not practice any form of supply chain mapping, while C003 turned to supply chain mapping after failing to detect risks within the supply chain and C004 after unknowingly violating trade restrictions. Due to a need to adhere to REACH requirements, C006 strategically maps its supply chain by focusing on critical points. While there are compelling reasons to produce strategic supply chain maps, there are some concerns that firms must address before publishing such a map, either internally or externally. These risks include giving away competitive information, changing the chain dynamics, getting lost in too many details, and providing an ineffective perspective for management use (Farris, 2010; Gardner and Cooper, 2003). In the case of C006, it found itself having to address some of these issues because its supply chain was too big to fully map out, today it maps only specific parts that are of strategic importance. This shows that the form that supply chain mapping should be intrinsically linked to the purpose of mapping. Supply chain mapping is a valuable tool that helps companies understand and have information on the suppliers they buy directly from and those companies who indirectly contribute components or services across the extended supply chain. This is particularly beneficial for companies that practice ENPD as they have to have an understanding of the lifecycle impacts of their products.

7.1.5 Use of Information Technology and Industry Consolidation

The use of IT and practicing supply chain mapping also aid in attaining visibility, which is essential to supply chain information sharing. Four out of six of the case companies, the ENPD organisations, use IT for supply chain information sharing, and the ones that don't are considering it. Many managers define and manage information sharing as a technology issue (Cachon and Fisher, 2000; Chatfield *et al.*, 2004; Robinson *et al.*, 2005; Lee, 2000; Zhang, 2002; Frohlich, 2002; Fiala, 2005); C003 in particular took the same view and was looking to rely on the power of technological innovation to drive collaboration.

However, there is a misperception regarding the valid nature of information sharing capability. This results in technology being purchased and sold as the solution to a company's information sharing deficiencies. Regardless of this, for many companies, the sought after information sharing capabilities and higher levels of cross-enterprise collaboration never materialise (Fawcett and Magnan, 2001). In the case of C006, they found that some of their suppliers, the SME's, did not have the capacity to dedicate resources to information sharing. When it came to information sharing, C001's biggest concern with sharing information through emerging information sharing technologies such as databases is that the users of the information will use it to unjustly compare them against their competitors, especially if they focus mainly on price comparisons.

Technology alone is not the solution to information sharing. In their study, Fawcett et al (2007) found that there are some companies that manage to have more success with supply chain information sharing. These are the companies who have sharing embedded in organisational cultures; communication augments investments in technology to create better relationships and raise the level of information sharing. C004 and C005 are such companies. When it comes to managing its suppliers, C005 is proactive and views open communication as essential. Purchasing managers and officers have regular contact with suppliers; this occurs through supplier meetings, supplier conferences, quality audits, visits to suppliers etc. To ensure the reliability of data coming in from the supply chain and improve its mechanisms for environmental management, C005 have their data verified by a third party. Through these interactions, C005 amasses a vast amount of information. It employs the use of business enterprise software to facilitate supply chain information sharing. And has found that when making information requests to suppliers it is essential to assure the supplier that any confidential information will be handled accordingly. To promote information sharing across their supply base, C005 shares information pertaining to itself freely with its suppliers, including information relating to the environmental performance of its products. Additionally, to promote environmental information transmission, C005 extend beyond their direct suppliers and make requests to their second and third tier suppliers that they also adopt their 'green procurement guidelines.' To help Japanese suppliers become more internationally competitive and to boost its ability to respond to sudden changes in market conditions, C005 started an air conditioning purchasing cooperation association. Through the association, it promotes information sharing among suppliers so that they can build among them a relationship of mutual benefit and growth.

While information sharing has countless benefits, it is important to understand the risks that are inherent in the practice and the consequences of providing accidental but harmful access to corporate information. Information sharing is not always beneficial to some supply chain entities due to high adoption cost of joining the inter-organisational information system, expensive technology investment, personnel training, lack of mutual trust (Cohen, 2000; Swaminathan *et al.*, 1997) etc. Evidence of these barriers to information sharing were found throughout the multi-case study. The practice of sharing information is inherently contradictory, it is essential that companies share information however, there are risks associated with sharing that need to be mitigated. To address information risk in the supply chain, organisations should adopt robust, scalable and repeatable processes that allow them to obtain assurance proportional to the risk faced. Supply chain information risk management should be embedded within existing procurement processes; it becomes part of regular business operations.

(Durbin, 2014) posits that there are three key reasons that organisations may find that they are vulnerable due to information sharing across their supply chain: lack of awareness of sensitive information being shared in contracts; too many contracts to assess individually; and lack of visibility and controls as information is shared in the supply chain. Some organisation focus on the first reason and assess the information risk of each contract, however, this is not scalable for organisations with a large number of contract and therefore is not scalable. Arguably the most challenging, the third vulnerability is more complex to address as typically organisations have no relationships with their suppliers' suppliers, increasing the risk as visibility and influence decrease upstream.

An example of a robust, scalable and repeatable process that can be used to mitigate supply chain information sharing risk is the Supply Chain Information Risk Assurance Process (SCIRAP) developed by the Information Security Forum. SCIRAP is an approach that helps organisations manage information risk across their supplier base by focusing on identifying information shared in the supply chain and the contracts that create the highest risk – it provides a scalable way to manage contracts so that efforts are proportionate to the risk.

As evidenced by companies such as C005, it is possible to mitigate some of the risks of supply chain information sharing through developing trust based alliances with suppliers. It is essential for goodwill, contractual and competence trust (Sako, 1992) to develop between the sharing parties. One such way of building trust-based alliances is through the adoption of law binding documents such as contracts. In the context of agency theory, such agreements can be seen as a mechanism intended to provide protection against moral hazard, however, Fraser et al (2003) found that agreements and contracts are seen more as a basis for trust based partnerships rather than as a mechanism to guard against mistrust and opportunism. When contracts are drawn up, it is essential that legal representation and technical, financial and management personnel from both sides are present and that the relevant aspects of the agreements then are communicated to project team members.

Like C003 and C004, companies can outsource their supply chain mapping to an enterprise software vendor that maps supply chains through the use of cascading invitations that are sent to suppliers and from suppliers' suppliers ad infinitum, helping to gather comprehensive information about the supply chain and supplier compliance within it.

7.1.6 Adopting A 3DCE- Based Approach

Adopting a 3DCE-cased approach to ENPD has implications on: how the product designers design the products; how the organisational functions work together, in particular the role of the procurement function within the development process; and how the organisation interacts and utilises its external supply chain. The most requested information during the controlled experiments was related to manufacturing and materials. The request for manufacturing and materials information is testament to how traditional concurrent engineering principles (simultaneous design of process and product) are already embedded into the designer's processes, however there is a need to bring supply chain design to the same level through 3DCE based approaches.

Although C001 and C002 were both prospective ENPD companies, their profiles were different. C002's supply chain function (or team) already worked closely with it's both design function and the external supply chain, the situation within C001 differed. The differences between the organisations that are looking to practice ENPD show that there are likely to be variations in the starting positions of companies looking to implement ENPD and it is important for an organisation to have awareness of their current state so they know exactly what they need to do in order to increase the likelihood of success. This ties in with the work of Buckingham et al (2014), who posits that when implementing ENPD it is important to understand the business context. Those organisations that have the supply chain function (particularly procurement) already supporting the product development process and working closely with suppliers are in a better position to adopt 3DCE based approaches that those who do not.

Product development time is reduced when the procurement function consolidates supply-side interactions and the design function practices preliminary supplier selection. This is because the back-and-forth between the internal and external functions and that between the design and procurement functions is reduced. While product designers can influence the product cost and product performance (technical and environmental), it is through the collaboration of the internal design and procurement functions that the development cost and time can be reduced. Consolidating supply-side interactions and having the design function practice preliminary supplier selection enables in early supply chain design and reduces the time and effort expended during the product development process by shortening the product design and development phase. This puts companies that adopt in 3-DCE based approaches to ENPD in the E-3DCE section of the trade-off model shown in Figure 13.

7.1.7 Main Research Findings Across Study Levels

The main research findings of this study are presented in a digestible from in Table 112; the table takes the form of a 3x3 matrix whose rows and columns are based on the product development and organisational levels outlined in Section 3.2 with the findings populating the appropriate cells.

TABLE 112: 3X3 MATRIX OF MAIN FINDINGS BASED ON PRODUCT DEVELOPMENT AND ORGANISATIONAL LEVELS

	PHASE	PROCESS	ORGANISATION
STRATEGIC		A. When transitioning to ENPD, environmental and supply chain considerations should be an integral part of the product design and be aligned with company strategy (5.5.2). B. Organisations that already have the procurement function supporting the PDP are in a better position to adopt a 3DCE-based approach to ENPD (5.5.2).	C. Companies are reluctant to share information due to unequal distribution of risks, costs and benefits (5.5.2).
TACTICAL	D. Supply-side interaction consolidation and design practicing preliminary supplier selection enable early supply chain design and shorten the product design and development phase (5.5.2). E. Cost per % PEP derived unit can help designers determine how a product's environmental performance affects the cost (6.9) F. Providing supplier-specific information to the designers through a supplier-specific database pushes the information that is required for ENPD to designers negating the need for them to pull it out (6.8).	G. The supply chain department can support the product development process by having all supply-side interactions consolidated and managed by the procurement function as they have the necessary expertise (5.2.2). H. The information that is typically found in an EMS system is the type of supplier-specific information that can enhance the ENPD process (Section 6.5). I. The procurement function should be involved early in the ENPD process as part of a cross-functional team to ensure adequate flow of supplier-specific information from the supply chain to the designers (5.5.2). J. The availability of supplier specific information during the design process allows designers to consider not just the environmental attributes of the product but also the suppliers of its components (6.8). K. Designers are able to adequately exploit supplier specific information for the benefit of ENPD objectives (6.8).	L. Supply chain information sharing can be aided by adopting an open approach and cultivating supplier relations for the attainment of mutual benefits through relationship-based supplier collaboration and strategic supplier relationship management (5.5.2). M. Information sharing behaviours surrounding environmental sustainability can typically be split into large organisations that possess the resources required to attain PEP information and publish it openly and SMEs who do not and thus do not share (5.5.2). N. Requesting ENPD information directly from the source can have the added benefit of fostering improved environmental awareness (5.5.2). O. Supply chain mapping can be improved for the benefit of information sharing by being intrinsically linked to the purpose of its undertaking, for ENPD this is gaining an understanding of a product's lifecycle impacts (5.5.2). P. To manage the risk inherent in information sharing, organisations should adopt robust, scalable and repeatable processes that allow them to obtain assurance proportional to the risks (5.5.2). Q. Use of IT and consolidating information sharing and supply chain mapping efforts across the industry can be used to address some of the challenges (5.5.2).

OPERATIONAL	R. Supply chain design considerations are not as embedded into designers' decision-making processes as much as product and process design considerations (6.8). S. Designers are able to practice early supply chain design by undertaking preliminary supplier selection during the design process and using supplier-specific information in their environmental considerations (6.8). T. Using of supplier specific information, designers make the least assumptions and more consistent decisions during the ENPD process (6.8). U. 'Normal' designers might be able to attain the same results as eco-designers if provided with the relevant information required to make informed decisions (6.8). V. 'Normal' designers can design products with improved product environmental performance and supply chain greenness using supplier specific information (6.8).	W. To aid early supply chain design, it is important that designers are adequately trained in supplier selection and supply chain design principles and supported by the supply department (5.5.2).	X. Information sharing challenges are typically related to willingness to share, availability of information and information technology (5.5.2). Y. Organisations have awareness of their tier 1 suppliers, beyond that the levels of awareness vary as they typically do not have relationships with suppliers past the first tier due to visibility and influence decreasing upstream (5.5.2). Z. The practice of multi-sourcing increases the complexity of supply chain mapping, making whole supply chains too complex to map (5.5.2).
	PHASE	PROCESS	ORGANISATION

7.2 Support Mechanisms

The 3DCE-based approach to ENPD holds promise in not only integrating environmental considerations into the product development process but also in reducing the product development cycle time. To aid in its successful implementation and adoption, various mechanisms were developed to support it. The support mechanisms come in the form of tools, insights and recommendations that address 3DCE and ENPD issues across all organisational levels and are detailed in Table 113.

TABLE 113: MECHANISMS TO SUPPORT 3DCE BASED APPROACHS TO ENPD

Organisational Level	Support Mechanism	Description
Operational	Cost per % PEP Derived Unit	A unit used to quantify the product environmental performance of products within a set relative to cost and each other; a way of quantifying the environmental of performance a set of alternative design solutions and relating it to cost.
Tactical	Procurement Involvement in ENPD Maturity Model	A process maturity model of procurement involvement in ENPD that serves as an audit tool to assess and guide how procurement is involved in and supports design during ENPD.
Strategic	Guidelines for Supply chain Mapping Focusing on Information Sharing	A list of issues to consider when practicing supply chain mapping for information sharing that are used to guide the process and as a check to assess if typical problems have been addressed.
Operational, Tactical and Strategic	Key Recommendations	A list of recommendations that address various issues that arise when a 3DCE-based approach to ENPD is adopted and the supply chain is integrated into the environmental product development process.

7.2.1 Cost per % PEP Derived Unit

The Cost per % PEP is a derived unit that expresses how much a product will cost when its environmental performance is evaluated relative to the product being improved or alternative designs being put forward. The value of Cost per % PEP is attained by dividing the forecast cost of a product by the product's PEP score relative to the existing product or alternatives.

The Cost per % PEP can be calculated when incremental product development takes place as a base product's environmental performance is improved through the integrations of environmental considerations into the product development process.

The process of calculating the Cost per % PEP is as follows:

	Process Steps	Example
Step 1	Conduct a LCA of the base design	
Step 2	To streamline the analysis, quantify the components, materials and processes that have the highest environmental impacts throughout the lifecycle of the products	Largest impacts are X (10%), Y (30%) and Z (40%) which equal 80%, therefore: 0.1X + 0.3Y + 0.4Z = 0.8 total product impact
Step 3	Assume that these represent 100% of the impacts and calculate how much each of the included components, materials or processes contribute to environmental impacts relative to the new assumed total	0.125X + 0.375Y + 0.5Z = total product impact

STEP 4	Create alternative designs by replacing the highest impacting components, materials or process with those that have better environmental performance without compromising technical performance	Base Design = $X_0+Y_0+Z_0$ Design 1 = $X_1+Y_1+Z_1$ Design 2 = $X_2+Y_1+Z_2$ Design 3 = $X_2+Y_2+Z_2$
STEP 5	Isolate the components, materials or components with the lowest environmental impacts and assign those a "relative efficiency" score of 100% and calculate the relative % scores of the others	X_0 = 4 = 40%, X_1 = 10 = 100%, X_2 = 7 = 70% Y_0 = 2 = 40%, Y_1 = 5 = 100%, Y_2 = 4 = 80% Z_0 = 5 = 50%, Z_1 = 7 = 70%, Z_2 = 10 = 100%
STEP 6	Convert the relative efficiency score into an 'environmental performance' score	X_0 = 0.4, X_1 = 1, X_2 = 0.7 Y_0 = 0.4, Y_1 = 1, Y_2 = 0.8 Z_0 = 0.5, Z_1 = 0.7, Z_2 = 1
STEP 7	Multiply the environmental performance score by the % it contributes to the total and add them all up to get PEP score	Base Design = 0.125x0.4 + 0.375x0.4 + 0.5x0.5 = 0.45 = 45% Design 1 = 0.9 = 90% Design 2 = 0.96 = 96% Design 3 = 0.89 = 89%
STEP 8	Add up the cost of the components in the to get the total cost	Base Design = £2 + £5 + £4 = £9 Design 1 = £5 + £9 + £5 = £19 Design 2 = £3 + £9 + £5 = £17 Design 3 = £3 + £8 + £5 = £16
STEP 9	Divide the cost by the PEP score as a percentage to get the Cost per % PEP value	Base Design = £0.20 per % PEP Design 1 = £0.21 per % PEP Design 2 = £0.18 per % PEP Design 3 = £0.18 per % PEP

The example shown is fictional and has been included to illustrate the process; Chapter 6 contains a worked example of the Cost per % PEP, based on a real product, being used to evaluate alternative design solutions.

For the Cost PEP per % PEP to be calculates, the following conditions have to be met:

- There is a base product (incremental product design)
- Results of LCA of base product are available
- A set of alternative new designs is developed

The derived unit of Cost per PEP is useful for evaluating alternative design solutions when ENPD is undertaken; it allows the designer to quantifying the cost of environmental improvements. Product development is about making trade-offs and within ENPD, the following five design objectives have to be balanced out: product performance, product cost, development cost, development speed, and product environmental performance (Kaebernick *et al.*, 2003). Development cost and development speed relate to the whole product development process, as opposed to the other three that mainly relate to the product design and development phase within that process, which is why they were not addressed within the exercises. When the cost associated with environmental performance is not separated from the cost related to technical performance, it is easy to sacrifice environmental performance to keep costs down. As a result, it is important to expand these objectives and have an understanding of the relationship between the environmental performance and the cost by determining the Cost per % PEP. The Cost per % PEP can be included in the design specification giving the designer a target to aim for; this means that an acceptable balance can be found between the two where you aim to attain the best ratio between PEP and cost. Cost per % PEP goes some way in addressing the common misconception, as was evident during the controlled experiments reported in Chapter 6, that integrating environmental considerations into a product is always expensive. While, it is true in some cases, it is not in others and it is important to understand the relative impact that environmental improvements will have on cost.

7.2.2 PROCUREMENT INVOLVEMENT IN ENPD MATURITY MODEL

Initially developed in the area of software development, maturity models have been widely applied as general models of the maturity of organisational processes. The use of a maturity model allows an organisation to have its methods and processes assessed according to management best-practice, against a clear set of external benchmarks. The term 'maturity' implies that the process is: well understood; supported by documentation and training; consistently applied in projects throughout the organisation; and is continually being improved by its users (Dooley *et al.*, 2001).

In the realm of product development, Fraser, Farrukh and Gregory (2003) devised the concept of collaboration maturity as a means of describing, in a few phrases, the characteristic behaviour exhibited by a firm at a number of levels of 'maturity' for key process areas in product development collaborations (Fraser *et al.*, 2003). Much in the same manner, involvement maturity was adopted here for describing the involvement of procurement in the product development process and a procurement involvement in ENPD model was created.

This model serves as an audit tool for assessment, and as a framework for improvement that can be utilised when 3DCE is being implemented as part of ENPD.

The procurement involvement in ENPD maturity model has the following three aspects:

- Process Maturity Levels – a 3-level process maturity continuum where the uppermost level is the ideal state of procurement involvement in ENPD.
- Key Process Areas – a cluster of related activities that, when performed together, form procurement involvement in product development.
- Features and Practices – characteristics and practices that contribute most effectively to the implementation of early-procurement involvement.

The process maturity levels are presented in Table 114, the key process areas in Table 115 and the features and practices in Table 116. At the lowest level, there is little collaboration between internal procurement and design function; however, moving up the levels procurement plays a bigger roles and takes control of most supply-side related interactions allowing design to focus on its core-capability of creating products while being supported by procurement who have expertise in dealing will supply-side issues.

The procurement involvement maturity model can be used in tandem with the framework for purchasing involvement in NPD that was created by Wysteria, et al. (2000). The framework specifies the activities that fall within the different process areas and is available in Appendix 7.1: Framework For Purchasing Involvement in Product Development. While both focus on the same levels and key process areas, the maturity model presented here mainly differs from the one presented by Wysteria, et al. in that it has a particular focus on ENPD and that it elaborates on the features and practices that relate to the procurement and design functions (the model by Wysteria, et al. only elaborates on the procurement function).

TABLE 114:LEVELS OF PROCESS MATURITY

	DESCRIPTION
LEVEL 1	No collaboration between procurement and design
LEVEL 2	External collaboration – procurement supports design in the management of supply-side interactions
LEVEL 3	Internal and external collaboration – procurement plays an integral part of design process and manages supply-side interactions

TABLE 115: KEY PROCESS AREAS FOR PROCUREMENT INVOLVEMENT IN PRODUCT DEVELOPMENT

DEVELOPMENT MANAGEMENT	Concerned with division of work between the manufacturer and suppliers in developing and maintaining technological knowledge.
SUPPLIER INTERFACE MANAGEMENT	Managing supplier relationships as a permanent and on-going activity.
PROJECT MANAGEMENT	Managing the undertaking of development projects.
PRODUCT MANAGEMENT	Related to activities that contribute to the design and determination of the specifications of products to be developed.

TABLE 116: FEATURES AND PRACTICES OF PROCUREMENT INVOLVEMENT IN PRODUCT DEVELOPMENT

LEVEL 1: NO COLLABORATION	
Procurement Function	*Design Function*
Not an active member of a cross-functional product development team Only involved in product development process after product design is complete Does not manage supplier involvement in product development Primary role is to procure materials specified by Design Conducts supply-based supply market research Collaboration with suppliers focused on cost, quality and delivery issues Supplier development based on supply issues Relationship management focused on supply issues	Conducts technology-based supply market research Carries out supplier selection based on technical capability, neglecting supply factors Collaboration with suppliers based on technical capability Manages supplier involvement in product development
LEVEL 2: EXTERNAL COLLABORATION	
Procurement Function	*Design Function*
Not an integral member of a cross-functional product development team Manages supplier involvement in product development Not involved early in product development process Procures materials specified by Design Conducts supply-based market research Collaboration with suppliers focused on design and supply issues Supplier development based on design and supply issues Relationship management focused on design and supply issues	Conducts technology-based supply market research Carries out supplier selection based on technical capability, neglecting supply factors Does not manage supplier relationships
LEVEL 3: INTERNAL AND EXTERNAL COLLABORATION	
Procurement Function	*Design Function*
An active and integral member of a cross-functional product development team Manages supplier involvement in product development Involved early in product development process Procures materials specified by Design Conducts supply-based and technology based supply market research Collaboration with suppliers focused on design and supply issues Supplier development based on design and supply issues Relationship management focused on design and supply issues Pre-selecting suppliers for design to collaborate with and use products from Providing supply-side information for Design to use	Selecting suppliers from list supplied by Procurement Vetted supply-side related information available during design process

7.2.3 *Guidelines for Supply Chain Mapping Focusing on Information Sharing*

The following is a list of issues to consider when practicing supply chain mapping to facilitate information sharing for ENPD purposes. These are used to guide the process and as a check to assess if typical requirements have been fulfilled:

- To fully understand the environmental impacts associated with the supply chain, practitioners should not rely on Tier 1 suppliers managing the lower ties, they should monitor each tier directly.
- Accurate supply chain mapping gives visibility that allows companies to direct information sharing efforts in your supply chain.
- An up-to-date supplier database is a prerequisite to building an accurate supply chain map.
- A 'cascading invitations' approach to mapping where the mapping is instigated by inviting Tier 1 suppliers to join the mapping process can be adopted; the Tier 1 suppliers pass the invite to Tier 2 suppliers and so on down through the tiers. The entity in the middle can link what they sell to whom and the details of what they buy to the next entity in the chain.
- Automation, through the use of enterprise software, allows companies to manage this process more effectively, especially with large supply chains.
- After the mapping activity focus can be put on attaining particularly relevant information regarding the members of the supply chain.
- Aim to have a map of the supply chain in its entirety or at the least that of high environmental impact contributors. This allows companies to assess which supplier manufacturing sites and products are the most exposed allowing them to become proactive in introducing counter measures to improve environmental impact of products.
- Suppliers' support is critical in mapping the supply chain. To incentivise suppliers into participating clearly explain the benefits. A major benefit is that suppliers will also be able to understand environmental impacts and risks in their own supply chains, allowing them to improve their environmental profile.
- Adopt a standardised approach to the management of the supplier information that you collect, an approach that can keep collected information secure.
- To mitigate supplier reluctance, ensure that there are measures in place and reassure suppliers that they can control who has access to their information and can maintain commercial confidentiality.
- Mitigate some of the risks of supply chain information sharing through developing trust based alliances with suppliers; one way of building trust-based alliances is through the use of contracts a basis for trust based partnerships rather than as a mechanism to guard against mistrust and opportunism.
- Mapping a supply chain can be a complex, time consuming and labour intensive activity, making it a tiresome exercise for any individual company working in isolation. As most industries share suppliers, the most efficient and effective way to do it is by working within a collaborative community, where effort and cost are shared. Individual chains remain visible only to individual buyers, but the mapping effort is shared.

7.2.4 *Key Recommendations*

The following recommendations are made to support and improve how the supply chain is utilised during the ENPD process:

1. Align environmental and supply chain considerations with company strategy and make them an integral part of product design: during NPD design products around the supply chain.
2. Procurement and design should have a symbiotic relationship where procurement is involved in product design and design in involved in procurement activities; this can be achieved by having procurement engineers who sit between both functions.

3. Involve the procurement function early in the development process. Procurement should be an integral and active part of a cross-functional product development team, and support the development process by managing all supply-side interactions and ensuring that there is a flow of information from the supply chain to the designers.
4. With more supplier information coming into the product design process, ensure that designers are in a position to deal with that information in the manner that results in environmental considerations being successfully integrated into the development process, this can be achieved by training the designers in eco-design methods and practices.
5. Adopt an open approach to sharing information across the organisation and with suppliers and work on cultivating supplier relationships for the attainment of mutual benefits, this will create an openness culture that results in higher levels of information sharing.
6. To mitigate the risks associated with information sharing, and to avoid the negative consequences of providing accidental but harmful access to corporate information, ensure that supply chain information risk management is embedded into organisational practice through robust, scalable and repeatable processes that organisation to obtain assurances proportional to the risks faces such as non-disclosure and partnership agreements.
7. Use IT for supply chain information sharing and work towards industry consolidation of the practice.
8. Use IT for supply chain mapping, and if the supply chain is too large and complex consider outsourcing the activity to business enterprise software companies that offer the service.

7.3 Supplier-Specific Information in ENPD Framework

A method to ENPD based on the 3DCE approach presented in Section 3.2.1 was created. This method takes the form of a framework and is based on the conceptual framework (See Section 3.2) and findings from literature (See Section 2.2). It is informed by: the analysis of existing available approaches, supports, industry practices, drivers and requirements relevant to ENPD in industry; the identification of the criteria necessary to include in industry approaches to effectively support the utilisation of the supply chain during integration of environmental considerations into the product development process; and assessment of the ability of existing approaches to meet the criteria and the gaps remaining.

The framework consists of a general guide to the use and attainment of supplier-specific information in the ENPD process and a tool kit of suitable supports. It is designed to be used in conjunction with other strategies and approaches to ENPD. While many tools have been developed in order to achieve the eco-design objective, most tools do not utilise the supply chain sufficiently nor explicitly. There is a strong need for a method that facilitates the integration of reasonable environmental considerations into the product development process through the use of the supply chain. The aim of the supplier-specific information for ENPD framework is to facilitate the availability and use of supplier-specific information for product environmental performance assessments and product re-design making the most of supply chain collaboration.

7.3.1 Process Guide

The guide to utilising supplier-specific information in the ENPD process is presented through Figure 57, which gives an overview of the process and Figure 58 (presented below) which focuses on the steps during the product design and development phase of the ENPD process. After sourcing suppliers, through supply chain mapping for information sharing, the procurement function collects information from the supply network regarding the suppliers themselves, the products they are providing and the supply chains of those products. This results in supplier-specific information being available for product designers to use when they perform product environmental performance assessments during the design and development phase of the product development process. When selecting components and materials to use in their designs the designers also have to specify which suppliers will be providing the components and materials. This results in the designers undertaking preliminary supplier selection and early green supply chain design, as the suppliers are selected based on environmental considerations. The procurement function can then take the completed product supply chain map and use it as input when they finalise the suppliers to use when products are manufactured.

Figure 57 (presented below) is an evolution of the Proposed E-3DCE Process Model presented in the conceptual framework (Figure 24). The model outlines the process that is central to embedding early supply chain design into the ENPD process through preliminary supplier selection. While the central concepts within the process have remained the same, there have been some changes to the process model. Some of main changes and their influences are as follows:

- Processes and actors evolved into differentiated supply chain and product design related processes and actors. Through undertaking the both the multi-case study (Chapter 5) and the controlled experiments (Chapter 6), a greater understanding of the design and supply chain related processes and actors within the product development process was gained allowing for them to be differentiated.
- Solid arrows were added to highlight the main process of using supplier-specific information during the ENPD process and the main outputs. Through various supply chain related processes - starting with supplier sourcing - the supply chain related actors provide supplier-specific information to the product design related actors who, through various design related processes create a preliminary product supply chain map which can be used by the supply chain related actors to conduct the final supplier selection. The main finding that allowed for the addition of the arrows was the conclusion from the controlled experiments that product designers are able to use supplier-specific information to conduct preliminary supply chain design, this provided a bridge between the supply chain side and the product design side.
- More specific supply chain related processes such as supplier sourcing, preliminary supplier selection and supplier management were added. Through the case study a greater understanding of the various processes that the procurement function undertakes to support the product development process and how it interacts with the external supply network was gained, allowing for more specific processes to the outlined.
- The E-BOM was removed as on output and the supplier-specific database was added as a tool. While it is possible that the E-BOM can play a role in the ENPD process, the controlled experiments were able to simulate the ENPD process with supply chain design without its use. Conversely, not included in the original process, the supplier-specific information proved to be an invaluable part of the process as it allows for information from the supply side to be available to designers in a manner that is digestible.

Figure 58 (presented below) is an evolved combination of Figure 20 and Figure 21, the two figures combine to show the steps within the product design and development phase of the ENPD process. Additionally, arrows were added to highlight the supply function related processes that result in supplier-specific information that can be used to inform design related processes. For example, during the concept development step the supply function can produce supplier-specific information through preliminary supplier section, this information can then be provided to the design function for use in the evaluation of impact concepts. These iterations were made in accordance with the insights gained from undertaking the multi-case study (Chapter 5) and the controlled experiments (Chapter 6).

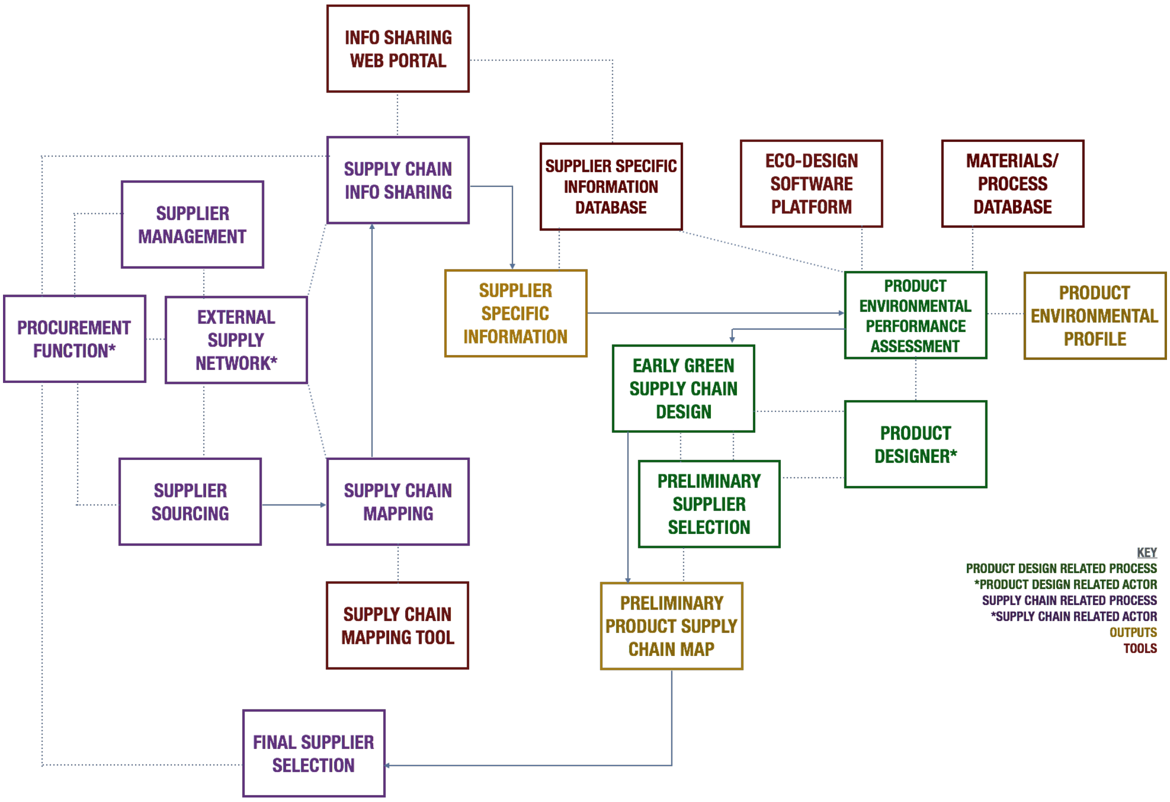


FIGURE 57: SUPPLIER-SPECIFIC INFORMATION FOR ENPD PROCESS (REVISED PROCESS MODEL FOR ENPD WITH EARLY SUPPLY CHAIN DESIGN PART OF CONCEPTUAL FRAMEWORK)

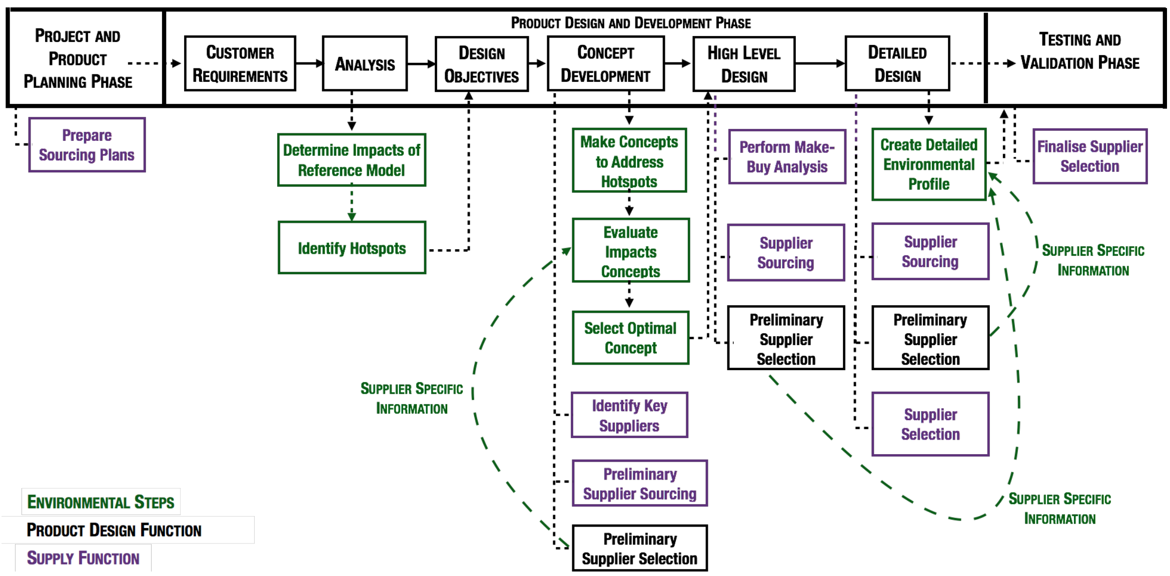


FIGURE 58: STEPS DURING PRODUCT DESIGN AND DEVELOPMENT PHASE OF ENPD (REVISED A 3DCE BASED APPROACH TO ENPD PART OF CONCEPTUAL FRAMEWORK)

7.3.2 *Toolkit*

The tool kit shown in Table 117 is made up of original tools that were proposed for specific use with 3DCE-based approaches to ENPD. As the aim of the research project was to explore and investigate the potential of a 3DCE-based approach to ENPD (See Section 3.4), the tools were proposed but not tested. These tools were proposed after an understanding of adopting a 3DCE-based approach to ENPD was established; further work can be carried out to test, iterate and validate the tools.

TABLE 117: SUPPLIER-SPECIFIC INFORMATION IN ENPD TOOL KIT

Tool	Used by	State	Details
Supplier-Specific Information Database	Design Function Procurement Function	Suggested; Concept used in Controlled Experiments	See Section 6.9
Cost per % PEP Derived Unit	Design Function	Developed; Concept used in Controlled Experiments	See Section 7.2.1
Procurement Involvement in ENPD Maturity Model	Management Function	Developed	See Section 7.2.2
Guidelines for Supply chain Mapping focusing on Information Sharing	Procurement Function	Developed	See Section 7.2.3
Web Based Supply Chain Information Sharing Portal for ENPD	Procurement Function Supply Network	Suggested	See Section 5.6
Key Recommendations	Management Function	Developed	See Section 7.2.4

7.4 Research Project Evaluation

To promote the use of 3DCE based approaches, make a case for the importance of supply chain involvement during the ENPD process and ensure that this research project has the desired impact on industrial practice; it is necessary to check the confidence in its findings, outputs and conclusions. The quality of a mixed methods study is directly dependent on the purpose for which the mixing of approaches was deemed necessary in that study (Teedlie and Tashakkori, 2009). As a mixed methods design was utilised in his study for completeness, to ensure that a complete picture of the phenomenon being investigated was obtained, it must therefore indeed provide a more complete understanding than its qualitative and quantitative strands can alone.

7.4.1 *Research Quality*

Distinction can be made of the research quality based on the research strand that it addresses. While there are overlapping standards between qualitative and quantitative quality, the two are mostly distinct; as a result, they will be addressed separately. Following that, to reconcile the two, the issues of quality will be addressed on a meta level.

Qualitative Quality

Indicators or audits of quantitative quality are matched to the factors that they address in Table 118.

TABLE 118: INDICATORS OR AUDITS OF QUALITATIVE QUALITY

Factor	Description	Indicator or Audit
Credibility	The accuracy and precision of the data. Also concerns the appropriateness of the data in terms of what is being researched.	There is an audit trail showing the connections between the data and interpretations (through the data, codes, and memos). The material is presented in a manner that allows other researchers to trace the original researcher's analysis and conclusions.
Confirmability	The quality of the results produced by an inquiry in terms of how well they are supported by informants involved in the study.	Member checks, where research participants checked data and interpretations were performed. One component selection exercise participant read and approved of the analysis outputs related to their exercise execution and one case study informant read and approved the case study report related to their case.
Dependability	Refers to the stability or consistency of the inquiry processes used over the project's duration.	Audit trail (see credibility).
Transferability	Refers to the applicability of findings in one context (where the research is done) to other contexts or settings (where the interpretations might be transferred).	There was purposive sampling to illustrate pertinent issues and factors when comparing two contexts and making judgements about similarities between cases. This is exemplified in the use of both students and professionals in the component selection exercises, the use of ENPD and prospective ENPD organisations in the case study, and the varying range of industries investigated.
Reliability	The stability of the findings.	Triangulation was employed as data was gathered from multiple sources (component selection exercises and case study) and using multiple data gathering tools (within the multi-case study).

Quantitative Quality

Indicators or audits of quantitative research quality in this research are matched to the factors that they address in Table 119.

TABLE 119: INDICATORS OR AUDITS OF QUANTITATIVE QUALITY

Factor	Description	Indicator or Audit
Internal Validity	Refers to correlation questions (cause and effect) and to the extent to which causal conclusions can be drawn.	Ensuring that the participants used in the experiments were as similar to each other as possible controlled for possibly confounding variables.
External Validity	The extent to which it is possible to generalise from data to a larger population or setting.	The participants used in the experiments had characteristics that closely matched designers in industry, especially having experience interacting with suppliers.
Construct Validity	Concerned with the measurement of abstract concepts and traits.	An eco-design expert, was consulted to check appropriateness of the experiment design to the problem being investigated.
Statistical Validity	The extent to which the study has made use of appropriate design and statistical methods that will allow it to detect effects that are present.	The statistical analysis was checked by MASH, an institutional mathematics resources centre, which offers help with maths and statistics problems at the University of Bath.
Content Validity	Associated with validating the content of the test.	The product and information used in the experiments was heavily based on a real-life product.
Reliability	Indication of consistency between two measures of the same thing.	The same experiment was carried out with all participants under identical conditions.

Mixed Methods Quality

The overall quality of a mixed methods study is dependent on the inference quality, an attribute of the meaning-making process and/or its outcomes, and data quality (an attribute of the inputs to the process of meaning making. Data quality refers to the accuracy and appropriateness of the collected data (Teddlie and Tashakkori, 2009); the findings and drawn conclusions are only as good as the data on which they are based (Punch, 2005). Inference quality is the term used to address validity claims and is defined as defined as how well the results can be trusted (Tashakkori and Teddle, 2003; Dellinger and Leech, 2007). The process of understanding in research consists of the following three distinct and inter-connected components:

- Data
- Results emerging from the systematic analysis of the data
- Interpretation of the results to gain an understanding of the phenomenon under study

Inference Quality

Inference quality is a combination of design quality, which can be defined as the extent to which the study adheres to best practice, and interpretive rigor, which is defined as how well the results can be trusted (Tashakkori and Teddle, 2003; Dellinger and Leech, 2007); this project aimed to produce quality based on the integrative framework for inference quality (Teddlie and Tashakkori, 2006, 2008).

Design Quality

Design quality refers to the degree to which the researcher utilised the most appropriate procedures for answering the research questions and implemented them effectively. Bergman (2008) posits that there are four basic standards for quality of research design and its implementation; these are as follows:

- Research Design Suitability – Was the method of study appropriate for answering the research questions?
- Research Design Adequacy – Were the components of the design implemented adequately?
- Within Design Consistency – Did the components of the deign fit together in a consistent and cohesive manner
- Analytic Adequacy – Are the data analysis techniques appropriate and adequate for answering the research questions?

Backed up by literature, the research questions and objectives were translated into elements of the research design. An effort was made to ensure that all the components of the research design fit together (See Section 4.2) and that adopted analysis strategies are appropriate and adequate enough to produce plausible findings and conclusions (Section 5.4 and Section 6.7).

Interpretive Rigor

Interpretive rigor is the degree to which credible interpretations have been made on the basis of obtained results (Tashakkori and Teddle, 2003). In order to assess such rigor, and improve the quality of inferences, the following five criteria or standards have to be met (Bergman, 2008):

- Interpretive Consistency – Does each conclusion closely follow the findings?
- Theoretical Consistency – Is each inference consistent with current theories in the academic field and/or with empirical finding of other studies?
- Interpretive Agreement –Would other scholars reach the same conclusions on the basis of the results from the study?
- Interpretive Distinctiveness –Is each conclusion distinctively different from other plausible conclusions regarding the same results?
- Integrative Efficacy – The degree to which inferences made in each strand of mixed methods study are effectively integrated into a theoretically consistent meta-inference.

Even with a strong and well-implemented procedure, it is plausible that one might fail to make credible and defensible inferences. To ensure that this was not the case within this research project, all inferences were made in a consistent manner in terms of type, scope and intensity and were consistent with literature around the appropriate and relevant subject areas. Care was taken to ensure that causal inferences were not made on the basis of correlation in quantitative data and that strong conclusions and recommendations were not made based on limited evidence. Using the same methods and data, researchers are likely to draw the same conclusions showing that the inferences made within this study are more plausible than any other conclusions that could be made on the basis of the same results. Elements of this research project were checked and accepted by other researchers, thus validating some of the inferences made. This includes through peer reviewed conference papers (See Publications Section), presenting and developing the research design at the Summer School on Engineering Design Research.

The technique of peer debriefing, a process where by a researcher calls upon a disinterested peer—a peer who is not involved in the research project—to aid in probing the researcher's thinking around all or parts of the research process, was employed. This was mainly done in relation to research design, methodology and data analysis elements of the research project with various academics with expertise in the fields of supply chain management, research design and methodology, and collaborative product development. This included Prof. Mike Lewis (University of Bath), Prof. Mogens Myrup Andreasen (Technical University of Denmark), Prof. Christian Weber Technische (Ilmenau University of Technology), Prof. Lucienne Blessing (Singapore University of Technology and Design), Prof. Janet McDonnell (University of the Arts London) and Dr. Ian Whitfield (University of Strathclyde).

Data Quality

Data quality is related to trustworthiness; trustworthiness is a global concept that indicates the quality of data through the collective use of four criteria – credibility, transferability, dependability and confirmability (Lincoln and Guba, 1985). For this study, the trustworthiness of the collected data is improved by prolonged engagement and the use of reflexive journalism.

Prolonged Engagement

Prolonged engagement allows the researcher to become more aware of multiple stakeholder perspectives and contextual factors that affect the topic being researched (Teddlie and Tashakkori, 2009). In the case of this project, prolonged engagement was attained through the following:

- In-depth analysis of relevant literature
- Experience working on a research project on implementing eco-design in industry
- Experience of researching supplier collaboration in new product development
- Experience of practicing supplier collaboration in new product development in industry
- Extensive contact with participants of the component selection exercises

Reflexive Journal

A reflective journal, which provides information for all four trustworthiness criteria, is a kind of diary in which the researcher on a daily basis, or as needed, records a variety of information relating to self and method (Lincoln and Guba, 1985). For the duration of this project, the researcher kept a number of project notebooks that contain notes, information on how decisions were made and details on the human instrument of the study; these notebooks act as reflexive journals for the research project.

7.4.2 Ethics and Professionalism

To uphold professional and ethical integrity, this research project was undertaken in accordance with the University of Bath's Institutional Code of Ethics. Informed consent was given by all involved participants; all data collected was handled in accordance with the Data Protection Act (1998) and where appropriate treated with the upmost confidence. In cases where the researcher was not sure about the ethical implications of certain actions, the Department of Mechanical Engineering's Ethical Officer was consulted. As a representative of the University of Bath whose behaviour is a reflection on the institution, the researcher exhibited professionalism when interacting and corresponding with both internal and external parties. Appendix 8.1: A Checklist for Ethical Issues was used to guide the process.

7.4.3 Delimitations, Limitations and Assumptions

Virtually all research projects have inherent flaws; the major influencing factors of a research project can be understood through its delimitations, limitations and assumptions. Delimitations refer to the characteristics that limit the scope and define the boundary of the study and are in the researchers control, limitations are potential weaknesses in the study that are out of the researchers control and assumptions are things that are accepted as true, or at least plausible (Simon, 2011).

Delimitations

The following are the delimitations that apply to this study:

- Study addresses ENPD on strategic, tactical and operational levels
- Focuses on implementing ENPD with supply chain involvement
- Case companies either practice ENPD or are actively looking to practice it
- Global case study companies
- Component selection exercises to simulate ENPD process
- Component selection exercise participant mechanical engineering students from the same university with industry experience

Limitations

The following are the limitations that apply to this study:

- Case studies are a snapshot in time
- Qualitative inferences are influenced by the researcher
- Component selection exercise outputs are only as good as exercise instrument
- Statistical analysis determines correlation and not causation

Assumptions

These are the assumptions that apply to this study:

- Informant and participant honesty
- Outputs are representative of population
- Research instruments were accurate
- Component selection exercise participants were not affected by observation
- Participants understood instructions

Chapter Summary

This chapter focuses on the outputs of the research work that was undertaken. It discusses the main findings and insights of the research study, along with their implications on practice and relation to literature. Following that, four mechanisms that were developed to support 3DCE-based approaches to ENPD are presented. These include a derived unit that relates costs to product environmental performance, a procurement involvement in ENPD maturity model, supply chain mapping for information sharing guidelines and a list of key recommendations. In addition, a framework for the use of supplier-specific information in ENPD and a 3DCE-based method that can be used in which environmental considerations are integrated into the product development process are detailed. The chapter concludes by evaluating the project and making a case for the overall quality of this research project by addressing issues relating to quantitative, qualitative and mixed method strands of the project. This is essential in instilling confidence in its findings, outputs and conclusions; on promoting supply chain involvement and the use of 3DCE-based approaches during the integration of environmental considerations into the product development process. Issues of ethics and professionalism were also addressed before the study's assumptions, limitations and delimitations were stated.

8. Conclusion

Today, no business operates in a vacuum unaffected by market forces; by their very nature business activities are competitive. Within a dynamic, rapidly changing business environment producers are constantly entering and leaving the market. Simultaneously, changing customer preferences provide signals for businesses to develop new strategies with different products and services; in this environment, some businesses will succeed by responding to and meeting market needs, while others may not perform as well.

With considerations for environmental sustainability at the forefront of societal concerns, driving both consumer preferences and corporate strategy, some organisations are enhancing their competitiveness through environmental new product development (ENPD) as they aim to create environmentally competitive product offerings. The ability to successfully integrate environmental considerations into the new product development process to can be anything from: the key to meeting trending market needs; a source of advantage over competitors; or the essential to survival.

Supported by concurrent engineering, three-dimensional concurrent engineering (3DCE) is a simple yet powerful concept of new product development (NPD) in which the traditional focus on an appropriate match between product and manufacturing process is augmented by an additional consideration of supply chain configuration. Adopting a cross-disciplinary perspective, this study contends that 3DCE-based approaches can be effectively used to more effectively integrate environmental considerations into the NPD process.

> *Research Aim: Explore and investigate the potential role and utilisation of the supply chain, through a 3DCE-based approach, during the integration of environmental considerations into the new product development process.*

While environmental concerns can be integrated into the NPD process without 3DCE, the added element of early supply chain consideration that is inherent in 3DCE is critical to the successful ENPD efforts. This is because the environmental performance of a product is the consolidation of its environmental impact through all the stages of its lifecycle, making it dependent on the supply chain. The aim of the project was defined based on the view that the synergy provided by 3DCE can aid in the successful integration of environmental considerations, allowing organisations to meet apparently conflicting goals of sustaining the environment while satisfying corporate profitability objectives and providing excellent new product performance.

Contributions to Knowledge

Adopting the new product development process as the unit of analysis, the research project took the form of a mixed-methods study with three distinct phases: the first, a multi-case study exploring the supply chain management and the NPD process; the second, controlled experiments exploring the impact of early supply chain design during ENPD; and the third, the development of research outputs based on the insights gained from the first two phases. Through the work carried out in those three phases, three research questions were answered and four research objectives addressed, resulting in the accomplishment of the research project's aim.

8.1.1 Research Questions

The research questions in this research project were devised such that their answers would feed into the fulfilment of the research objectives. The questions were answered by detailing what was found out, how it was found out and where appropriate linked to the 3x3 matrix of main findings in Table 112. Section 7.4.1 contains an evaluation of the quality of the research project where the confidence in the project's findings, outputs and conclusions was checked; this included validity, reliability, credibility, confirmability, design quality etc.

> *Research Question 1: When transitioning to a 3DCE-based approach to ENPD, (a) how should the supply department support the product development process and interact with the external supply chain, and (b) what changes are required in the way in which designers work?*

As evidenced by the ENPD practising case companies in the multi-case study, when transitioning to ENPD environmental and supply chain considerations should be an integral part of the product design and be aligned with company strategy (Finding A). As part of a cross-functional product development team, the supply chain department can support the product development process by having all supply side interactions consolidated and managed by the procurement function (Finding G). The procurement function should be involved early in the to ensure adequate flow of supplier-specific information from the supply chain to the designers (Finding I). It is those organisations that already have the procurement function supporting the product development process that are in a better position to adopt 3DCE-based approaches to ENPD (Finding B).

The controlled experiments showed that supply chain design considerations are not as embedded into the designers' decision-making processes as much as product and process design considerations (Finding R), however, when transitioning to a 3DCE based approach to ENPD, designers are able to practice early supply chain design by undertaking preliminary supplier selection during the design process and using supplier-specific information in their environmental considerations (Finding S). The availability of supplier specific information during the design process allows designers to consider not just the environmental attributes of the product but also the suppliers of its components (Finding J) and designers are able to adequately exploit it for the benefit of ENPD objectives (Finding K). However, to aid the preliminary supplier selection it is important that designers are adequately trained in supplier selection and supply chain design principles and supported by the supply department (Finding W). Providing the supplier-specific information to the designers in the form of a supplier-specific database pushes the information that is required for ENPD to designers negating the need for them to pull it out (Finding F). Through the use of supplier specific information, designers make the least assumptions and more consistent decisions during the ENPD process (Finding T). That the participants of the controlled experiments, with basic levels of eco-design principles, were able to design products with improved product environmental performance and supply chain greenness (Finding V) suggests that 'normal' designers might be able to attain the same results as eco-designers if they are provided with the relevant information they require to make informed decisions (Finding U).

RQ2: What are the challenges associated with supply chain information sharing and how can the practice be improved through the use of supply-based methods and relationships for the benefit of product development?

The information sharing challenges cited by the informants that took part in the multi-case study are typically related to willingness to share, availability of information and information technology (Finding X) as companies are reluctant to share information due to unequal distribution of risks, costs and benefits (Finding C). In particular, information sharing behaviours surrounding environmental sustainability can typically be split into two based on company size; large organisations tend to possess the resources required to attain product environmental performance information pertaining to their products and publish it openly while SMEs do not possess the resources to do so and thus do not share such information (Finding M). The procurement company case studies showed that supply chain information sharing can be aided by adopting an open approach and cultivating supplier relations for the attainment of mutual benefits through relationship-based supplier collaboration and strategic supplier relationship management (Finding L). To ensure that supplier-specific information flows from the supply chain to the designers, it is essential that *the procurement function manages supply side interactions, as they have the necessary expertise (Finding G). As was experienced by some of the case companies, requesting information directly from the source for ENPD can have the added benefit of fostering improved environmental awareness on the part of the supplier (Finding N). To manage the risk inherent in information sharing, organisations should adopt robust, scalable and repeatable processes that allow them to obtain assurance proportional to the risks they face (Finding P). Additionally, the widespread use of IT and attempts at consolidating supply information sharing efforts across the industry by the case companies can be used to address some of the challenges associated with supply chain information sharing (Finding Q).*

RQ3: What is the state of supply chain awareness in companies and how can it be improved for the benefit of supply chain information sharing?

As evidenced by the case companies, organisations have awareness of their tier 1 suppliers, beyond that the levels of awareness vary as they typically do not have relationships with suppliers past the first tier due to visibility and influence decreasing upstream (Finding Y). The practice of multi-sourcing also increases the complexity of supply chain mapping making whole supply chains too complex to map (Finding Z). Supply chain mapping can be improved for the benefit of information sharing by being intrinsically linked to the purpose of undertaking the exercise, in the case of ENPD this is gaining an understanding of the lifecycle impacts of products (Finding O). As with information sharing, the use of IT and industry consolidation can improve the practice of supply chain mapping (Finding Q).

8.1.2 Research Objectives

The research project had four objectives; this section will re-iterate the research objectives and outline how they were realised.

RO1: Establish what changes are required of the (a) internal and external supply and (b) design departments when adopting a 3DCE-based approach to ENPD

Through the multi-case study, it was established that the procurement function is required to play a vital role in the product design and development phase of the product development process when adopting a 3DCE-based approach to ENPD. The role of the purchasing function has to extend beyond being an interface between the internal design department and the supply chain to include management for supply-side interactions and facilitating supply chain information sharing. How this is can be achieved is addressed above in the answer to RQ1a.

Through the component selection exercises, it was established that adopting a 3DCE-based approach would put specific requirements on product designers as they will assume the responsibility for preliminary supplier selection as they integrate environmental considerations into their design process and simultaneously design products and supply chains. How this can be achieved is addressed in the above in the answer to RQ1b.

RO2: Develop a method, based on 3DCE and with a supply chain focus, which can be utilised during the environmental new product development process.

Based on the insights and outputs from the multi-case study and the component selection exercises, a 3DCE-based method to ENPD was developed. The method takes the form of a framework that is comprised of a process guide and a toolkit (see Section 7.3). The supplier-specific information in ENPD framework allows for the utilisation of the supply chain during the ENPD process through the use of supplier-specific information. The process incorporates supply chain mapping, supply chain *information sharing, supplier selection, green supply chain design and product environmental performance assessment. The toolkit is comprised of tools that were developed or explored that can support the implementation of the process. The framework elements cover all three internal levels of the organisation (strategic, tactical and operational) and cover interactions on all three product development levels (product design and development phase, new product development process and organisation). The framework is designed to be used in conjunction with other ENPD strategies and methods (such as LCA); it facilitates the integration of more accurately identified environmental considerations into the product development process through the use of real supply chain information.*

RO3: Critically assess the impact of early supply chain design on environmental new product development outputs.

The impact of having supplier-specific information - which allows designers to simultaneously design product and supply - during the ENPD process was assessed during the controlled experiments. The ENPD outputs investigated were product environmental performance, product cost and supply chain greenness. The results of the inferential statistics analysis on the participants' outputs showed that while supplier-specific information had no statistically significant impact on the product cost (H_{F1}), it has a statistically significant impact on the supply chain greenness (H_{E1}). Overall, during the exercises, the designers were willing to pay more to have products with improved environmental performance (H_{A1}) and supply chain greenness (H_{B1}). However, when presented with cost information, the designers tended to spend less on their products (H_{I1}) but still managed to produce products with better product environmental performance (H_{G1}).

RO4: Make recommendations to support and improve how the supply chain is utilised during the ENPD process.

The insights and outputs from the multi-case study and the controlled experiments were used together to inform the development of mechanisms to support and improve how the supply chain is utilised during the ENPD process. This resulted in the formulation of the following tools:

- *Cost per % PEP Derived Unit – A unit used to quantify the product environmental performance of products within a set relative to cost and each other; allows designers to evaluate product design alternatives based on how much they will pay per % PEP. The derived unit was developed and used during the analysis of the component selection exercise outputs.*
- *Procurement Involvement in ENPD Maturity Model – A process maturity model of the procurement function's involvement in ENPD that serves as an audit tool to assess and guide how the procurement function is involved in and supports the design function during ENPD. This tool is based on the framework for purchasing involvement in NPD that was created by Wysteria, et al. (2000); it has a particular focus on ENPD and elaborates on the practices and features that relate to both design and procurement functions, unlike the Wysteria, et al. framework which only focuses on the procurement function.*
- *Supplier-Specific Information Database – A database that contains information that relates to suppliers (e.g. location, transport methods, certifications, environmental practices etc.) which can be used by product designers during the ENPD process. The database is based on a combination of the supplier database and parts catalogues that were given to some of the participants during the exercises.*
- *Guidelines for Supply Chain Mapping focusing on Information Sharing – A list of issues to consider when practising supply chain mapping for information sharing*

that are used to guide the process and as a check to assess if typical requirements have been fulfilled. The guidelines were developed based on the findings of the multi-case study.

- *Key Recommendations – A list of recommendations that address various issues that arise when a 3DCE-based approach to ENPD is adopted and the supply chain is integrated into the environmental product development process. These recommendations are mainly related to how the supply function can support the ENPD process and were developed based on the findings of the multi-case study.*

8.2 Revisiting the Proposed Process Model for ENPD with Early Supply Chain Design

Upon completion of the main research activity, revisions were made to the proposed process model for ENPD with early supply chain design that was presented in Section 3.2.3 as part of the preliminary framework. The revised model, shown in Figure 57, is an evolution of the previous model, shown in Figure 24. The elements in the revised framework are those that are suggested by the findings from the research; while the central concepts within the model have remained the same, the revised model contains fewer elements, outlines the process that is central to embedding early supply chain design into the ENPD process through preliminary supplier selection and highlights the supply chain- and product-related actions and actors when supply chain design is conducted during the ENPD process. Section 7.3 contains detailed information regarding the changes that occurred. The revised conceptual model forms the basis for the supplier-specific information in ENPD framework and the final proposal for a 3DCE-based method to ENPD (see Section 7.3).

8.3 Reflections on the Contributions to Knowledge

By fulfilling its aim of exploring and investigating the potential role and utilisation of the supply chain, through a 3DCE-based approach, during the integration of environmental considerations into the new product development process, the work presented in this thesis contributes to knowledge and discourse within new product development.

3DCE as a Theoretical Lens

Following a 2008 study that adopted 3DCE as a theoretical lens, in which Ellram et al were able to demonstrate that ERM efforts can support both traditional and environmental product development goals, they concluded that adopting a 3DCE theoretical lens was beneficial when investigating ENPD. This study supports this view of 3DCE as it was able to effectively use 3DCE as a theoretical lens for demonstrating that supply chain efforts can support the integration of environmental considerations into the NPD process. In addition to adopting 3DCE as a theoretical lens, this study also builds on the work of Ellram et al (2007) adding to their existing 3DCE theoretical framework through the development of a supply chain design in ENPD framework. Effectively using 3DCE as a theoretical lens, showing the adoptability of its principles within an ENPD context, and adding to the existing 3DCE theoretical framework through the development of a supply chain design in ENPD framework adds to the credibility of the concept.

Procurement Involvement in ENPD

The findings of this study advocate for the early involvement of procurement in ENPD; the procurement function can actively support the design function during the design and development phase by consolidating the company's product design- and supply-based supply-side interactions. The view that the procurement function can assume a new 'dual' role for the benefit product development efforts supports that by Schiele (2010). Schiele (2010) suggests that in addition to its role of managing overall costs and integration, the procurement function can support NPD by implementing an advanced sourcing department as an organisational unit, using 'innovation meetings' with suppliers as a tool and employing technology roadmaps to link in-novation and sourcing strategies. By suggesting the procurement function manages and consolidates all of the product design- and supply-based supply-side interactions, this study adds to how the procurement function can support NPD efforts. Additionally, this study revisits and builds upon builds the work of Wysteria et al (2000) on how the procurement function can be involved in the NPD process by extending it to ENPD and elaborating on the practices and features that relate to both procurement and design functions.

A Supply Chain Perspective to ENPD

During this study, environmental considerations were successfully integrated into the product development process through the designers' practice of early supply chain design and use of supplier specific information showing how a supply chain perspective can be applied to ENPD. As the environmental performance of a product is the combination of its environmental impact through all the stages of its lifecycle, it is important that the supply chain perspective incorporated into ENPD practices. While there are some methods to ENPD that include suppliers, none fully exploit the supply chain as a valuable resource for ENPD; this study comprehensively explored how the supply chain can be utilised, from its design to the role of and interactions with suppliers.

Recontextualising Supply Chain Design

Through preliminary supplier selection, supply chain design was successfully re-contextualised from a procurement function based activity to a technique that can be used by product designers. Supply chain design during the product design and development phase results in the availability of supplier-specific information for use in product environmental performance assessments during ENPD. This work explicitly demonstrated the relationship between green supply chain design and supplier-specific information in ENPD. While there was enough evidence in literature to suggest that environmental design initiatives result in the greening of the supply chain (Carter and Carter, 1998; Walker et al., 2008; Large and Thomsen, 2011; Buyukozkan and Cifci, 2012; Koh et al., 2012; Kumar, 2013), it was yet to be investigated from the perspective where supply chain design is an integral part of the design process and is carried out by designers.

Supply Chain Mapping and Information Sharing

This work explored how supply chain information sharing can be directed through strategic supply chain mapping that is intrinsically linked to understanding the lifecycle impacts of bought in products, a process that is not without its challenges. Essentially, information sharing problems were categorised as related to: willingness to share; availability of information or information technology, and it was deemed paramount that the supply chain mapping be strategic and intrinsically linked to linked to the purpose of its undertaking the exercise, which in the case of ENPD this is gaining an understanding of the lifecycle impacts of bought in products. While the categorisation of information sharing challenges differs from that currently found in literature, the two are complementary and not contradictory. Durbin posits that the main supply chain information sharing challenges are related to: lack of awareness of sensitive information being shared in contracts; too many contracts to assess individually; and lack of visibility and controls. Cohen (2000) and Swaminathan et al., (1997) cite high adoption cost of joining the inter-organisational information system, expensive technology investment, personnel training, lack of mutual trust as barriers to supply chain mapping. The challenges available in the literature support the categories presented in this work as they adequately fit into them. Within this study, the challenge of lack of visibility was explored through supply chain mapping. As was found by Roy (2011), this study supports the view that the process of supply chain mapping is a highly complex one that organisations find particularly challenging and it is not as developed as perhaps it could be.

Supply-Specific Information

Typically within ENPD, the three key objectives that are used for decision making are product performance, product cost, development cost, development speed, and product environmental performance (Kaebernick *et al.*, 2003), this study expands this view by positing that the product environmental performance objective should include not only the environmental aspects of the product but also of its supply chain. This can be achieved through the use of supplier-specific information. To do this, designers need to effectively take into consideration, not only the environmental information relating to the technical performance of components and materials, they also need to consider the profiles and environmental activities of the suppliers of themselves when they determine the environmental performance. When supplied with supplier specific information, designers were found to make fewer assumptions and more consistent decisions, and are able to exploit the information for the benefit of ENPD objectives. This is in line with the findings by Green (2013) that 42% of global business leaders don't have confidence in decisions made due to a lack of information; such decisions are typically inconsistent and based on assumptions. The use of supplier specific information ensures that the designers have the information they require to make informed decisions.

It was previously though the use of standardised questionnaires (Andersen and Choong, 1997; Brink *et al.*, 1998) that environmental information moved through the supply chain to product designers. With the rising use of EMSs, this study explored the plausibility of using EMSs instead to move environmental information through the supply chain to product designers as supply chain departments that practice green supply chain management typically evaluate their suppliers based on environmental criteria and have a requirement that suppliers develop and maintain some form of EMS (Zhu *et al.*, 2012; Zhu *et al.*, 2005; Large and Thomsen, 2011; Min and Galle, 2001). The information that is typically found in an EMS system (e.g. location, waste management, raw material use etc.) is the type of supplier-specific information that can enhance the ENPD process.

ENPD Tools and Techniques

A wide range of original tools and technics that can be used in industry- and research-based contexts to facilitate the use of the supply chain during the ENPD process and allow for a deeper understanding of the important link between the product design function and the procurement function were developed and explored. It is the supply chain perspective that is adopted by these tools that makes them a useful addition to the extant body of ENPD tools. Taking into account the assertion by Lofthouse (2006) that most ENPD tools fail to offer practical solutions for day-to-day use in design and engineering departments because they are usually stand-alone and do not allow for easy integration with other design tools, this study's tools were carefully developed such that they can be used in conjunction with other ENPD tools, such LCA and hotspot analysis.

8.3.1 Implications of Research Findings

The implications from this work can be considered as two-fold, those that impact academia directly, and those that impact industry. For academia, this study: expands the knowledge surrounding the role and utilisation of the supply chain during the integration of environmental considerations into the product development process; and contributes to the concept of 3DCE. In addition, its findings and outputs can be used as a basis for further research (See Section 8.5). By developing findings of practical relevance to industry, this study not only improves industry understanding of various organisational issues that surround the integration of environmental considerations into the product development process, it also proposes pragmatic mechanisms to support organisational ENPD efforts. Through the findings of this research project, industry practitioners are made aware of the importance and usefulness of suppliers during the ENPD process, prompting them to view suppliers differently and actively include them in the ENPD process. Additionally, the outputs of this research project give industry a good starting point by guiding them through various scenarios surrounding integrating environmental considerations into the ENPD process through the utilisation of the supply chain. The findings have implications for a wide range of organisations, from those that do not currently practice ENPD to those that do.

8.4 Reflections on the Research Process

The ability of the researcher to provide a transparent accounting of their journey throughout the research process is an essential component of rigorous inquiry (Welch, 2004). In keeping with this view, a brief summary of this project's researcher's personal reflections of, and insights gleaned from, their experience as the research project was conducted will be presented in this section. In keeping with the traditional mode of diaristic writing, the summary will be written from a first person perspective.

The research that is presented in this thesis started as a continuation of the research work that I had undertaken for my Masters dissertation. In that work, I had looked into supply chain collaboration in new product development (SCNPD) from the perspective of the suppliers being incorporated into other organisations product development process. It synchronised well with another research project that I was working on; the G.EN.ESI project was a collaborative project looking to develop software and a methodology for eco-design. Within that project, I was mainly responsible for supply chain collaboration issues, particularly those relating to supply chain information sharing. When I accepted to work on that project I wasn't particularly interested in the environmental aspect of it, I was more interested in continuing to explore the intricacies of supply-chain collaboration. This meant in the beginning, as I was scoping the topic for my PhD research project, I did not have much of an environmental focus. Initially, I had been reticent to include environmental issues in the project because I held the somewhat archaic view that ENPD was a fringe topic and that it would not only limit the impact of the research but could potentially pigeonhole me as a researcher. However, through working on the G.EN.ESI project I learnt more about issues of environmental sustainability and environmental new product development from literature and the people that I was working an interacting with. Soon I was convinced not only to have elements of ENPD in my project but also to make it the focus of the whole project. Not only was there was an undeniable synergy between ENPD and SCNPD which piqued my interest, but the social climate made a strong case for the relevance of research into the organisational implementation of ENPD. Research in this field was not only relevant but its relevance looked to only increase with time. Looking back to when I started this research project three years ago I can unequivocally say that environmental issues seem more pertinent now than they were back then.

Unlike with other methods, the premise behind the mixed methods methodology that I adopted for this research study is to 'custom- make' a research design to suit the research questions. To fully harness the advantages it offers it is necessary for the researcher to have intimate knowledge of various qualitative and quantitative approaches and how they relate to each other, as it ensures that the generated research design is comprised of complementary components that collectively work towards generating a valid answer to the research questions. It can be a particularly challenging methodology, especially when compared to quantitative and qualitative research separately. When it came to deciding on a methodology to use, I did not devote too much musing over different approaches to inquiry. I had prior experience of using the mixed-methods methodology, I had used it for the SCNPD research, and I was comfortable with it and confident that the theoretical positions that underpin it were well suited to the ENPD study. As a consequence of my confidence in the methodology, gained from experience, I moved away from engaging in academic debates concerning the primacy of particular research paradigms within the community of scholars. Through the process of working on the G.EN.ESI project and doing this and prior research I had become more comfortable with testing the boundaries of conventional scientific inquiry. I focused *instead on being creative and meticulous during the inquiry process as I sought to design a study that I felt would best allow me to attain what I set out to achieve.*

I felt like the component selection exercises were the most creative part of the study. When I started designing them all I had was technical and environmental performance information, a product specification and a parts list relating to an existing cooker hood. I was able to use that information and some working knowledge that I had gained on how cooker hoods work though working on the G.EN.ESI project and working with one of the companies used as a case in this study to create a CAD model of a cooker hood for the component selection exercises. This allowed me to create technical drawings that I would supply to the participants of the exercises. I also created a history behind the company that, in turn, a history behind the product its self; this included a product series history that would put into context why this new product was to have a better environmental performance than its predecessor. What I wanted to do was to create a fully immersive design scenario where the participants felt like they were undertaking an actual redesign of the product.

Even though what I was really interested in was how the participants would select components, I did not just want to throw them in to the exercise at that point. Instead I wanted it to follow the product design process as closely as possible. This meant that they started at the beginning by being presented with the design brief; they then had to brainstorm ideas and advance through various processes until they got to the part of actually selecting components to put in their product. Because I was looking at how the participants would select components when given a number of different choices, I had to compile a catalogue of components that they had to select from. Taking the components that were used in the original cooker hood as a starting point, I did the job that the procurement department would do. I sourced a number of different components that could be used in the new design; all the components at least matched the technical performance of the original product but had other variations. This was a particularly long process as I had to ensure that all the options I put in the catalogue were viable options and that there was enough variety in the components to test which factors the participants would prioritise. The last component of the exercises was the environmental management systems (EMSs) that were associated with the suppliers of the components. While I had real information pertaining to the components, when it came to the component supplier I only had information related to their location. After conducting research into EMSs and the typical information that is contained in their databases I was able to create what I deemed to be a realistic EMS database for the company that was being used in the study. In an attempt to create an exercise that was comprehensive, appropriate for the research question and objectives it was addressing, and could be undertaken in less than two hours, a lot of iterations were made to the experimental materials. The consultations with Dr. Domingo were invaluable. All the work that was carried out prior to carrying out the exercises with the participants meant that nothing needed to be amended or adjusted once the data collection began.

Usually there are various approaches that can address research questions, that was the case with the research questions that I chose to address with the case studies. While adopting a case study approach had the added benefit of incorporating contextual factors that would enrich the data and inferences, these questions could have been addressed using just interview data. I had never conducted a case study before and in addition to the benefits it would have in answering the research question I was keen to challenge myself by learning and executing a research approach that I was not familiar with. Understanding the *underpinning of the approach and executing it were not a challenge, I have a penchant for research methodology so I found that aspect very enthusing. The challenge manifested when it came to analysing the data and writing the case study narratives; this was the most technically challenging aspect of the whole research project. While I have experience of coding and analysing qualitative data, I had never encountered such a large amount of data before. Not only was there a vast body of data that had to be analysed, the task of sifting through the data to isolate what was relevant and then incorporating that into the write up, where it was essential that I weave a coherent narrative that was rooted in the data, was a particularly demanding one.*

While the actual gathering of the data was very exciting as I got to discuss various aspects of the study topic with the participants and informants, gaining access to those informants and participants was daunting. Unlike in the instances presented above where despite ups and downs I was in control of the situation, issues regarding access to participants were particularly frustrating as they were out of my control. Even with the understanding that organisations are very complex and people working within them very busy, making it often difficult to gain access to the people that can provide information, I was not prepared for just how challenging it can be to get data from industry. At one point I was attached to a research project into supply chain information sharing within the aerospace industry. The project was in collaboration with the Environmental Materials Information Technology (EMIT) consortium and would have allowed me access to a large number of organisations and their suppliers. Due to organisational inertia, the project kept being postponed until it was no longer compatible with the time scale of my research project. In another scenario, I was set to carry out the component selection exercises within a company with a cross-functional team present and even though the company expressed an interest in taking part in the exercise when it came down to actually doing it they never seemed to have the time.

These, coupled with other complexities of researching in the real world, meant that the research study was ever changing in form as I had to adjust to changes. It was an iterative process where I continually had to revisit previous stages of the process. This research project demanded that I adopt an interdisciplinary approach incorporating ideas from a diverse range of subject backgrounds. Amongst other things, I found myself relearning how to code in Matlab, something that I had not attempted in over six years, teaching myself advanced statistics and coming from a predominately engineering and design background, delving into supply chain management literature.

Overall, the experience of undertaking this research project has been overwhelmingly positive. Through this project, I feel that I have not only been able to make contributions to knowledge and industrial practice but have also developed immensely as a researcher. I have managed to gain a vast and varied amount of research-based experience and amassed a range of academic and industry-based contacts; but perhaps the most was the paradigm shift that was induced in my personal life. The knowledge and understanding of environmental issues that I gained through this research has altered the way I see the world as I now try incorporate environmental considerations into all aspects of my life.

8.5 Recommendations for Further Work

During this research study, a number of industry- and research-related tools were explored and developed. As they are currently untested within industry, this project has produced what can be described as a preliminary set of tools. To validate and improve the tools proposed, an industry testing approach is proposed. Through industry testing, the effectiveness of the tools in supporting the integration of environmental considerations into the product development process could formally be evaluated. The further work could take the form of action research, whereby the researcher collaborates with professional practitioners. During this process include elements of validating and building a theory (basic research) and having a practical focus that has an emphasis on achieving measurable outputs (action research).

In addition to testing, iterating and validating the proposed tools and methods, the following work can also be undertaken to further explore the research topic:

- Conduct the controlled experiments with eco-design experts in each the conditions to see how close they can get to the Pareto optimal solutions based on the information they are given. By comparing their results to those in this research project, how close 'normal designers are to eco-design experts' can be investigated.
- Relate cost per % PEP to price per % PEP (how much customers are willing to pay for environmental performance). Through this investigation, a deeper understanding of how much the market can bear can be had allowing companies to know what cost per % PEP targets to aim for during product development. Although more consumers are claiming that they are willing to pay for sustainability, current literature suggests that there is no consensus as to how much consumers are willing to pay for sustainable products and if they actually would pay for it and not just claim to.

This is not an exhaustive list of the possible research avenues.

8.6 Closing Statement

Supported by concurrent engineering, 3DCE is a simple yet powerful concept of NPD in which the traditional focus on an appropriate match between product and process is augmented by an additional consideration of supply chain configuration. Through early supply chain design, supplier-specific information can be made available during the design and development phase of the environmental product development process. This availability of information not only improves product environmental performance assessments, but also facilitates green supply chain design. Through 3DCE, environmental considerations can be integrated into the NPD process, helping companies tap into the competitiveness potential that environmental performance can offer.

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PUBLICATIONS

The work presented in this thesis resulted in the following publications:

Mombeshora, I.M., Dekoninck, E.A. & Cayzer, S. 2014. Environmental New Product Development through the Three Dimensional Concurrent Engineering Approach. *DESIGN 2014: The 13th International Design Conference. Cavtat, Dubrovnik, Croatia.*

Mombeshora, I.M., Dekoninck, E.A. & Cayzer, S. 2014. Exploring Environmental New Product Development through the Three Dimensional Concurrent Engineering Approach. *SDM'14: The 1st International Conference on Sustainable Design and Manufacturing. Cardiff, Wales.*

Mombeshora, I.M. & Dekoninck, E.A. 2013. Supply Chain Eco-Information Sharing in the Product Development Process through Computer Aided Design. *ICED13: The 19th International Conference on Engineering Design. Seoul, South Korea.*

Mombeshora, I.M. & Dekoninck, E.A. 2013. Web-Based Portal for Sharing Information through CAD/PLM Software during the Eco-Product Development Process. *PLM13: The 10th Product Lifecycle Management Conference. Nantes, France.*

APPENDICES

APPENDIX 5.1: MULTI-CASE STUDY PROTOCOL SECTIONS AND TABLE OF CONTENTS

This appendix contains a table that details the sections of the case study protocol and the table of contents for the protocol.

SECTIONS WITHIN THE CASE STUDY PROTOCOL AND THEIR CONTENTS

SECTION	DESCRIPTION
OVERVIEW OF CASE STUDY PROJECT	Includes project objectives, case study issues, and presentations about the topic under study
FIELD PROCEDURES	Includes reminders about procedures, credentials for access to data, location of those sources
CASE STUDY QUESTIONS	Includes questions that the investigator must keep in mind during data collection
GUIDE FOR CASE STUDY REPORT	Includes the outline and format of the report

CASE STUDY PROTOCOL TABLE OF CONTENTS

Appendix 5.2: Evaluation of Strengths and Weaknesses Used Evidence

This appendix contains a table which outlines the strengths and weaknesses of the sources of evidence used within the multi-case study.

STRENGTHS AND WEAKNESSES OF SOURCES OF EVIDENCE

Source of Evidence	Strengths	Weaknesses	Form in this Study
Interviews	Targeted – focus directly on case study topic Insightful – provide original and illuminating data	Danger of bias due to poorly constructed questions Response bias Inaccuracies due to poor recall Reflexivity – interviewee gives what interviewer wants to hear.	Interviews (semi structured and unstructured) were under taken with key informants.
Documentation	Stable – can be reviewed repeatedly Unobtrusive – not created as a result of the case study Exact – contains precise details Broad coverage – long span of time, events and settings	Access - problem of confidentiality in many organisations Reporting bias – reflects (unknown) bias of document author Retrievability – can be difficult to find	Collected documents included presentations, site visit reports, company reports and company profiles.
Archival Records	(Same as for documentation) Precise and usually quantitative	(Same as for documentation) Accessibility due to privacy reasons	Collected archival records included organisational charts and IDEF0 diagrams.
Direct Observation	Reality – covers events in real time Contextual – covers context of events	Time-consuming and costly Narrow focus – unless broad coverage Reflexivity – event may occur differently because it is being observed	Direct observations were made through site visits during which other evidence, such as that from interviews was collected.

APPENDIX 5.3: PROVISIONAL 'START LIST' OF CATEGORIES AND CODES

This appendix contains a table that contains the provisional categories and provisional codes that were expected to be within them in the interview transcript data from the multi-case study.

PROVISIONAL CATEGORIES

PROVISIONAL CATEGORIES	PROVISIONAL CODES
CONTEXT	Industry
	Products
NPD	NPD Process
	Environmental NPD Drivers
	Product Development Drivers
	Compliance Drivers
	Costing
INTERNAL AND EXTERNAL COLLABORATION	Internal Interactions
	External Interactions
	Change Management
	Supply Chain Collaboration
	Collaborative Communication
	Collaborative Relationships
ORGANISATIONAL INFORMATION SHARING	Supply Chain Information Sharing
	Information Mining
	IT and Information Sharing
	Operational Impact of IT
	Initiating IT for Information Sharing
SCM	Supplier Sourcing
	Supply Chain Relationships
	Supply Chain Management Strategies
	Supply Scenarios
	Supplier Assessment
	Supply Chain Awareness
	Supply Chain Risk Management
	Supply Chain Mapping
	Supply Chain Compliance
	Green Supply Chain Management
	Costing

Appendix 5.4: Case 1 Coding Output Codes

This appendix contains a table that contains the output codes for the first coding cycle for Case 1 and another for the second coding cycle output codes.

TABLE 120: CASE 1 FIRST CODING CYCLE OUTPUT CODES

<table>
<tr><th colspan="2">THEMATIC CODES AND SUBCODES</th></tr>
<tr><td>
• BACKGROUND
• BARRIERS
↳ Lack of Corporate Buy In
↳ Lack of Expertise
↳ Lack of Resources
↳ Priorities
• COMPETITION
• COMPETITIVENESS
• CONTEXT
• CORPORATE VS. CUSTOMER VALUE PROPOSITION
• DUPLICITY
• ECO PERFORMANCE VS. COST
• TRENDS
• RELATIONSHIP VS. COST
• SCM
↳ Compliance
↳ Cost
↳ Driver
↳ Dynamics
↳ Environmental
↳ Relationships
↳ Risk Management
↳ SCM Strategy
↳ Supplier Sourcing
    ↳ Collaborative Sourcing
    ↳ External Challenges
    ↳ Internal Conflict
↳ Supply Chain Awareness
    ↳ Mapping
• COMPANY
</td><td>
• NPD
↳ Capability
↳ Compliance
↳ Cost
↳ Drivers
↳ Eco-Driver
↳ Environment
↳ Process
    ↳ Information
↳ Product
• COLLABORATION
↳ Change Management
↳ Communication
↳ External Interactions
↳ Internal Interactions
    ↳ Challenging
↳ Relationships
↳ Supply Chain Collaboration
• ORGANISATIONAL INFORMATION SHARING
↳ IT and Information Sharing
    ↳ Concerns
    ↳ Them vs. Competitors
    ↳ Web Portal
↳ Information Mining
↳ Supply Chain Information Sharing
    ↳ Proprietary Information
• END OF LIFE
• EXPECTATIONS VS. REALITY
• IN-USE
• QUOTES
</td></tr>
</table>

TABLE 121: CASE 1 SECOND CODING STAGE OUTPUTS

MAJOR THEMES, CODES AND SUBCODES	
• THE INDUSTRY, COMPETITIVENESS AND THE ENVIRONMENT ↳ C001 Protective of their Eco-Findings ↳ Eco-Efficiency of Motors ↳ Industry Dynamics Implications on Environmental Development ↳ Barriers to Them Entering Other Markets ↳ Can overcome Barriers through ENPD ↳ Competiveness is a Barrier to Information Sharing and Environmental Design ↳↳ Eco-Competition within Industry ↳ Highlighting Eco-Initiative in Industry ↳ History of Efficiency Considerations in Industry ↳ Industry Considers Eco-Findings Proprietary ↳ Protection of Eco Findings in Industry ↳ State of Industry Environmental Assessments ↳ Need for Change ↳ Need to Move with Times • C001 ↳ C001 and the Environment ↳ Challenges to Overcome ↳ Always Something More Important to Do ↳ Bottom Up Environmental Design ↳ Conflict with Using Findings for Competitiveness ↳ Cost wins Against the Environment ↳ ENPD not Prioritised ↳ Eco Design not Corporate Necessity ↳ Lack of Top Down Incentives ↳ Not Prioritising Environmental Issues ↳ Not Really Concerned with Environmental Sustainability ↳ Organisation Considers Eco Findings Proprietary ↳ Selling Greener Products to Customers ↳ Goals for ISO 14001 ↳ Strategic Environmental Drivers ↳ Eco Vision ↳ Environmental	• TACTICAL INTERNAL COLLABORATIONS ↳ Conflicts between Supply and R&D ↳ R&D Decides What They Want, Supply Gets Best Price and Scenario ↳ Supply Believe R&D-Supply Interactions Not Ideal • OPERATIONAL NEW PRODUCT DEVELOPMENT ↳ Challenges and Difficulties ↳ Challenge is Efficiency for Lowest Cost ↳ Lack of Eco-Design Implementation Knowledge ↳ Reticent to Explore Radical Innovation Possibilities ↳ Risk of Neglecting Non-Incremental Innovation ↳ Customer and End User Implications ↳ Customer Projects Demand Efficiency ↳ Educate Customers on Quality Benefits ↳ Educating Customer Base on Efficiency ↳ End User Driven Product Development ↳ Design for Reparability ↳ Eco and Non Eco Performance Necessary ↳ Impact of Position in Supply Chain on Requirements ↳ The Product ↳ Custom Product Attributes ↳ Motor Performance Basis ↳ Product Development Cycle Time ↳ Typical Product Life • OPERATIONAL SUPPLY CHAIN MANAGEMENT ↳ Ethical and Environmental Aspects ↳ Eco Dynamics Based on Company Size ↳ Inherently Doesn't Think Traceability Matters but Figures He Should ↳ Open Minded to Traceability – Doubtful ↳ Global Supply Chain Co-Ordination a New Challenge ↳ Sourcing Suppliers ↳ Component Type has Impact on Freedom that Supply Has to Make Changes ↳ Cost Major Supply Driver ↳ Freedom in Mechanical Part Supplier Sourcing ↳ Mechanical Components Not as Complex as Electrical

Development Key to Securing Position and Improving
        ↳ Marketing like Green Image
        ↳ Recognise Eco-Opportunity
    ↳ Quality Standard Compliance
    ↳ Strategy
        ↳ Bespoke Offerings Result in Long Term Customers
        ↳ Competes on Quality not Price
        ↳ Exercise their Core Capability
        ↳ Fast Follower Strategy
        ↳ Focused on Growth
        ↳ Green Competition based on Efficiency
        ↳ Impose Software as Barrier to Access
        ↳ Incremental Innovation
        ↳ Product Offering Strategy
    ↳ Working Relationship Between C001 and X001
    ↳ X001 and C001 Complementary Assets

- TACTICAL EXTERNAL INTERACTIONS

↳ After Sales
    ↳ Application Engineers (Sales) Interact with Customers
    ↳ Disassembly not Cost Effective
    ↳ End of Life Bring Back Rare
    ↳ Faulty Product Bring Back Rare
    ↳ Incentives to Get Back Faulty Products
    ↳ Provide Training Regarding their Products
    ↳ Recycling Outsourced after Products are Split
    ↳ Repairability Cost Dependant
    ↳ Service Scheme in Place
    ↳ Service and training schemes
↳ Collaborate with their Suppliers to make New Products
↳ Role of Sales Department
↳ Supply Department Collaboration with Supply Chain Centres around Cost

    ↳ Part Size has Impact on Cost
    ↳ Sourcing Based on Component Type
    ↳ Strategic Sourcing Based on Multiple Factors
↳ Supply Chain Information Sharing Issues
    ↳ Challenges and Conflicts
        ↳ Big Problems Regarding Comfortability with Information Sharing
        ↳ Fears associated with Information Sharing
        ↳ Use of Information for Procurement a Big Issue
    ↳ Communication though visits, phone calls
    ↳ Company Attributes Impacts on Information Sharing
    ↳ Data Collection Activities
    ↳ How Information is Shared and Not Shared
    ↳ Information Sharing and Technology
        ↳ Databases and Information Sharing
        ↳ Would Like Communication through Technology
        ↳ Type of Component has Impact on Available Information
↳ Supply Chain Relationships
    ↳ Relationship Management Based on Supplied Components
    ↳ Relationships Cultivated for Cost Benefits
    ↳ Relationship has Positive Impact on Cost

APPENDIX 5.5: CASE BASED META-MATRIX

This appendix contains the case-based matrix that was created using the data from the multi-case study.

C001		
Research Question 1	How the supply department supports the product development process	Component supplier sourcing R&D fully specifies what they require and purchasing source it for the best price and logistics scenario Cannot change specified electronic part without R&D approval More freedom afforded with mechanical parts Believes that the supply-R&D interaction is too one sided and that is not ideal Conflict in objectives between supply and R&D (cost and logistics vs. functionality)
	How the supply department interacts with the external supply chain	External communication mainly face-to-face via site visits Communication centres mainly around getting the best price for parts Supplier collaboration centres around cost reduction Discussing sharing information using customer's web portals - internet security company investigating Practices strategic sourcing with different approaches when interacting with electronic vs. mechanical part suppliers, more hands on with mechanical part suppliers Outsource sourcing of cheaper components and collection of related data to certain suppliers. Sometimes supply part manufacturers with components to use (components sourced by other suppliers)
Research Question 2	Challenges associated with supply chain information sharing	Co-ordination of global supply chain Very uncomfortable with sharing eco-information as might be abused Fear of having shared eco-information used to compare them to competitors Only comfortable sharing typical technical data As an SME, fear being large organisations dictating things if possibly proprietary information is shared Mistrust of databases Inputting data on custom products can be time consuming and difficult to have a standard database Uncomfortable with sharing whole unit information but can share part data Would not feel comfortable sharing information that would allow their suppliers to do their own LCA assessments Being an SME makes it harder to keep up with large organisations that have more resources Fear that information will be used for procurement Concerns about security of information if input into someone else's portal Non-disclosure agreements in place but acknowledge they are just pieces of paper Lack of Information Mechanical parts are usually provided with more detailed data sheets than electronic components. Ever-changing technology means they need to keep changing the software that is used to share information
	Information sharing practices	Has access to web portal for sharing information but it's too complex so it is not utilised Information mainly shared through data sheets

	Use of supply based methods and relationships	Cultivating strong relationships for cost benefits Components classified in terms of importance and/or availability Relationship management is based on how supplied component is classified Relationships determine how much collaboration there is with a supplier
Research Question 3	State of supply chain awareness	
	Supply chain awareness and information sharing	
C002		
Research Question 1	How the supply department supports the product development process	Component supplier sourcing Part of cross functional product development team early in design process For electrical components, supply department is usually involved from the feasibility stage For mechanical components, supply department usually involved after the feasibility stage Industrialisation team finds and inputs cost data into company databases* Stage gate development process with everyone involved in the development process attending major meetings Through working together in cross-functional teams, the supply department has knowledge of other organisational functions
	How the supply department interacts with the external supply chain	Primarily practices sole sourcing shifts to multi-sourcing to meet demand. Parent company pushing for more multi-sourcing for risk management Supplier collaboration revolves around quality control External communication mainly telephone calls
Research Question 2	Challenges associated with supply chain information sharing	Global supply chain result in cultural and language barriers hampering information sharing Strong relationships with suppliers negate the challenge of unwillingness to share information Accurate materials information hard to acquire but international databases offer adequate alternatives Lack of Information
	Information sharing practices	Extensive use of databases to collate and share information internally Strong information sharing culture with suppliers Test parts and component to generate technical information they don't have Main focus on getting information regarding the critical components
	Use of supply based methods and relationships	Components classified in terms of importance and/or availability Relationship management is based on how supplied component is classified Relationships determine how much collaboration there is with a supplier
Research Question 3	State of supply chain awareness	
	Supply chain awareness and information sharing	
C003		

Research Question 1	How the supply department supports the product development process	Component supplier sourcing Ethically sourcing components Purchasing department under time pressures to source components Interface between internal functions (engineering and design) and the supply chain Part of cross functional environmental product development teams
	How the supply department interacts with the external supply chain	Due diligence based around supplier sustainability and supplier capability to meet specific import fleet requirements Supplier sourcing process could stand to be more data driven and less emotional through the use of tools and robust methodologies Historically practiced sole sourcing but shifting to multi-sourcing for risk management Sets up licensing agreements – splits development and production thus lowering costs
Research Question 2	Challenges associated with supply chain information sharing	IT infrastructure not fully supportive of advanced information sharing Too many various pieces of software, needs to be reconciled Complexity and size of supply chain (approx. 20000 components) Co-ordination of global supply chain Global supply chain result in cultural and language barriers hampering information sharing
	Information sharing practices	Advocate a move from matrix relationships to network relationships to allows for better internal information sharing and collaboration Extensive use of databases to collate and share information internally
	Use of supply based methods and relationships	Suppliers classified by type of services they offer (value made to print to full) and also by the relationship that will be cultivated Suppliers can progress through the classifications Supplier collaboration is sometimes split between product development and product delivery Suppliers are categorised according to the major design groups within the company Use of web based software to manage supply relationships and share information Bonus-Malus supplier evaluation system Shift from should to parametric costing
Research Question 3	State of supply chain awareness	Traceability is an issue, especially when components look the same and you have multiple suppliers Sole sourcing makes traceability easier vs. multi-sourcing Traceability is essential for scenarios regarding litigation defence, warranties, ability to sell in certain markets, tracing failures etc. Strategic supply chain mapping is practiced Supply chains mapped based on the different engineering groups that they support, competency, capability, investment, development plans, etc. Mapping conducted as part of business intelligence "Simply to mean, lets distribute data in a more intelligent linked up manner… looking outside yourself to what everybody else is doing"
	Supply chain awareness and information sharing	Incomplete information regarding some 1st tier and below suppliers due to complexity (over 20000 parts)
	C004	
Research Question 1	How the supply department supports the product development process	Cross functional teams Component supplier sourcing Impact on supply chain is a big consideration during product development and supply provides this input Supply chain management issues an integral consideration in product development Supply department offers input through all development stages

		Interfaces between the supply chain and engineering Purchasing sources and works closely with engineering and quality
	How the supply department interacts with the external supply chain	Supply chain collaboration that involves sharing of information between supply chain partners, congruence of goals across the supply chain, synchronisation of decision-making, alignment of incentives and sharing of resources. Important to note that collaboration can create insecurity as it breaks down functional silos. Important to manage it correctly through trust and aligned goals. Communication is mainly face to face Aim to minimise number of suppliers and create long term partnerships instead of growing number of suppliers to induce competitive price bidding. Historically practiced sole sourcing but shifting to multi-sourcing for risk management Active supplier capability development
Research Question 2	Challenges associated with supply chain information sharing	Co-ordination of global supply chain Applying information technology to the supply chain is challenging and focus should be more on the operational impact than the technology. Application of technology vs. how it is used.
	Information sharing practices	Use of information technology to share information with supply chain and coordinate supply activity Believe that information sharing leads to stronger supplier performance, better supply chain relationships and new forms of collaboration. Require information from suppliers when any changes are made to manufacturing Communication is key to learning and information flows freely up and down and across hierarchy "Listen intently in an open environment" Initially suppliers are anxious about sharing a lot of information but over time mutual respect develops and supplier realises that involvement is beneficial.
	Use of supply based methods and relationships	Use of KPIs to evaluate suppliers (on time delivery, quality and cost targets) Global system to supplier management that centres around mutual understanding and trust, interlocking structures, control systems, compatible capabilities, information sharing, joint improvement activities, and Kaizen and learning Approach to SCM that features close relationships across the supply chain and collaboration to maximise supply chain performance Suppliers Suppliers classified by type of services they offer (drawing-supplied to drawing-approved) The relationship with suppliers varies based on what is being produced During negotiations purchasing managers breakdown components into commodities such as steel and plastic. Then a cost index method benchmark is used to identify a globally competitive cost point for each commodity.
Research Question 3	State of supply chain awareness	Thought supply network was typical triangle shape but it was actually a sort of barrel shape Experienced disasters in sub-tier suppliers which crippled their own manufacturing and lack of awareness and management made the situation worse Actively pursues gaining full visibility and managing sub-tier suppliers Information on sub-tier suppliers increases visibility and accelerates crisis response Visibility is the first step then you move to manage

	Supply chain awareness and information sharing	Information on sub-tier suppliers increases visibility
C005		
Research Question 1	How the supply department supports the product development process	Component supplier sourcing Practice green procurement Enlists help of suppliers to improve quality and production Promotes suppliers practice eco-design (part of checklist) New base model of product development means supply has a central role in product development as products share common parts Part of a cross-functional team, joins design team to review designs
	How the supply department interacts with the external supply chain	Communication via written requests, face to face meetings Collaboration to improve suppliers environmental profile Dissemination of EMS Urge suppliers to practice green procurement Suppliers responsible for greening their own suppliers Hands on assistance offered to help suppliers improve themselves and their supply chains Continually educating suppliers on green procurement and its importance
Research Question 2	Challenges associated with supply chain information sharing	Global supply chain coordination Global supply chain result in cultural and language barriers Time is needed to change culture and build trust
	Information sharing practices	Openly share production information with suppliers Active promotion of information sharing amongst suppliers Purchasing cooperation association bring manufacturers together to build relationships of mutual benefits and growth Providing information is part of the green procurement checklist Aims to disclose environmental information of own products in a fair and truthful manner Information sharing technologies used Quality information on common parts centrally stored in Japan Audits play a big role in working with suppliers and managing their progress
	Use of supply based methods and relationships	Green procurement guidelines and survey Communication enhancement efforts include purchasing executives visiting suppliers to hold briefings and goodwill gatherings Lead by example and urge that suppliers follow Wide spread company culture means indoctrinating others gets easier
Research Question 3	State of supply chain awareness	
	Supply chain awareness and information sharing	
C006		
Research Question 1	How the supply department supports the product development process	Collate material declaration forms Purchase raw materials Component supplier sourcing
	How the supply department interacts with the external supply chain	Slow moving nature of the industry means that they supply base remains fairly consistent as the frequency of new substitute technology is low
Research	Challenges associated	Things move on and change so it is important to continue revising

Question 2	with supply chain information sharing	and updating the information you have SMEs sometimes lack capacity to spare on information sharing activities, this creates bottlenecks Adequate communication requires a deep understanding To make certain declarations it is essential to have suppliers deliver material declarations, they have to be chased down for this Co-ordination of global supply chain Global supply chain result in cultural and language barriers Requesting information that has not historically not been asked for Passing information up and down supply networks that have SMEs who lack extra capacity When you purchase a small amount form a supplier you are not a priority regardless of who big your organisation is Lack of Information
	Information sharing practices	"To develop product and process information we have to understand sufficiently well what our product is and what is used to make it" Collating information pertaining to hundreds of thousands of components used and specified in their products over the years Use information systems to keep track of what they are using, what needs to be changed and when Sometimes recognize and accept that expecting communication flows within the supply chain is unreasonable To ensure that information overload does not happen, information sharing within the organization is compartmentalised Information is managed such that specific users are only present with information that is of interest to them Product life cycle management system captures information during the product development process Information sometimes collected from supply chain through phone calls Educating suppliers in the importance of REACH initiatives in order to encourage information sharing Information sharing embedded in contracts Supplier web portal to facilitate information sharing
	Use of supply based methods and relationships	Cross functional teams to manage supply chain risk In some cases, small suppliers do not have the capacity to cultivate a hands on relationship with them Interacts with suppliers at different tiers and sometimes bypasses certain levels Suppliers classified by type of services they offer and also by the relationship that will be cultivated Global supplier management system In specific cases works with suppliers to implement changes
Research Question 3	State of supply chain awareness	Strategic supply chain mapping is practiced Supply network is just too big to map Sandwich analogy of supply network complexity Mixed up points of distribution make forward mapping difficult for suppliers In the past used to attempt to track back through the tiers most components Mapping is based on criticality of components in terms of obsolescence and compliance Supply network has approx. 8-10 tiers
	Supply chain awareness and information sharing	Bottlenecks in communication and information sharing hamper and mapping activities Knowledge of suppliers on different tiers means they can bypass certain suppliers and interact directly with their suppliers Information naturally flows downstream No relationships between ends of chains

APPENDIX 5.6: CASE STUDY REPORTS FOR CASE 2 – CASE 5

This appendix contains the full case study reports for cases 2 – 5.

Case 2: Prospective ENPD Organisation

Headquartered in Switzerland, the X002 Group has over 9000 employees working in 72 of its subsidiaries on 4 continents; it exports to over 100 countries worldwide and generates an annual revenue of approximately €2 billion. X002 provides products and solutions for residential kitchens and bathrooms, professional foodservice, coffee preparation, beverage delivery and semi-/public washrooms, with its products falling in to the following categories: kitchen systems, food service systems, water systems, coffee systems and beverage systems. In 2005, X002 expanded its kitchen systems business unit through the acquisition of C002, an Italian cooker-hood design and manufacturer.

With manufacturing and commercial bases in eight countries over three continents, C002 are one of the world leading manufactures of cooker hoods and they pride themselves in their heritage in the industry that spans back to 1955. With its headquarters, where product design and development is undertaken, and its main manufacturing facility located in Italy, C002 takes pride in being an Italian cookerhood producer. Currently, C002 employs approximately 1500 people and has an annual turnover of over €255 million. 46% of its cookerhoods are sold to OEMs while 18% are sold under the X002 brand and 36% under their own brand. C002 believe that the best solution is one that is yet to be invented and through this philosophy, they strive to offer "unbeatable performance and an exclusive competitive advantage" through their products. Their product innovation is centred around improving air quality, conserving energy, noise reduction and kitchen safety and is governed through a lean six sigma approach where by processes are sped up and quality levels maximized, all with a focus on customer value creation.

Context Setting

While post-acquisition C002 remains fairly autonomous from X002, it occasionally finds itself in a position where it has to work towards X002's objectives. One such instance is related to environmental sustainability and X001's attempt to promote "product development and innovation geared towards efficiency and energy saving strategies" and "environmentally friendly and resource-efficient production" across its companies. Due to prior interest, C002 was selected as the company within the group that would actively work toward designing eco-friendly products; a process that would cumulate in C002 providing X002 with eco-profiles of their product offerings. X001 is looking to C002 to pave the way to practicing environmental new product development (ENPD) within the group.

Outside of X002's interest in environmental sustainability, C002 already had a growing interest in ENPD. While at the moment they do not formally practice ENPD, they currently integrate environmental considerations into their products by focusing on improving the in-use energy efficiency of their products. This form of efficiency improvement is prevalent across the cooker hood industry due to associated user cost savings and impending environmental legislation that requires manufactures to display the energy consumption of their products at the point of sale, providing customers with a tool for direct comparison.

C002, along with much of the industry, has turned to efficiency improvements as the initial step in meeting this mandate and being competitive in the market place. C002 are also being inundated with requests from their OEM customers to provide product energy consumption information, this falls in line with their current focus on in-use energy efficiency.

Efficiency improvements, mainly associated with lighting and electric motors, do not offer any significant advantages over the competition in terms of product environmental performance. For C002, this is just a tip of the iceberg and they believe that through ENPD they can produce products that are environmentally competitive, looking beyond energy efficiency.

"No one is considering this kind of development. So we could be the first in this kind of field. And also the eco-profile of our cooker hoods can be greater."

As the market is currently not asking for eco-friendly products, they see this as an opportunity to be ahead of everyone else and possibly attain an advantage. Additionally, low cost cookerhoods, particularly from manufacturers in China, mean C002 cannot compete purely based on price. Consequently, going forward, environmental product development provides an opportunity for them to differentiate their offerings. To be truly environmentally competitive, it will be essential to fully integrate environmental considerations into all aspects of their product development and practice ENPD.

Central to ENPD within C002 is its R&D department as it is the one that currently has the best understanding of environmental issues within the whole company. All the environmental activities that they have conducted thus far have been ad-hoc and C002 recognises that they have low environmental knowledge and need to implement a more formal approach to ENPD if they are going to attain their goal of producing environmentally competitive cooker hoods. The lack of understanding regarding the potential that lies within eco-friendly products is seen as a major barrier to further development by those within R&D, particularly regarding marketing and sales. While R&D acknowledges that market demand for eco-friendly products does not exist at the moment, it sees an opportunity to attain first mover advantages by pushing eco-friendly products to the market. Propagated by its R&D department, C002 finds itself in a situation where it is looking to adopt a formal approach to ENPD that will allow it to produce eco-friendly and commercially viable products.

New Product Development

Primarily, C002 is a designer of cooker hoods with their main expertise laying in their ability to develop new technologies and design aesthetically appealing products. While they do have a production plant where produce some parts from stainless steel through simple processes such as cutting and bending, they primarily outsource or purchase parts and components that are in their designed cookerhoods; their cookerhoods are assembled domestically at their production plant. Figure 59 illustrates the phases that typically make up C002's product development process, much of the development work is carried out during the feasibility and development phases.

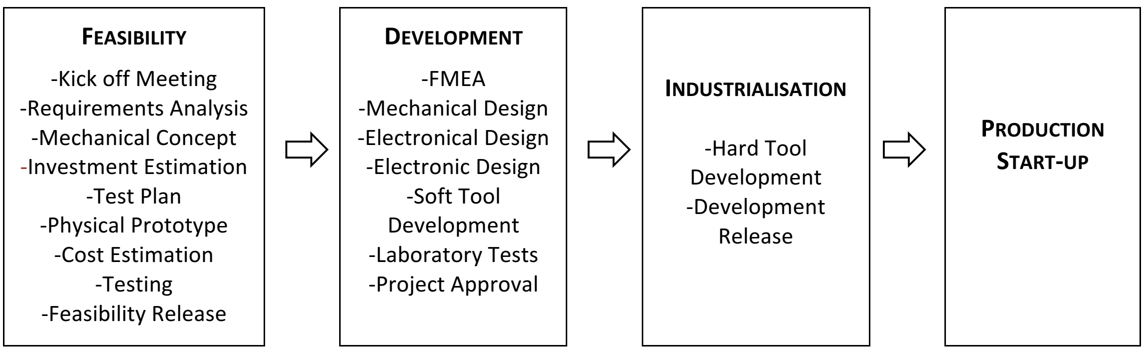


FIGURE 59: PHASES IN C002'S PRODUCT DEVELOPMENT PROCESS (FROM DOCUMENTATION)

Product development within C002 is classified in terms of project streams and types. Projects fall into either the feasibility project stream or development project stream. There are six different types of projects, these are: Hood (product or component), Electronic, Functional, Research, Range Extension and Change or Modification. The project types fall into the project streams as shown in Figure 60; the change or modification project type falls into neither of the two streams. Project type and stream has an impact on the duration of the product development cycle. For example, a hood development project that aims to produce a new cooker hood shape takes approx. 35-60 days while a function feasibility and development project that aims to produce a cookerhood with new technology can take up to two years.

	Feasibility Project	Development Project	Other
Hood	X	X	
Electronic	X	X	
Functional	X	X	
Research	X		
Range Extension	X	X	
Change or Modification			X

FIGURE 60: PROJECT STREAMS AND TYPES (FROM DOCUMENTATION)

While the focuses of the projects vary greatly depending on the project type, there are common elements in all projects that C002 undertakes. Both feasibility and development project streams have kick off considerations at the start and release considerations at the end. During the development process, the people involved work to define and undertake the different types of work and considerations, the outputs of the process are documented in reports whose contents are typically like those shown in shown in Figure 61.

Feasibility Project		Development Project	
Kick off	Release	Kick Off	Release
High Level Product Requirement - Feasibility Objective - New Product Idea Business Requirement - Market Rational - Target Costs - Quantities Resources - Team - Feasibility cost and investment impact Risks/ Critical Aspects - Critical Components - Critical Technology - Critical Links to Other Projects	Technical Release - Can kick off goals be achieved? - Industrialisation Team Release Cost Estimation - Investment Estimation Prototype - Test Report Development Timing Estimation	Detailed Technical Product Requirement Business Requirement - Market Analysis - Target Costs - Quantities Timing - Master Plan Agreement - Project Plan Supply Base Validation - Audits Resources - Project Leader - Team Definition Risks/ Critical Aspects - Critical Components - Critical Activities - Critical Links to Other Projects	Product Configuration Test Summary Special Components Release (if any) Review of Development Process Quality Department Sign Off

FIGURE 61: TYPICAL CONTENTS OF REPORTS PRODUCED DURING FEASIBILITY AND DEVELOPMENT PROJECTS (FROM DOCUMENTATION)

Internal and External Collaborations

At the core of all of C002's product development, its R&D department is comprised of the following groups: Mechanical Design, Industrialisation, Electronic Design, Electrical Design, Functional Design and Laboratory Product Release. While ultimately the makeup of a project team depends on the specific requirements of the projects, representatives from each of these groups are present at all kick off meetings. Additionally, to ensure that the product development is rooted in the company's economic bottom line, representatives from commercial departments are also present. In addition to the core team that is comprised of members of various R&D groups, during the duration of the projects members from other groups are involved in the projects. Figure 62 shows when members from various groups typically get involved in projects during the product development. As shown in the figure, the mechanical design group is the most involved group.

	Feasibility Project			Development Project				
	Feasibility Phase			Development Phase			Industrialisation Phase	Production Start Up
	Technical Analysis	Economic Analysis	Prototype	Design	Soft Tool Development	Approval		
Mechanical Design	X	X	X	X	X	X	X X X	X
Electronic Design	X			X				
Electrical Design				X				
Industrialisation Team		X			X			
Laboratory Product Release	X		X	X			X	
Functional Design				X				
Quality						X		X X
BOM Management							X	
Documentation							X	
Production								X

FIGURE 62: TYPICAL INVOLVEMENT OF ORGANISATIONAL GROUPS IN NPD PROCESS (FROM DOCUMENTATION)

C002's R&D department is relatively small and there is a real sense of good working relationships. While the kick off and release stages in the projects are usually accompanied with meetings where those involved in the projects get a chance to have group discussions, during the projects themselves the team members work closely with each other. As a result of working in cross proximity with each other, and with members of other departments, members of C002's R&D department have cross-functional knowledge and are have enough awareness of issues that relate to more than just the group they belong in. This is relatively new for C002 because in the not so distant past, their product development was very segmented and internal and external collaboration and information sharing was discouraged in an attempt to keep what the R&D department was doing secret.

> *"The secrets of C002 R&D departments must stay inside the R&D departments so people were locked inside the department and inside the company and information between the departments was really few (sic)…But this was ten years ago, today it is different. We need to speak to each other."*

While, through their commercial department, they occasionally get input from their OEM customers that they use in their development process, they do not have any input from the users of their products. They realise that their product development could stand to be more user driven, however they believe that this is something that commercial department should support them with. It also would also offer a way to open up dialogue regarding eco-friendly products with the end users.

Supply chain considerations enter the development process through the industrialisation team. The team is primarily responsible for considerations and decisions made regarding investments, cost and supply chain design issues. They source possible raw material and component suppliers and manufacturers to outsource to and then work with the core design team to compare various viable options; together they compare economic offers and define the supply chain for the product being developed.

In addition to having the people from the production group at their manufacturing plant involved during product development, C002 also works closely with its suppliers. When designing new components whose manufacturing is to be outsourced, or when they are specifying requirements for components that they will have produced for them, they consult with their suppliers whenever necessary.

With the majority of the components and parts in their cooker hoods being brought in from the outside, the environmental impact C002's products will depend heavily on the nature of the components that they are using and who is supplying them. This means that the supply chain will play a major role in their product development process as they look to make eco-friendly products. At the moment, due to the energy efficiency work that R&D is conducting, C002 give their electric motor and light suppliers power and energy consumption targets that they must meet. These were not always part of the product specification but now are a necessity, one that is a requirement that has to be met.

Supply Chain Management

C001 employs a number of different strategies when sourcing suppliers for its components. For those components that it deems as core, such as electric motors, it practices sole sourcing. This is due to a belief that having a one-to-one relationship means that they can cultivate the relationship and form strong ties with their supplier, ties that allow them to work much closely with the supplier to ensure that they get the best products possible and offer fringe benefits. Occasionally, they have to source multiple suppliers for components that they deem as key; this is the case with the blower where they have three different suppliers. In this case, they had to have multiple suppliers because none of the individual suppliers had the capacity to meet their demand.

Practicing sole sourcing has not been without its challenges; a year ago they ran into some problems and had to switch their supplier for electric motors. This was a big change for the organisation as they had worked with that one supplier for years. The need to manage supply risks, along with pressure from X002, sees C002 looking to change the way it sources its core components as it looks to multi-sourcing.

> *"In the case of a crisis of the first [supplier], we can switch to the second. But it is just an economical question, just a question of survival in the case of a crisis of one."*

In addition to securing supply for components and materials that are used in their products, the industrialisation team has to ensure that they get the best prices. Price and quality are their main concerns, with quality taking precedence as they occasionally pay more to ensure that they get products that meet their exacting quality standards. On occasion, they work with their suppliers to improve their quality levels.

Organisational Information Sharing

With blowers from Turkey, push buttons from Italy, motors from China etc. C002 has a global supply chain and this is not without its challenges. The main challenge they currently face regarding information is a result of cultural and language barriers; this is particularly the case during discussions about technical requirements. They anticipate that this will affect discussions that they will have with their suppliers regarding environmental aspects, however they are keen to tackle them head on.

> *"The problem is that electric motor suppliers are all in China, and work with this kind of information in Chinese is really, really hard. At the moment it is hard to*

talk about technical aspects and I think that it is harder to talk about this kind of information [environmental information] but we are working towards this."

Through the use of enterprise software, the industrialisation team are able to keep a wealth of information and share it within the organisation. They have a series of databases that contain information that is classified in terms of the cooker hood design that designers can access from their workstations; this includes cost, supplier and materials information. This is information that is captured during various product development projects through phone calls, visits, data sheets, reports etc.

Where appropriate, C002 makes requests for technical information regarding components they get from their suppliers. This is particularly the case with electric motors as they want to know as much as possible about the performance of the motors. However, they do not always get everything they require and in those cases they do their own tests on the motors to determine a range of technical aspects relating to it.

To date, C002 have not made any requests to their suppliers regarding environmental information that extends beyond energy efficiency, such as material recyclability, embodied energy of materials etc.). Resultantly, it is impossible to know if their suppliers have information and if they would be willing to share it. However, as they did with energy efficiency information, they will ask; it is a request that should not seem out of place considering that they recently made the sharing of efficiency information a requirement. As they transition to ENPD, they realise that there is a large possibility that they will not be able to get all the information that they require. They are not deterred and they plan to supplement the information they get from suppliers and in-house testing with information that is available in environmental and materials databases. Their priority will be to ensure that they have the most accurate information regarding the components that are the most critical in terms of environmental aspects.

As a company that designs, manufactures, outsources, purchases and assembles, C002's supply base is made up of raw material suppliers, component manufacturers and distributers. Most of the knowledge that they have regarding the supply network of their products is related to their Tier 1 suppliers, the ones that they have direct contact with.

At the moment they do not map their supply chains however, as they look towards creating a formal approach to ENPD, they will be asking their suppliers for information that can be used to map their supply networks beyond the first tier.

Conclusions

Looking to pave the way within the X002 group, C002 are looking to adopt a formal approach to ENPD that will allow it to produce eco-friendly and commercially viable products. While there are no clear market drivers for eco-products that go beyond in-use energy efficiency improvements, C002 sees an opportunity to attain first mover advantages by pushing eco-friendly products to the market. However there is a lack of understanding of the potential that lies within eco-friendly products outside of the R&D department. This means that the R&D department is in a position to not only learn how to practice efficiently ENPD, they also currently have the responsibility of disseminating environmental understanding to the rest of the company.

C002's R&D department takes the lead role in product development. While ultimately the makeup of a project team depends on the specific requirements of the projects, representatives from each of these groups are present at all kick off meetings. During product development cross-functional teams work closely together. As a result, members of R&D and other functional departments have cross-functional knowledge and enough awareness of issues that relate to more than just the group that they belong in. This culture of organic organisational learning should allow the R&D to spread environmental awareness across the whole of the company.

C002's industrialisation team which is in responsible for sourcing and supply chain design gets involved early on in the product development process. Whenever necessary, they are responsible for co-ordinating collaboration efforts with suppliers. The impending legislation that requires display the energy consumption of their products at the point of sale has resulted in C002 working even more closely with its suppliers. Unlike in the past, C002 now gives light and electric motor suppliers power and energy consumption targets that the products they supply should meet. This is not something that they did in the past as it was not necessary, however it now is due to legislation and suppliers are working to comply with these needs. This shows that there is potential for C002 to request that their supplier provide them with products that meet certain environmental performance targets, if C002 are dedicated to implementing ENPD. C002 have a history of paying more to ensure that they get the best quality possible, such a practice could be extended to environmental consideration if they pay more to get products that have higher environmental performance.

C002 practices both sole and multi-sourcing; they prefer sole sourcing as it allows them to cultivate strong ties with their suppliers. Where they practice multi-sourcing, it is mainly due to individual suppliers not having enough capacity to miss their demand. By mainly favouring sole sourcing, C002 are exposing themselves to supply risk. If there were to be a problem with their suppliers, they would likely find themselves in a situation where they could not meet their product demands.

Due to a number of different factors, which include cultural and language barriers, C002 are not always able to get the information that they require from their supply chain. In these cases, they do their own tests to determine a range of technical aspects relating to the products. There is there possibility of utilising the same tactic to acquire information related to the products they buy in to use in environmental assessments. It the moment C002 do not know if their suppliers have information relating to the environmental performance of the products that they supply and if they would be willing to share it. C002 plan to supplement the information they get from suppliers and in-house testing with information that is available in environmental and materials databases. Their priority will be to ensure that they have the most accurate information regarding the components that are the most critical in terms of environmental aspects.

C002's industrialisation team are able to gather a wealth of information and share it within the organisation through the use of enterprise software. This is information that is captured during various product development projects through phone calls, visits, data sheets, reports etc. There are a series of databases that contain information that designers can access from their workstations. This means that these databases can be used to ensure that information that is coming from the supply chain is available to the designers as they design products. This means that designers can make environmental decisions using information that comes in from the supply chain. Information for ENPD can be enriched if C002 adopts an EMAS, resulting in more information regarding suppliers' environmental issues being available to designers.

Even though C002 does not map its supply chain and has no visibility beyond tier 1 and 2 suppliers, it can use its enterprise system and the information within it to build supply chain maps. As they practice ENPD, C002 will need to ask their suppliers for information that can be used to map their supply networks beyond the first tier.

Case 3: Procurement in ENPD Organisation.

C003 is an automotive business that is built around one of the world's premier luxury sports saloon and sports car marques and the world's leading manufacturer of premium all-wheel-drive vehicles. All of its vehicles are engineered and designed in the UK, where the business is headquartered. With more than 80% of the vehicles it produces being sold abroad and selling to 178 countries, C003 one UK's largest exporters by value; it is also its top investor in R&D in the manufacturing sector and is in the global top 100 for R&D spend. It has a number of assembly facilities and test and development centres located around the world. Globally, it employs approx. 32k people and supports a further 210K though its dealerships, suppliers and businesses.

> *Delivering sustainable growth and continued innovation is at the heart of our continued transformation, to become a world-class premium automotive manufacturer – Environmental Innovation Strategic Core Pillar*

With environmental innovation as one of its three core strategic 'pillars', C003's strategic approach to sustainability aims to minimise the impact of its cars on the environment either through technologies embedded in its vehicles, more sustainable manufacturing or CO_2 offsetting. It was one of the first companies to be fully certified under the international environmental standard ISO14001 and one of the first UK vehicle manufacturers to complete an officially recognised study of the overall environmental impact of a vehicle. Its sustainability governance structure is part of the reason why sustainability is so embedded strategically in the way it does business; all business functions have a set of sustainability targets that they are responsible for working towards.

> *"We got some very specific things that come from the very top of the business and are things that we must do. Environmental innovation is one of the company's three passions so we have it is in the triangle."*

Context Setting

C003 seeks to establish profits by offering products that customers desire in the premium performance car and all-terrain vehicle segments. Higher degrees of globalisation, fuelled by increased penetration of Internet and social media channels, has resulted in greater customer awareness and increased competition, which has driven the automotive industry to become more customer-centric in recent years. This is particularly the case for the premium automotive sector in which C003 operates, where sophisticated customers demand the very best. Resultantly, to ensure that their products remain relevant, C003 undertakes significant market research to understand customer needs and anticipate emerging trends.

> *"We have a whole group of people who troll various fashion magazines, blogs and websites… they say in two years' time, four years' time, there is a market gap opening up. We then have to put something together to answer the fashion lines that they have picked up to deliver at that point in time."*

Some of C003's actions are governed by legislation. Currently, they have a legal requirement to support their customers wherever they are in the world for ten years, subject to local legislation; however, they structure their business such that they are in a position to do that for fifteen years. C003 looks at legislation as the minimum that it has to achieve to remain in business, it is its ability to give the customers what they desire by anticipating fashionable market needs that they believe sets them apart.

> *"In some respect the product has a different set of facets. It isn't a must have, it is a fashion accessory. Because it is a fashion accessory driven by the natural fashion attitude that occurs in the world. We have an attitude that says we have to refresh them every couple of years otherwise they get tired."*

Over the last few years they have broadened their market research to gain an understanding of the kinds of perceptions that their customer base has regarding the environmental performance of vehicles. While this process has yielded varying results across different market, there are cases where there is customer demand for improved environmental performance. This drives environmental product development and goes beyond C003's own drivers for environmental innovation.

New Product Development

New product development is the cornerstone of C003's business. As they aim to keep up with trends, they give their vehicles regular 'facelifts' however, while they might keep the name the same they cannot keep the vehicle the same eventually they replace the underlying componentry and architecture. Every few years, a whole group of vehicles from a particular platform are replaced, every two years one of the vehicle lines has to be refreshed. C003's products are mass customised to meet their customers exacting needs. They have such high levels of personalisation that even with approx. 900 individual part members in an individual vehicle, it is possible that no two cars on a single production line will be identical for a whole year within a single vehicle line. The shortest development cycles that C003 has are predominantly associated with the introduction of legal issues and these take approximately one and a half years to go from concept to production. Developing a full platform of vehicles typically takes approximately six years for the same concept to production cycle and falls on the opposite end. All other development projects come in-between.

The environmental innovation that is at the heart of C003's corporate strategy trickles down from the very top of the business into the development process where it manifests as a series of complex decisions to be made as conflicting attributes that need to be reconciled arise. An example is how to proceed when there is the opportunity to produce a lighter product that produces less CO_2, requires less horsepower to drive and uses less fuel but requires exotic materials that come at a premium cost.

Internal and External Collaborations

Environmental new product development is undertaken in C003's Group Engineering department. The Group Engineering department is made up of a number of key groups, one such group, which is central to C003's product development process, is the Design Group. This group is split into four core groups: Body Design, Chassis, Power Train and Electrical. These groups are responsible for designing components and work on specific vehicle lines ensuring that all the vehicle development, testing and verification are all done on time. Supply chain and finance issues are key in the product development process and as shown in Figure 63, the Cost Engineering department sits between Group Engineering, Purchasing and Finance and acts as an interface for cross-departmental product development issues. By recognising that ENPD requires both internal and external collaboration and through working with Cost Engineering and Purchasing, Group Engineering has access to the companies in the supply chain.

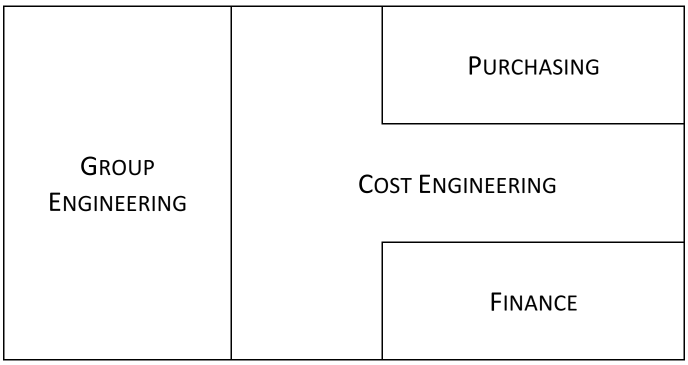


FIGURE 63: COST ENGINEERING INTERFACES BETWEEN GROUP ENGINEERING, PURCHASING AND FINANCE

The engineering that goes into C003's products is collaborative, such that it can be the case that while some of it is engineered in-house the rest is engineered with fifty fully serviced suppliers who specialise in vehicle systems; C003 source from, sell and make their products available around the world. The pursuit of ENPD means that C003's product development has taken on a life cycle perspective, as a result they have started to place greater burdens in terms of environmental impact reduction on their supply chain and the materials and components that they supply. They are placing greater emphasis on educating suppliers to make them understand what underpins ENPD and what they are trying to achieve through it; they also hope to stimulate innovations and solutions that can help them reduce their environmental impacts further.

Supply Chain Management

With a supply base that is comprised of upwards of 600 suppliers, C003 segments its suppliers in terms of the services that they provide. These range from 'off-the-shelf' suppliers, where C003 pays for standards parts to be delivered, to 'value made' suppliers, where C003 provides the supplier with a specification and pays for the specified product to be delivered. Figure 64 outlines the different supplier types and services that C003 categorises its supply base into.

SUPPLIER TYPE	SERVICE DESCRIPTION
OFF THE SHELF	C003 orders standard parts that are delivered by the supplier.
MADE TO PRINT	C003 completes all the design work and undertakes all the risk; the supplier makes and delivers specified number of the part.
VALUE	Supplier with capability but no capacity, C003 gives the supplier who has technological know-how a specification to work to and the supplier delivers part designs to be manufactured by a 'made to print' supplier.
VALUE MADE	Supplier with both capability and capacity, the supplier designs and develops a product to specification, manufactures and delivers it to C003.

FIGURE 64: TYPES OF SUPPLIERS AND SERVICES

Over time, C003 has found that while 'value made' suppliers provide the best technological know-how, they tend to manufacture products at a higher cost when compared to 'made to print' suppliers.

> *"The mere fact that a company has development capabilities and expertise that you do value does mean that the product that they deliver has a nasty tendency to be expensive."*

Resultantly, they have started splitting the development and delivery of products wherever benefits can be attained.

> *"If we have paid for the design and development provided we have achieved ownership and rights to the I.P. then we should be able to get it manufactured by anybody."*

For example, C003 commissioned the design of an audio system from a high-end audio company and had a separate speaker manufacturer deliver the speakers licensed via the high-end audio company. In the end, by splitting the development and production, C003 ended up with a system that was delivered at a lower net cost. Additionally, C003 also segment their suppliers based on the relationships that they have with them; these relationships are outlined in Figure 65.

A: FULL SERVICE SUPPLIER	B: DEVELOPMENT SUPPLIER
Full board partnership, supplier brought in-house as a family member.	Investment is made into developing a supplier with promising 'full service supplier' potential
C: PERFORMANCE SUPPLIER	D: BASIC SUPPLIER
Collaborative relationship, involved parties work together to attain mutual goals.	Arm's length relationship, transitory and cost driven.

FIGURE 65: TYPE OF RELATIONSHIPS WITH SUPPLIERS

There is potential for suppliers, if they desire to do so, to move through the quadrants and evolve from a basic supplier relationship to a full service supplier relationship. The natural progression is for the suppliers to start from a basic supplier relationship and work upwards, however, it is possible for a supplier to start higher up. In some instances they put suppliers straight into supplier development, for instance when they encounter a company that has a technology they are interested in but does not seem to have long term stability. Typically, performance relationships involve C003 working collaboratively with the supplier to ensure that the supplier can produce components to volume and cost and occasionally C003 takes co-ownership of any intellectual property that comes out of that process.

Currently, one of the biggest challenges faced by C003's purchasing department is that of concluding its purchasing duties in the time that is assigned to them during the product development process. At the moment, they have on average three months to make the necessary sourcing decisions regarding approx. 20000 components that go into a vehicle. This is particularly challenging because they have to know which suppliers to approach and complete due diligence as to whether that particular supplier is sustainable in the long term and whether or not they meet their requirements to be able to supply into particular regions. They primarily use a 'bonus-malus' or 'rewards-penalties' methodology to review a supplier's capability to deliver what is required and their ability to sustain the supply. Within C003, the sourcing decision is a very complex one.

To ensure that they have an in-depth understanding of their suppliers, the purchasing team is divided into four major groups, Body Design, Chassis, Power Train and Electrical, which correspond to the core groups in Group Engineering's Design Group. Through various methods like site visits and discussions, each group aims to attain specialist knowledge of the suppliers that they deal with.

C003 are constantly looking for ways to improve their supplier sourcing process and are actively looking to develop tools and methodologies that will make supplier sourcing less emotional and more robust and data driven. One example of this is their shift from 'should costing' to 'parametric costing' to help them make better cost estimates and projections of economies.

Historically, C003 have practiced sole sourcing with one supplier for each component. However, the company's business strategy requires that they have multiple suppliers and this is what they are transitioning to. The biggest challenge that they face with multi-sourcing is that of traceability; it is hard to know who produced what when the parts allegedly look the same. With one supplier under one plant, it is relatively easy to know who supplied a part that was fitted onto a particular vehicle. When multiple suppliers are producing the same part, things get more complicated. For example, C003 pays for parts and components after they have been fitted onto their products so having multiple suppliers for identical parts makes it difficult determine whom to pay when the time to process payment comes. Another complication arises when the suppliers producing the same part are from different regions and for whatever reason you have to pull the part from one region and not another. This means that adequate segregation of parts and suppliers is required.

Supply Chain Mapping

For C003, their ability to map their supply chain has a myriad of implications. It affects anywhere from their ability to sell the vehicle in the first place to being able to defend litigation that can be brought against them if a particular component on their car fails and they have to ascertain if it was the part that was fitted originally or if the part came out of the grey market.

In addition to mapping their supply base in terms of the internal engineering groups that they support, C003 map their suppliers in terms of their capability and competency, which relationship segments they fit into, their geographical location, the levels of investment that they are putting into the future, their short/long term development plans etc. C003 terms this 'business intelligence' as they attempt to distribute data in a more intelligent and linked up manner that allows them to look outside themselves to what their supply base is doing.

C003 recently found themselves in a situation where, due to insufficient knowledge of their supply network beyond the first tier, they supplied into a region vehicles that contained parts from an embargoed state. They recognise that it is key that they are able to map their supply chains beyond the first tier and accurately trace where parts in vehicle comes from and acknowledge that it is not an easy task. However, it is something that they are working on actively solving. While they were not willing to disclose exactly how they are tackling this issue, they hinted towards the use of an 'intelligence tool' that can manage complex supply chain relationships. Working in conjunction with a business enterprise software producer, C003 hope to develop a web-based system that can help the automotive industry better understand where key sustainability risks lie in their supply chains.

Organisational Information Sharing

When it comes to sharing information within the automotive industry C003 have found that there are far too many business areas that are segregated and driven from the top. This slows down any interactions and to become nimbler, a move is required from matrix relationships to networked ones where cross fertilisation can happen quicker. However, it is more than just the organisational structures that are hampering this agility, there is also a lack of adequate supporting IT infrastructure. The automotive industry shares common suppliers, by consolidating the information sharing, what may be difficult to do for an individual organisation becomes easier to achieved collectively. In essence with the tool, everyone can feed data in; without the tool only one-to-one information sharing is achieves and dissemination of that information becomes difficult. Through the web based system information can be disseminated on a minute-to-minute basis.

Conclusions

C003 is a company that is driven by customer needs and emerging trends; they are finding through their market research that some customers are demanding cars with improved environmental performance. This supplements C003's internal drivers for environmental product development. Internally, environmental drivers trickle down from the very top of the business and are embedded in practices that the employees have to adopt.

To aid Group Engineering during ENPD, C003 has the Cost Engineering group playing an interfacing role with internal functions as well as the supply chain. Due to the important role that the supply chain plays within ENPD, C003 works closely with their suppliers to ensure that they understand what C003 is trying to achieve and how they fit into the picture. Essentially, they try to disseminate environment awareness to their supply chain. With C003 working collaboratively with their suppliers to improve cost, quality and potential to deliver, it is not out of scope that they would also work with their suppliers to improve environmental performance where possible. C003 extensively maps their supply base in terms of a number of different factors as a form of business intelligence that allows them to have an in depth understanding of industry dynamics.

A shift from sole to multi-sourcing is proving challenging to C003 in terms of traceability for risk management. It is now harder to know exactly where components are coming from and to keep track. This also likely adds complexities to ENPD as an increase in suppliers means more information is needed from more sources. C003 is looking to address some of the issues associated with managing supply chain relationships through the use of a web-based system that helps the automotive industry better understand where key sustainability risks lie in their supply chains. As many of the companies within the industry share customers and suppliers, by consolidating the information sharing, what may be difficult to do for an individual organisation becomes easier to achieve collectively as an industry. However, this is more than a technology issue and it is essential that the right organisation structures are in place that make sharing information easier.

Case 4: Procurement in ENPD Organisation.

An automotive manufacturer headquartered in Japan, with a global workforce of over 330k employees, C004 is not only one of the largest vehicle manufacturers in the world, it is also one of the largest companies in the world by revenue. It currently has an annual production output of over ten million cars a year and through its lifetime has produced over 200 million vehicles. Its product offerings, which are produced under five distinct brands, include standard vehicles, luxury vehicles, commercial vehicles and engines.

C004's long-term success is widely attributed its unique production system that drives down cost and improves quality, a concept which it captures relatively simply as follows:

> *"A production system which is steeped in the philosophy of 'the complete elimination of all waste' imbuing all aspects of production in pursuit of the most efficient methods" – C004 Production System*

C004's philosophy and approaches are much more complex than can be captured by simple statements; they are culturally embedded and spread across the whole supply chain. While many other organisations have adopted some of the techniques implemented by C004, the durability of the competitive advantage lies within the implicit aspects of C004's organisational knowledge and is driven by organisational culture. This makes replicating C004's operations challenging for competitors. While initially, C004's success was attributed to the Japanese national culture, the world-wide network of the C004 production facilities would indicate that C004's approaches have been proven to be successful outside of Japan and its national culture.

Context Setting

Today, the automotive industry faces the following three challenges regarding energy and environmental issues:

1. Finding energy sources alternative to oil
2. Preventing air pollution
3. Reducing CO_2 emissions

Additionally it is faced with issues that extend past vehicle usage such as those within the manufacturing process and disposal of the vehicle at its end of life. While some of these are driven by legislation, rising costs and the need to source cost-effective materials for components are also critical to competitiveness. Most major automotive manufacturers deal with the environmental agenda in similar ways but each have their own unique projects that attempt to create competitive advantage. In addition to conventional vehicles, with models in over 20 vehicle series, hybrid vehicles are a cornerstone of C004's product offering. It is also working on the development of range of technologies, including plug-in hybrids, electric vehicles and fuel cell vehicles, so that customers can choose the type vehicle best suited to their application.

New Product Development

C004 is renowned for its ability to bring to market a new product in much less time than its competitors. The design and development of a new platform of vehicles typically takes 36 months, from concept to production. As illustrated in Figure 66, the process is split into two distinct stages. The first stage, the fuzzy front end which serves as a means for coming up with several wide-ranging design options, and the second, the detailed design phase where the final chosen design is developed for production.

	Product Development		Production
	Fuzzy Front End	Detailed Design	
Time (months)	0	18	36

FIGURE 66: C004'S PRODUCT DEVELOPMENT PROCESS

During the first stage of the development process multiple sets of possible design alternatives, all aimed at broad goals, are explored. Connections between subsystems devised during the initial stages are kept loose to give designers flexibility in how they approach specific problems.

> *"Product development isn't so much about developing production as it is about developing knowledge about the products"*

C004 splits the product development process because during the first stage the design is not stable yet and developing manufacturing process plans at the same time would likely result in wasted efforts. Instead, manufacturing and engineering jointly decide on trade-offs in that early stage and only once they have finished the resulting sets of trade-off curves, then it is okay to do process planning and detailed design simultaneously.

The second phase is focused on development for production and is undertaken through the use of concurrent engineering and stage gates. One of the key factors that are considered during this phase is the impact of the supply chain. For example, the more parts that can be shared by multiple vehicles, the greater the efficiency, as there will be fewer part numbers and a higher volume of parts produced per part number. The result will be improved economies of scale and the ability to source high-volume parts multiple suppliers. This means that the C004's purchasing department has a pivotal role within the product development process.

Internal and External Collaboration

Working in close collaboration with quality and engineering departments, the purchasing department is responsible for the sourcing of parts and components. And with many of C004's suppliers collaborating with the engineers on the design and development of selected components, purchasing is responsible for managing supply chain relationships. Greater global complexity has resulted in supplier considerations becoming central to C004's strategy. C004 is organised into the following operational functions: Plant Engineering, Production Control, Logistics, Quality, Information Systems, Accounting/Finance, Purchasing, Sales/Marketing, Distribution, Product Planning, Design and R&D.

It has a matrix organisational structure and ensures that processes are standardised by functional area. Practices are spread through C004's global network through a top down approach. Global function management is responsible for 'best practices' of processes, while local management is responsible for day-to-day operations. This is the basis of the concept they use to spread best practice supply chain practices, not only to the parts of the supply chain internal to themselves but also to dealers, suppliers and contractors.

C004 have a culture of improvement that is built from a philosophy and specific practices aimed at continuous improvement in manufacturing, business, and life by eliminating all forms of waste. Individuals across the company are encouraged to develop and submit improvement ideas into an enterprise-wide database. Additionally, they promote cross-functional teamwork to ensure that all internal and external parties are collaborating to continuously improve both processes and operations.

Supply Chain Management

C004's approach to supply chain management is an element of its operations strategy and is based on the philosophy of its production system. During the sourcing process, purchasing considers a myriad of factors; these include supplier capability and capacity, current supply base location, price etc. Additionally, they consider the impact that the supply chain has on the product. For example, they enable flexibility to change option closer to production by purchasing option-related parts from suppliers located closer to the assembly plant. C004 is extra diligent when sourcing suppliers as they aim to ensure that chosen suppliers are a good fit with the rest of the network. Some of C004's suppliers are selected due to the capability that they possess to improve processes or decrease cost. Both new and existing suppliers are expected to share their innovations with others that supply similar products. Being a C004 supplier comes with an opportunity to benefit from innovations and ideas generated across the supply network. C004's approach to the supply chain emphasises close relationships across the supply chain and collaboration to maximise supply chain performance. Its goal is it minimise the number of suppliers and create long-term partnerships by nurturing existing suppliers to expand instead of increasing the number of suppliers to induce price competitive bidding.

Relationships with suppliers range from 'drawing supplied' to 'drawing approved' and vary depending on what is being produced, with intermediate relationships involving C003 providing drawings and the suppliers completing all the rest. These relationships are outlined in Figure 67. C004 outsources a lot of design and manufacturing work, while suppliers may be given flexibility during design, they are subject to tight monitoring during manufacturing.

Relationship		C003	Supplier
	1	Purchases out of catalogue	Delivers
Drawing Supplied	2	Provides drawings and detailed manufacturing instructions	Manufactures and delivers
↕	3	Provides complete drawings	Designs the manufacturing process, manufactures and delivers
	4	Provides rough drawings	Completes drawings, designs manufacturing process, manufactures and delivers
	5	Provides specifications and generates manufacturing instructions	Generates drawings, manufactures and delivers
Drawing Approved	6	Provides specification	Generates drawings, designs manufacturing process, manufactures and delivers

FIGURE 67: TYPES OF C004 RELATIONSHIPS WITH SUPPLIERS (FROM DOCUMENTATION)

Through the use of key performance indicators (KPIs), C004 has high levels of monitoring across its operations. Some of the KPIs it uses to evaluate suppliers include quality, on-time delivery and cost targets; suppliers are required to review and share these KPIs daily. Essentially, C004's suppliers are governed by three goals the following three goals:

1. Produce quality goods
2. Maintain and improve production volumes
3. Reduce costs

As a result, it can be difficult for them to embrace ideas or changes that put any of these goals at risk. Suppliers also tend to be initially anxious about the high levels of collaboration and information sharing required by C004 as they require the break of down any organisational functional silos that might exist and are usually guarded; their breakdown creates insecurity. Additionally, based on past traditional relationships, there is initially a general lack of trust between the suppliers. C004 emphasises an alignment of goals, congruence of incentives, synchronisation of decision making and sharing of resources across the supply chain, and over time mutual respect develops and suppliers realise that involvement is beneficial. By having suppliers as partners, C004 can work closely with them to operate an effective and efficient supply chain. Supply chain partners share in the profits during good times and experience the hardships of the challenging times.

C004's philosophy is based on eliminating waste, and one such way is through the removal of unnecessary cost. This is imprinted on the suppliers who understand that C004 want to decrease costs. During price negotiations, C004's purchasing department practices parametric costing; parts are broken down into specific commodities and a cost index method benchmark is used to identify a globally competitive cost point for each commodity.

Organisational Information Sharing

With employees urged to "*listen intently in an open environment*", informal information system exist within C004 that allow free flow of information up, down and across the hierarchy. Collaborative communication is crucial for C004 as it facilitates the creation of joint knowledge and through information technology, information can be shared across the supply chin and activity coordinated. For C004, investment in information technology is not enough; it is simply not the application of the technology that is important but rather, how it is used. While they are continually exploring ways of utilising technology, they also assess its operational impact to combat the challenges that are associated with the application of information technology to supply chains. By giving freedom to people to voice contrary opinions, making tacit knowledge explicit and having frequent face to face interactions, C004 ensures that communications are reinforced and that employees and supply chain partners alike are kept informed.

Supply Chain Mapping

In a bid to remove slack from its supply operations C004 pruned its supplier base severely, for some parts to a single supplier, and used just-in-time parts delivery to keep inventories to a minimum. In part thanks to its tightly managed supply chain, they attained the position of 'best-selling automaker worldwide.' However, this exacerbated the risks inherent in their supply chain and left it vulnerable to disruption. Following a series of natural disasters in Asia, despite having no significant damage to factories of its own, C004's production suffered. They found that many of the shortages originated from sub-tier supplier that were not tracked or managed for risk. Stung by the experience, C004 set to transform its supply chain to make it more responsive and to get to know it better.

> *"We thought our supply chain was pyramid shaped, but it turned out to be barrel-shaped"*

Before they mapped their supply chain C004 had assumed that the number of suppliers increased with each sub tier in a pyramid hierarchy, which would tend to provide redundancy. However, upon completion of the exercise, they found that in reality supply chain sub tiers included unique factories that provided materials, parts or production processes to many upstream suppliers and that their supply chain had more of a 'barrel' shape; the two supply chain shapes are shown in Figure 68. As a result, they did not realise that they had critical sub tier suppliers and they had failed to manage the risk at these and other hard-to-replace sub tier suppliers.

			C004			
		T1	T1	T1		
	T2	T2	T2	T2	T2	
T3	T3	T3	T3	T3	T3	T3

		C004		
	T1	T1	T1	
T2	T2	T2	T2	T2
T3	T3	T3	T3	T3
	T4	T4	T4	

FIGURE 68: PERCEIVED SHAPE OF SUPPLY CHAIN VS. ACTUAL SHAPE

Following the experience, C004 worked on developing a more flexible and effective supply chain with high visibility. Visibility, gained through supply chain mapping, is the crucial starting point for managing sub tier supplier risks and this visibility is gained through the sharing of information through the supply network. Today, C004 is working collaboratively with other automotive manufactures and business enterprise software designers to develop technology that enhances the industry's understanding of complex supply networks.

Conclusion

C004 is an organisation that is driven by its strong organisational culture and its success is deeply rooted in the knowledge and understanding it has of itself as an organisation. It offers its customers a range of both conventional and eco-motor vehicles that are globally competitive. Supply chain considerations come into C004's development process early, even though finalisations are not made until the second phase of development, during the first stage manufacturing and engineering jointly decide on trade-offs. In the second phase, the supply chain is then designed. Within this phase, supply chain design has a great impact on the product design as products are designed to share parts to make supply chain management easier. This means that the purchasing department has a pivotal role in product development as it influences how the products are designed. The relationship between engineering and purchasing is a two-way one where one influences the other. In addition to sourcing components and collaborating with internal engineering, the purchasing department is also responsible for supply chain relationships for both procurement and supplier collaboration in new product development.

As a large company, C004 practices are spread through a top down approach internally and with its supply chain and those associated with their business. C004 promotes cross-functional teamwork to ensure that all internal and external parties are collaborating to continuously improve both processes and operations; this feeds into a strong company culture of improvement. This culture of improvement extends outside of the company as C004 expects its suppliers to share their innovations with others that supply similar products. Through this all the suppliers benefit from innovations and ideas generated across the supply network. C004 encourages informal information systems to exist, with information flowing freely across the organisation and across the supply chain information technology aids information sharing. While there are challenges that C004 faces when inducting new suppliers to its way of doing things, over time the benefits of being part of such a system are soon evident. While it might seem like being open would leave you exposed to various kinds of business risks, C004's way of doing things shows if managed correctly otherwise competing companies can work together for mutual benefits.

While many of C004's initiatives have been successful, when it streamlined it supply base to single suppliers for some parts, C004 exposed itself to supply risk. Because it did not have full visibility of its supply chain, it was not able to adequately manage the risk that was associated with some of its sub-tier suppliers. C004 has made assumptions about its supply chain, assumptions that turned out to be erroneous. This incident highlights why it is important for organisations to have adequate visibility of their supply chain. This is a practice that is not only essential for the management of business risk but also one that is key to ENPD. This is not an issue that affects C004 alone and they are working collaboratively with others within the industry to develop technology that enhances the industry's understanding of complex supply networks.

<u>Case 5: Green Procurement in ENPD Organisation.</u>

A leading global manufacturer and supplier of residential, commercial and industrial use air conditioning systems; C005 is a multinational company with a well-established presence in China, South-East Asia, Europe, North America, and its native Japan. The company employs a staff of approx. 56k, has over 80 production bases worldwide, sells its products in over 140 countries and achieves annual sales in excess of $10 billion. C005 is an innovation leader that focuses on cultivating next generation technology from three of its cutting edge core technologies. As a testament to its dedication to technological innovation, C005 recently invested $300 million in Technology and Innovation Centre where it aims to converge diverse technologies and knowledge in one place, from both inside and outside the group, in the hope of creating an environment that gives birth to new value.

> *"Be a company that leads in applying environmentally friendly practices" – C005's Environmental Philosophy*

While continuing to develop its various business operations, C005 is on a mission to proactively develop initiatives to respond to environmental issues. It prides itself on being a leader in the practice of environmental management who contributions to a healthier global environment. As a company that is keen to boost environmental awareness both internally and externally, C005 has a number of environmental education programs that employees can partake in.

Context Setting

C005 aims to actively formulate initiatives that sustain and improve the environment in all aspects of its business operations, including product development, manufacturing and sales, while actively promoting the development of environmentally sustainable new products and innovative technologies. The company's environmental action plan is based on the following three pillars:

1. Providing Environmentally Conscious Products
2. Eco-conscious Factories and Offices
3. Environmental Cooperation with Stakeholders

Following on from that, C005 has five action guidelines that embody the essence within the three pillars. One is regarding C005's goal to be a leader in society by developing products, technologies, and business opportunities that contribute to sustaining and improving the environment through the development and implementation of environmental initiatives in all aspects of its business operations, including product development, production, sales, distribution, services and recycling. Another is to establish, promote, and continuously improve an environmental management system (EMS) to actively and effectively implement environmental management as a Group. All major C005 bases around the world have ISO 14001 Certification. In Japan, all its bases and subsidiaries come under an integrated ISO 14001-based EMS and the company is working towards building and operating the EMS across the entire group. At C005's headquarters the Environmental Management Department is responsible for all EMS related issues, the department is comprised of seven groups as illustrated in Figure 69. The other three guidelines are related to organisational learning surrounding environmental issues, promoting implementation of environmental initiatives by external organisations and openly disclosing environmental information.

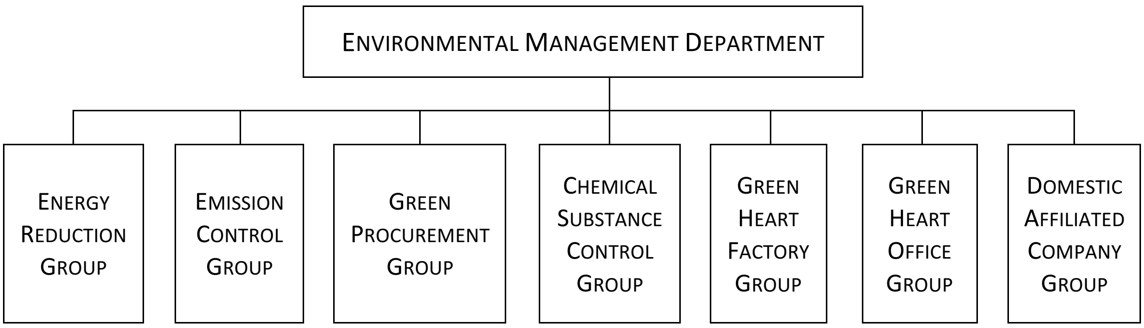


FIGURE 69: ORGANISATION OF C005'S EMS (FROM DOCUMENTATION)

New Product Development

Historically, C005 launched air conditioners developed for the Japanese market in overseas markets, which made them a hard sell with their overabundance of features and high prices. Resultantly, it spent more time on product development in order to redesign products to meet the demands of regional needs. As C005 was looking to rapidly expand its worldwide presence in emerging markets, the ability to launch timely products to meet the specific needs of each regional market became the key for further growth. This required a change in the way that they developed their products and resulted in the development of the base concept model of product development, a modularisation or platform based approach. Through this concept, and a boost in development capabilities at its worldwide bases, C003 could satisfy the needs of specific regions by having the overseas bases mix and match the basic performance factors and common parts from Japan; this concept is illustrated in Figure 70. Through the base model concept, C005 were able to simultaneously start product development in multiple countries, cutting time to market in half while producing constantly high quality products at lower costs.

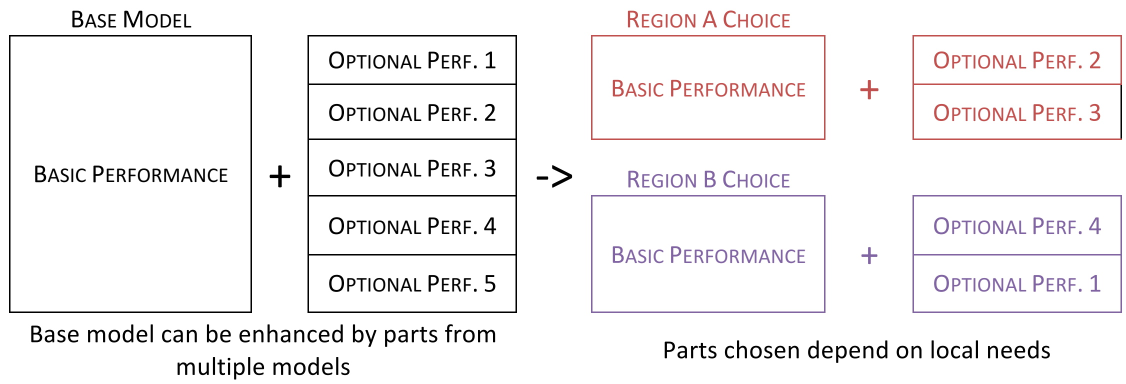


FIGURE 70: C005'S BASE MODEL OF PRODUCT DEVELOPMENT (FROM DOCUMENTATION)

Over 90% of CO_2 emitted by an air conditioner throughout its life cycle, from design and manufacture to use and disposal, is emitted during the use phase. This means that the environmental performance of C005's products is intrinsically linked to energy efficiency. Resultantly C005 considers product environmental performance to be on par with other basic product development factors such as performance, aesthetics and ease of use. Along with switching to refrigerants that have the least possible burden on the environment and making products easier to recycle at the end of their life, C005's environmental efforts in product development are also concerned with improving energy efficiency. C005 practices what they call 'environmentally conscious design through assessment' where they incorporate product assessment in the planning and design stages of new products.

> *"Guided by assessment results, we design our products so that they are smaller and lighter, have fewer parts, and that they are easy to maintain, separate and recycle."*

C005 designers have a product assessment process that contains 14 assessment items, which they adhere to strictly when developing products. They primarily use the life cycle assessment (LCA) method as it allows them to determine the environmental impact at each stage of the product's lifecycle. Figure 71 is an illustration of the typical lifecycle of C005's products; the design team considers the impact of products at the stages shown in the diagram. Products only make it to market after they have been assessed against predecessor products to confirm that they exert less environmental impact.

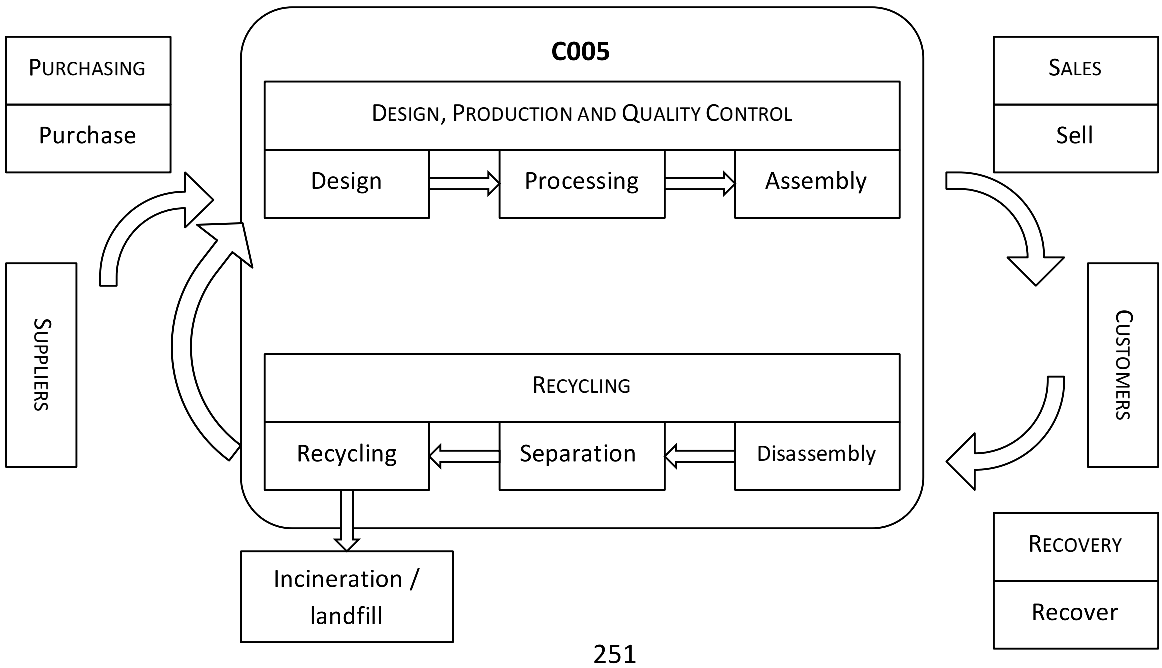


FIGURE 71: TYPICAL LIFECYCLE OF C005'S PRODUCTS (FROM DOCUMENTATION)

Internal and External Collaboration

The design team is primarily involved the product development process; however they are supported at various stages of the process by members of production, purchasing, quality control, sales and service and distribution. The contributions of the other functions are particularly evident in the design review process that C005 adopts; the review process is illustrated in Figure 72. First, products are inspected in the individual design review and when they pass, they are assessed at the gate design review; only those that pass both make it to market. In addition, C005 enlists the help of its suppliers during various stages of the development process, particularly in improving quality and achieving zero defects.

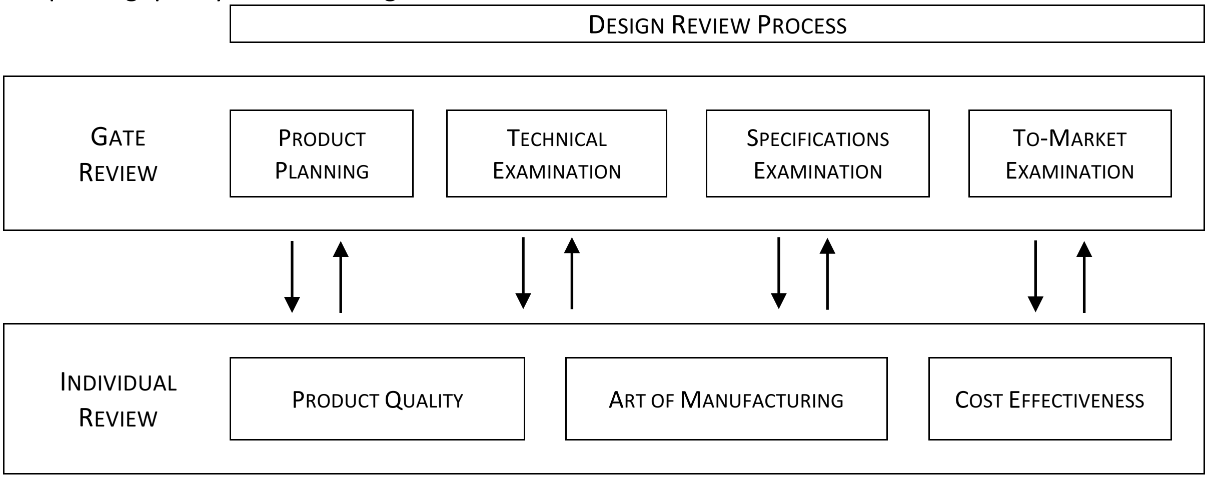


FIGURE 72: C005'S DESIGN REVIEW PROCESS

Supply Chain Management

As they develop products that have minimized environmental impacts throughout their lifecycle, C005 also aim to procure parts and materials with as little environmental impact as possible. Resultantly, C005's purchasing department practices green procurement. This means that as they source suppliers for parts and materials to go into their products, they will prioritise those that aim to reduce their environmental impacts. An added benefit of green procurement to C005 is that it links to risk management and through it C005 can ensure that its products do not contain any hazardous chemical substances. During procurement, C005 places equal emphasis on the factors that are presented in Figure 73.

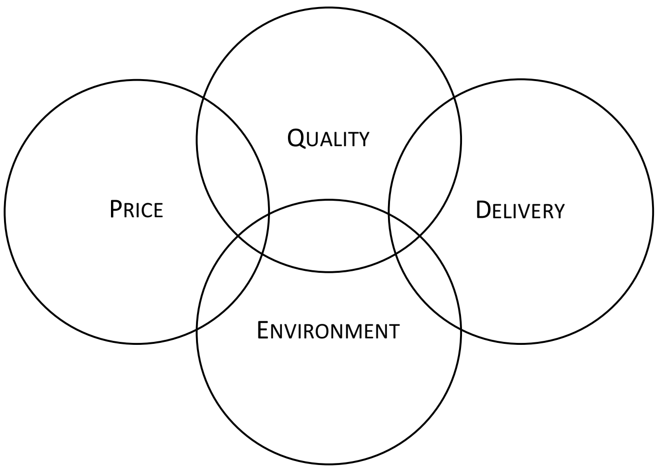


FIGURE 73: KEY FACTORS IN C005'S GREEN PROCUREMENT PROCESS

Environmental issues manifest at various stages of the lifecycles of C005's products, Figure 74 lists environmental actions that C005 implements or aims to implement to tackle these issues; it shows the action that C005 takes internally during design and manufacturing along with how the green procurement impacts actions that suppliers take.

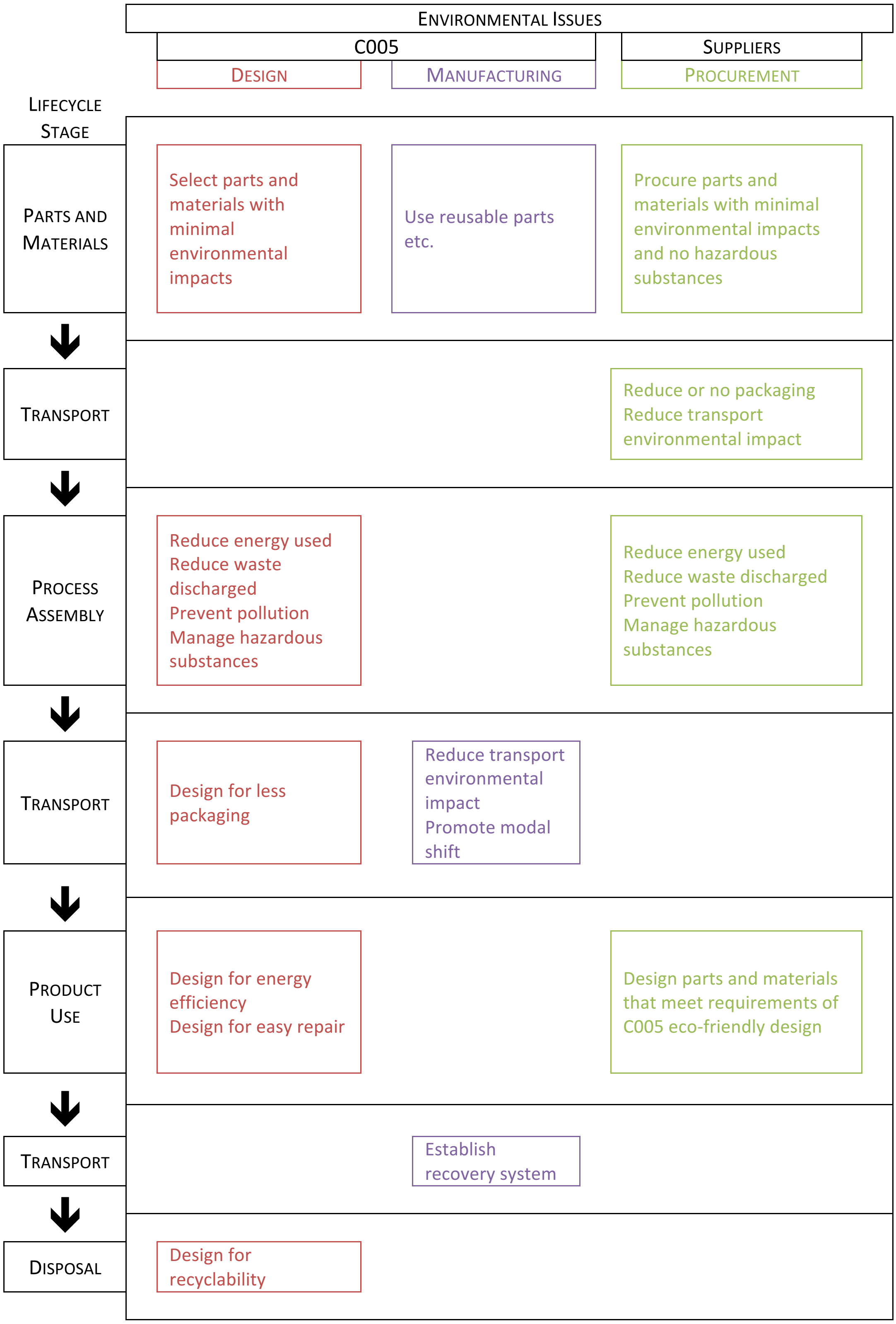


FIGURE 74: ENVIRONMENTAL ACTIONS THROUGHOUT THE LIFECYCLE OF C005'S PRODUCTS (FROM DOCUMENTATION)

The key to C005's green procurement is purchasing green materials and parts from green suppliers wherever possible. It has 'green procurement guidelines' that are the cornerstone of its procurement activities. To get them to conduct their business in an environmentally conscious manner, C005 suppliers are required to follow C005's 'green procurement guidelines' when they undertake their own procurement activities, and are also urged to establish and operate their own EMS and obtain ISO14001. C005 extends this to all supplier in their supply base. However, depending on the products being supplied and the quantities, some suppliers are given the opportunity to voluntarily opt out. It has a system of managing the relationships that it has with its suppliers where suppliers are segmented based on the products that they supply.

> *"We have been urging our suppliers to comply with our 'green procurement guidelines' in order to conduct their business in an environmentally conscious manner."*

One of the requirements in the 'green procurement guidelines' is that whenever suppliers are designing anything they employ eco-design. When sourcing suppliers, C005 gives precedence to those suppliers that actively undertake initiatives implementing their environment related requests. C005 requires that all its suppliers, in Japan and abroad, abide by the procurement guidelines and their environmental activities are assessed by C005 through a green procurement checklist. This assessment is informed by self-evaluations that C005 requests its suppliers conduct using an inspection sheet that they supply. Based on the results they may ask suppliers to make certain improvements on their environmental activities and whenever necessary they collaborate with the suppliers to achieve the improvements.

C005 also carries out inspections on supplied goods; whenever this is done C005 feeds back to the suppliers, which leads to improved quality levels. When C005 renew contractual agreements with suppliers, those suppliers that fail to meet environmental, quality, cost or delivery standards are required to write up plans for improvement. C005 then follows up on these plans to ensure that they are implemented and that outcomes will be positive.

Organisational Information Sharing

When it comes to managing its suppliers, C005 is proactive hands on views open communication as essential. Purchasing managers and officers have regular contact with suppliers; this occurs through supplier meetings, supplier conferences, quality audits, visits to suppliers etc.

> *"We hold meetings where we engage in dialogue with our suppliers on ways to improve their quality."*

To ensure the reliability of data coming in from the supply chain and improve its mechanisms for environmental management, C005 have their data verified by a third party. Through these interactions, C005 amasses a vast amount of information. It employs the use of business enterprise software to facilitate supply chain information sharing. And has found that when making information requests to suppliers it is essential to assure the supplier that any confidential information will be handled accordingly. To promote information sharing across their supply base, C005 shares information pertaining to itself freely with its suppliers, including information relating to the environmental performance of its products. Additionally, to promote environmental information transmission, C005 extend beyond their direct suppliers and make requests to their second and third tier suppliers that they also adopt their 'green procurement guidelines.'

> *"We take every possible opportunity to communicate with our suppliers and promote mutual understanding and trust."*

To help Japanese suppliers become more internationally competitive and to boost its ability to respond to sudden changes in market conditions, C005 started an air conditioning purchasing cooperation association. Through the association it promotes information sharing among suppliers so that they can build among them a relationship of mutual benefit and growth.

Conclusion

C005 has a culture that has environmental sustainability embedded deep in everything that it does; this extends from all its internal functions to its supply chain members. For C005, integrating environmental incentives into corporate management can lead to business performance, business expansion, and further credibility with outside parties. It not only aims to have all 80 of its production bases adopt EMSs but also to have its suppliers do the same and encourage their suppliers to do the same as well. In C005's view, the future will centre on environmental issues and it aims to be a leader in society through the development of products, technologies, and business opportunities that contribute to sustaining and improving the environment.

During product development, C005 considers product environmental performance on par with other basic development factors. This means that it is not seen as an afterthought but is an integral part all the products that they develop. It is important that products only make it to market if they have better environmental performance compared to their predecessor. This environmental focus extends to their purchasing activity where they aim to procure parts and materials to use in their products that have as little environmental impact as possible. The purchasing department practices green procurement, the environment is considered a factor on par with other traditional procurement factors such as cost, quality and delivery. The purchasing department also supports the product development process by encouraging suppliers to practice their own ENPD. They try to purchase eco-friendly products wherever possible. When coupled with their emphasis that their suppliers adopt EMSs, this behaviour means that ENPD flows backwards through C005's supply chains turning the whole chain green.

C005 does not leave all of this to chance; it has a number of internal and external guidelines that are support various environmental initiatives. Additionally it is proactive and hands on when managing its suppliers and encourages open communication. It even takes extra measures to ensure the reliability of data coming in from the supply chain and improve its mechanisms for environmental management by having data verified by a third party and extending its management to sub-tier suppliers within its supply chain. C005 takes a very comprehensive approach to managing it environmental initiatives.

Case 6: Compliance in ENPD Organisation

A provider of power systems and services for use in the air, on land and at sea, C006 is a multinational holding company that primarily services four market sectors – civil aerospace, defence aerospace, power generation and oil and gas pumping, and commercial and naval marine systems. Predominantly, but not exclusively, C006's products are based on the core technology of gas turbines; it is one of the world's largest aircraft engine manufacturers in both civil and defence sectors. C006 is a global business with customers in over 150 countries and an operational presence in over 50 countries. Across all sectors it has a global workforce of approx. 54K, 15.5k of these are engineers. In civil aerospace, the sector where C006 has the biggest presence, it has 23K employees worldwide. C006 designs, develops, manufactures and services integrated power systems and has an annual revenue of approx. £15.5 billion. C006 is a long lifecycle business and its products can have an in-use life in excess of thirty years, as a result they have approx. £71 billion on the order book; this accounts to about four years' worth of revenue.

Context Setting

C006's core gas turbine technology has created one of the broadest product ranges of aero-engines in the world, with 50K engines in service with airlines, 2.4K utility and corporate operators and then 100 armed forces. With a large and growing portfolio of products and an increasingly comprehensive range of services, C006 invests heavily in R&D. It invests approx. £1.1 billion into R&D annually; this investment goes into technologies that help improve the effectiveness of their development programmes as well as technologies they intend to take to market. With approx. 600 patent applications per annum, C006 is one of the strongest patent filers in the UK.

Due to C006's engineering expertise and strong tradition of innovation, many of its products are currently market leaders in terms of environmental performance. Environmental requirements are embedded into the detailed specifications of C006's products and they focus on making products cleaner, quieter and more efficient. Over two thirds of C006's investment in R&D is dedicated to the improving environmental performance to lower fuel consumption, emissions and noise. C006's environmental strategy reflects the main focus of its investment and effort, concentrating on three areas:

1. Supporting customers by further reducing the environmental impact of products and services
2. Developing new technology for future low-emissions products
3. Maintaining the drive to reduce the environmental impact of business activities.

New Product Development

The nature of products that C006 produces is such that environmental impacts over the 'in-use' phase dominate over the product lifecycle; this is where their focus for addressing environmental impacts lies as they aim to reduce fuel consumption, noise and emissions. However, this also means that environmental impacts from other phases of the lifecycle tend to be overlooked.

> *"We are more specific in what we mean by green, it comes down to fuel consumption for example… Product design is more driven by CO_2 in the use phase and not in the manufacturing phase or the supply chain."*

With products designed to have such a long operational life, environmental problems evolve in this time making it difficult to foresee what future considerations might be. Additionally, C006's products are technically mature which limits the freedom that designers have to make more significant changes. This also extends to their supply chains, their supply base remains largely constant and they try to utilise existing supply channel for any new products.

> *"There is a lot less scope to be creative within the product development process because of the long lifecycle of products and because we are producing spares for products that were designed thirty years ago."*

While they currently focus on 'in-use' impacts of their products, C006 are open to exploring environmental performance improvements outside the 'in-use' phase if they are proven to transform into a business benefit, either through customer value or by reducing operation costs.

> *"… we have a new technology for this we need a different supply chain or we need to encourage the supplier to change over to new equipment, again this doesn't really happen at the moment because we are not having the substitute technology coming in."*

Supply Chain Management

With upwards of 15K suppliers in over 70 countries, C006's global supply chain is an integral part of its business. C006 acts mainly a system integrator and a prime contractor; Figure 75 shows what C006's supply chain looks like and the interactions between the different tier suppliers. While there is no typical C006 supply chain, as its design is highly dependent on the product and nature of component, a C006 supply chain can be up to 10 tiers deep. To successfully meet the challenges set by its customers C006 needs to continuously improve and develop, as do its suppliers. C006 believes that the key to achieving its increasingly challenging goals is to work with its suppliers to develop mutual respect, shared goals, open and honest relationships and to help each other to develop to the next level of performance. The major supplier-facing business processes within C006 are detailed in Table 122.

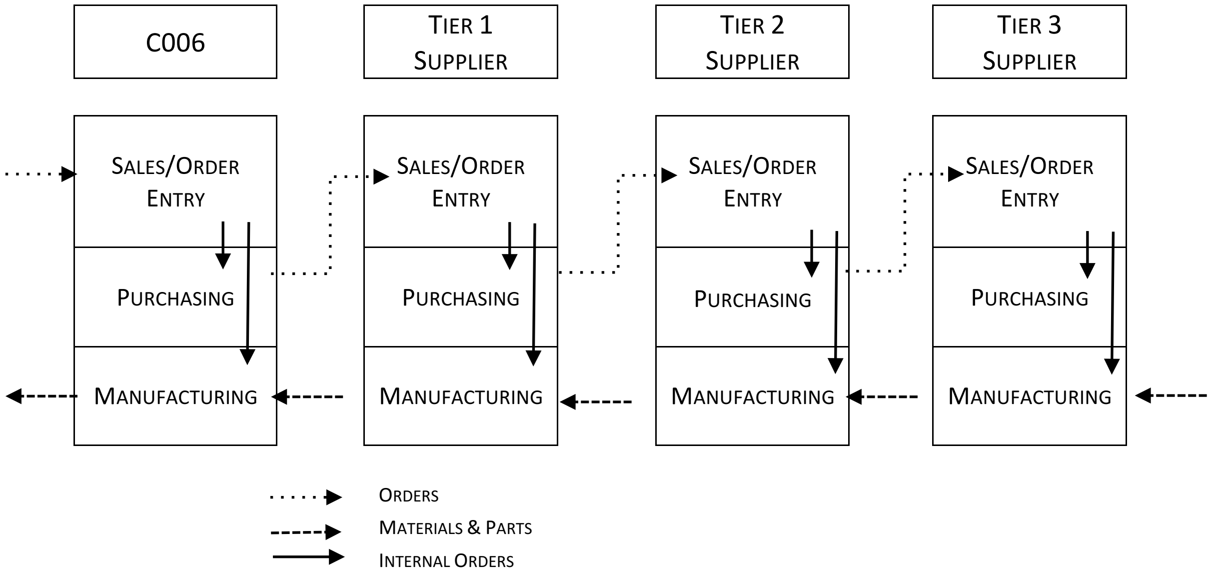


FIGURE 75: C006'S SUPPLY CHAIN EXTENDING BEYOND THE FIRST TIER (FROM DOCUMENTATION)

TABLE 122: MAJOR SUPPLIER FACING BUSINESS PROCESSES AT C006

Supplier Business Processes	
Supplier Selection and Segmentation	C006 has a global supply base, comprised of suppliers it shares with its competition. C006 classifies it supply base into strategic and non-strategic suppliers. Strategic suppliers differ from their non-strategic counterparts as they are defined as high risk or business critical.
Collaborative Product Development	Some strategic partners are also collaborators with whom C006 jointly finances and co-develops products with. In these cases, the suppliers are business partners and provide capability and/or capacity to support the product development process.
Procurement	C006 has an A-C classification of items supplied by its suppliers; this denotes the criticality of the items and influences how the items and suppliers are handled. In some cases, C006 outsources the procurement of less critical items. C006 was also a pioneer in the use of paperless procurement through the use of information sharing portals.
Supplier Management and Development	C006's engineers work with suppliers to improve suppliers' processes and mitigate any risk that their operations might place on C006's ability to deliver. It invests in developing the supplier's ability to deliver on time, at low cost and high quality. C006 also encourages its suppliers to develop complementary capabilities by sharing knowledge and transferring technology. In some cases suppliers are delegated more responsibility, such as managing tier 2 suppliers; this helps certain practices trickle down through to the lowest levels of the supply chain

C006 has two major tools that support its management of supply chain and external relationships for supplier quality assurance; the first being a standard set of processes, requirements and framework agreed upon with its suppliers. The second is a supplier portal that can to be accessed by suppliers and C006 employees anytime; the portal enhances and accelerates purchasing business functions.
C006 has instances where it develops the quality of its supply chain; these key functions are as follows:

- Supplier Approval and Maintenance – an approved vendor list is created and maintained, this involves assessments that primarily measure the capability and performance of suppliers
- Supplier Development – issues of delivery performance are assessed and required

improvement areas are highlighted on the required areas of the supply chain.

- Supplier Quality – verification of deliverables in the supply chain is achieved by many activities including physical testing, process observing, and documentation reviewing.
- Manufacturing Engineering Purchasing – to enhance the manufacturing capability of suppliers a team of manufacturing engineers is assigned to constantly support suppliers with advice and insights regarding process related issues

C006 shifted to parametric costing to tackle some of the problems that it was facing during procurement. Some of these problems included significant purchasing and operational costs, lack of control over pricing in supply chain restructuring and tiering, design building in cost early in the development process. Through parametric costing, the visibility of pricing drivers can be used to identify focus for price reduction initiatives; there are opportunities from concept stage through to design change. C006's parametric costing is driven by data collection that focuses on geometric data, commercial data, manufacturing data, design data, technical data and performance data.

While encouraging, not mandating, them to work openly and collaboratively to ensure continuous improvement of operations, C006 works to align its suppliers to its ambitions in ethics, reducing energy and reducing waste. Its suppliers are expected to implement a health and safety management in line with the requirements of OHSAS 18001 and an environmental management system comparable with the requirements of ISO 14001.

Compliance Management

One of the biggest environmental risks faced by C006 is associated with the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation. REACH is a EU regulation that addresses the production and use of chemical substances, and their potential impacts on both human health and the environment. For C006, REACH is "not just another health, safety and environment issue" but a purchasing, manufacturing, design and strategic issue, one that is about more than just compliance. It is seen as an obsolescence issue, where there is a risk to the supply of materials that are used in manufacturing. When chemicals are restricted, there may be a direct impact on products and processes that will require replacement and modification. It is essential to appropriately manage the risks associated with compliance and obsolescence through the supply chain as 80% of the parts and components used by C006 come in through the supply chain. For C006, REACH is linked to obsolescence, not only because they have to replace any banned materials but also because instead of going through the REACH authorisation process, due to the effort required, some of their suppliers might chose to stop producing certain materials meaning C006 has to find replacements for those materials too. As materials affected by REACH continue to change, this is an issue that persists.

> *"To develop product and process information we have to understand sufficiently well what our product is and what is used to make it."*

While REACH falls within the chemicals management group within the Health, Safety and Environment Department, it requires cross-functional teams with members from Purchasing, Engineering and Design, and Manufacturing working together. When the REACH regulation was to be introduced, C006 set out to ensure that it and some of its suppliers were in a position to attain authorisation and to manage any supply risk associated with chemicals. Table 123 shows the steps that C006's chemicals management group created to help them and their suppliers prepare for REACH authorisation by the European Chemical Agency.

TABLE 123: STEPS LEADING TO REACH AUTHORISATION (FROM DOCUMENTATION)

STEP 1: THE END OF IGNORANCE	As most of the supply chain and internal managers are probably ignorant about REACH, senior managers need to be briefed first followed by top suppliers. To maintain access to chemicals and raw materials, it is necessary to get other departments to take on the implementation of REACH.
STEP 2: GET RESOURCES AND PLAN	Develop an action plan, find out what is imported and what is not imported but is still strategically important and check that the supply chain is going to meet their obligations for registration.
STEP 3: BUILD A MATERIAL INVENTORY	If one does not already exist, make a list of all the materials used by the business. Purchasing needs to find out names and specifications of bought-in chemicals, names and locations of suppliers and quantities purchased. Materials group needs to find out the substances in each of the materials and how vital the chemicals are to products and manufacturing processes.
STEP 4: TURN THE MATERIALS INVENTORY INTO A SUBSTANCE INVENTORY	All the data should be rearranged by name/specification to be listed by substance and ensure that each substance has the correct identifying code. Off-the-shelf REACH software is helpful for this.
STEP 5: DECIDE WHAT TO PRE-REGISTER	If importing more than a tonne per year or you are a manufacturer, pre-register. If substance is strategically vital and the supplier will not guarantee that they will pre-register/register, find a supplier who will or take on the pre-registration to minimise business risk.
STEP 6: PRE-REGISTER	Registering is a lot of work; consider sharing a 'third party representative'.
STEP 7: SUBSTANCES OF VERY HIGH CONCERN (SVHCS) IN PREPARATIONS	Cross-reference your substances inventories to other chemicals databases to determine chemicals that might be on the 'candidate list' to become SVHCs. Determine if any of these are 'strategically important' and if customers would be unhappy is they are changed.
STEP 8: PLANNING FOR AUTHORISATION	Determine whether the use of potential SVHCs is needed. Be prepared for the implication REACH will have on cost/benefit arguments and to have suppliers place requirements on you. Monitor the candidate list and where a move from candidate list substances is not easy, contact others within the industry in the same boat, discuss the issue with customers, find out customers plans for authorisation and start looking for alternatives (align with R&D programs). Start planning for authorisation in advance.

When it came to tackling the REACH issue, C006 took an incremental approach. This is because it recognised the amount of work that it entailed and postulated that a radical introduction would highlight how difficult the task was to the workforce. By introducing it slowly, there would be more time to prepare and adjust to the new changes.

C006's supply chains are long, complex and comprise of 8+ tiers; they look like the supply chain shown in Figure 76. The map shows that C006's supply chains are likely to be comprised of a number of SMEs in the middle, as well as a small number of chemical formulators that serve multiple chain members. C006 has to have a deep understanding of its supply chain, supply chains are surprisingly complex, not every actor can apply nor has the same commercial interests; understanding the supply chain helps C006 understand intentions and strategy. It does this through supply chain mapping and sharing information through the supply chain. Due to the sheer size of its supply chain C006 cannot map the whole supply chain. While in the past it worked to track back through its supply chain, today it strategically maps its supply chains. It maps those suppliers that it views as critical; for the smaller, non-critical components like bolts, pipes and tubes, it does not.

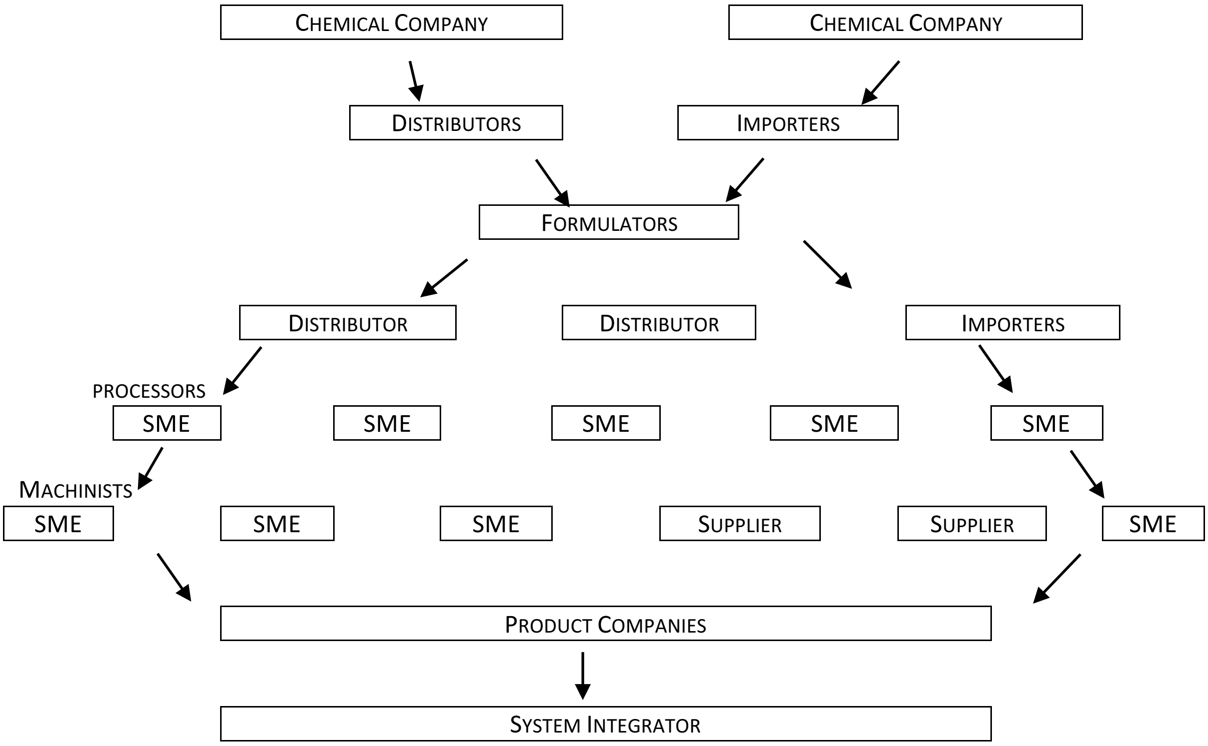


FIGURE 76: TYPICAL C006'S SUPPLY CHAIN (FROM DOCUMENTATION)

When it first embarked on the REACH issue, C006 knew that the task would require cross-functional teams and new information to be collected within companies and passed up and down the supply chain. It anticipated that, due to their size, SMEs would find the first task relatively easy as coordinating a small company would be less complex and that the second would prove more challenging as the SMEs would not have the resources that would allow them to acquire this new information. What they found however, was that both would prove challenging for SMEs.

C006 does not expect to have communication flowing effectively across the supply chain particularly due to SMEs. It is C006's view that typical SMEs do not have an understanding of REACH and that it is these companies that usually occupy the middle tiers in its supply chains, this creates bottlenecks in communication. To fully partake in the level of communication required a company would need to have an employee that is fully dedicated to the role; this is something that is unaffordable to SMEs due to their lack of capacity.

> *"You need to be full time to really understand (REACH). To expect that communication be flowing through the supply chain effectively is unreasonable therefore you don't expect any relationship."*

This means that SMEs struggle with not only with the amount of work required internally but also with external interactions; close-knit relationships are harder for C006 to foster with smaller companies. For an SME to fully be engaged in REACH activities, they have to have a member of staff dedicated 100% to the role of understanding and working on the Issue.

REACH has proven to be a complex issue, particularly for mid-chain SMEs within C006s supply chain, this is not made easier by the fact that C006 has a global supply chain which introduces further communication issues. What it requires from suppliers depends highly on the supplier and what they are providing. When C006 has designed the product and the supplier is only manufacturing it for them, C006 has control over substances that are used and is in control. However, there are cases where the supplier designs and manufactures for C006 and in this case C006 needs to find out what chemicals are being used in the products.

Having knowledge of the different tiers within their supply chain means that C006 can bypass certain suppliers and target others. For example, it has been working on determining who the formulators are by bypassing some of the SMEs and getting information straight from the formulators, this means that the information requests are more targeted and do not trickle backwards through the chain.

It is not only mid-chain SMEs that cause challenges for C006. In cases where C006 is purchasing small quantities it finds that despite its size as a large multination company it does not have enough influence to urge big upstream chemical producers to go through the authorisation process with certain chemicals if the transactions do not make business sense. The chemical producer decides to discontinue producing a chemical purely because the authorisation processes is too cumbersome for the amount they are producing. This is one of the cases where obsolescence is a big risk.

Internally, in addition to buying raw materials, the purchasing department is in charge of handling supplier declarations. This means that they have the responsibility of ensuring that suppliers provide material declarations because without those declarations C006 cannot make its own declarations. Due to the complex nature of C006's products, its product development involves system design; it is about how components fit into the system. Unlike with smaller products, no one owns the design or development of the whole process of creating aircraft. This means that different parties make varying contributions to the process.

Regarding REACH issues and materials, when designers work they are only presented with materials that have been designated as appropriate to use. In this case, the materials engineer is responsible for evaluating the materials lists and ensuring that only appropriate materials are on the lists; the designer only sees the results of that process. Essentially, there is no dialogue that is had with the designers regarding compliance issues; it is out of their scope. Designers will find that over time some of the materials they are used to seeing in the materials specification selector are no longer there, they need to work within those constraints.

> *"… it's changing all the time and the idea that we can keep everyone up to date in terms of what's going on, so they can make intelligent choices based on that information, simply can't happen."*

As the legislative agenda changes continually, C006 does not aim to keep everyone updated but rather to understand how the regulation it affects various parts of the business and to work out how to manage it. C006 has a product lifecycle management system that allows information to not only be captured from designers during the design process, but also from suppliers as they conduct their design activities. Additionally, C006 continues to conduct research into materials and generating new knowledge. It now has an inventory of materials and substances that is continually updated, it details where substances are used and the volumes, suppliers, factories etc. associated with the substances. It is the use these information systems that allow C006 to manage not only materials and substance lists but also ensure that they keep on top of compliance and obsolescence issues.

From C006's viewpoint, compliance and obsolescence are industry wide issues that can only be tackled by developing relationships with suppliers. C006 recognises that its suppliers have many customers and desire consistency of approach in making declarations, resultantly C006 will support and adopt industry standardisation where it meets these intents. C006 is an active member of a working group whose aim is to facilitate the creation of Authorisation consortia for the benefit of aerospace by establishing a structure, process, tools and supporting expertise that can be repeatedly used.

Conclusion

With its products having the most environmental impacts in the use phase, and with environmental requirements addressing fuel consumption, emissions and noise an integral component of product specifications, many of C006's products are market leaders in terms of environmental performance. While they focus mainly on 'in-use' environmental improvements as those have the biggest impacts, if other phase improvements are proven to transform into a business benefit, either through customer value or by reducing operation costs, then C006 are open to exploring them. C006's strategy is to focus on those improvements that have the most impact on the environment.

As a system integrator with very large product, C006 has a very complex and large global supply chain. C006 manages it supply chain through frameworks and information technology and encourages its suppliers to adopt initiatives, such as EMS, that will improve them. Within procurement, risk is considered on par with traditional procurement factors such as price, delivery and quality. The key to its supply risk management lies in collaboration and information sharing within the supply chain; this is supported by the use of a web based supply chain portal.

When REACH was pending C006 was proactive in devising guidelines and procedures that would ensure that it and its critical suppliers would be ready for authorisation. One of the key parts of C006's process was ensuring that there was enough knowledge within organisations about what the regulation actually entailed. Much like with ENPD, the key to REACH is in supply chain information sharing and it requires cross-functional teams to work together.

Initially C006 was hoping that if it acted as the initiator at the top, the authorisation would flow naturally backwards. What it found however was that there were bottlenecks in the supply chain, caused mainly by SMEs with limited capability that they had to overcome. This resulted in C006 strategically targeting those supply chain members that were most critical and bypassing those that were not. While C006 took an incremental approach to tackling the issue, it did not aim to inform everyone within the organisation about it. Only those that were directly responsible for gathering information, like the purchasing and materials, are involved with REACH matters. Designers for example who work with some of the substances affected have no working knowledge of risk, what they are presented with is a list of substances that they can use in product development that has already been deemed REACH compliant. Due to the size of the organisation, and with legislative agenda continually changing, C006 made a strategic decision to focus on managing the situation rather than ensuring widespread understanding among the employees.

For C006, REACH is an issue that can be tackled by developing relationships with suppliers, suppliers that the whole industry shares. As a result it supports the development of REACH standardisation for the aerospace industry.

APPENDIX 6.1: THE CLEANAIR STYLISHECO PROJECT BRIEF

This appendix contains the project brief that was created for the StylishEco Cookerhood during the controlled experiments.

THE CLEANAIR STYLISHECO PROJECT BRIEF

One year ago, CleanAir introduced the 1st generation Stylish wall cooker hood. Following its success, CleanAir is looking to launch the next generation Stylish cooker hood. Named the StylishEco, the new cooker hood aims to have an outstanding environmental performance profile.

ABOUT CLEANAIR

Located in Fabriano, Italy, CleanAir has been producing high quality cooker hoods since 1955. With 50% market share, it is the market leader in Italy – a country that values premium kitchen ventilation. CleanAir products show the company wide commitment to technology, quality and design. Its expertise lies in the design and assembly of cooker hoods. All cooker hoods are designed in house and incorporate a mixture of standard and made to order parts. After parts have been appropriately sourced, CleanAir, in Fabriano, assembles them into the final product. CleanAir does not have any manufacturing capabilities; product design is conducted in-house and manufacturing is outsourced.

CleanAir™ has recently become verified under the Eco-Management and Audit Scheme (EMAS) to reflect its commitment to environmental issues. As part of this, CleanAir conducted an environmental review of its supply base. During the review, CleanAir used key performance indicators (KIPs) to evaluate suppliers and to measure and monitor improvements.

CleanAir™ has the following certifications:

- ISO 9001 – Quality Management
- OHSAS 18001– Occupational Health and Safety Management Systems
- ISO 14001 – Environmental Management

ABOUT THE PROJECT

The main aim of the StylishEco project is to update the 1st generation Stylish cooker hood into the StylishEco. The StylishEco will be the first cooker hood to be produced by CleanAir since its EMAS verification. The StylishEco will be characterised by differences that aim at lowering environmental impacts during various life cycle stages.

You have been assigned the role of product designer on the project and it is your role to design the new generation cooker hood. Your main objective is to determine and describe the characteristics of a new prototype and have been given the following constraints:

- The new cooker hood should have a better environmental profile
- The new cooker hood should not cost too much
- The new cooker hood should be similar to its predecessor style wise

To help you have been supplied with the following:

- 1st generation Stylish technical data sheet
- 1st generation Stylish promotional flyer
- 1st generation Stylish simplified LCA report
- 1st generation Stylish partial assembly drawing
- 1st generation Stylish motor assembly drawing

- Transport scenario
- Standard parts catalogue

You are required to product the following outputs:

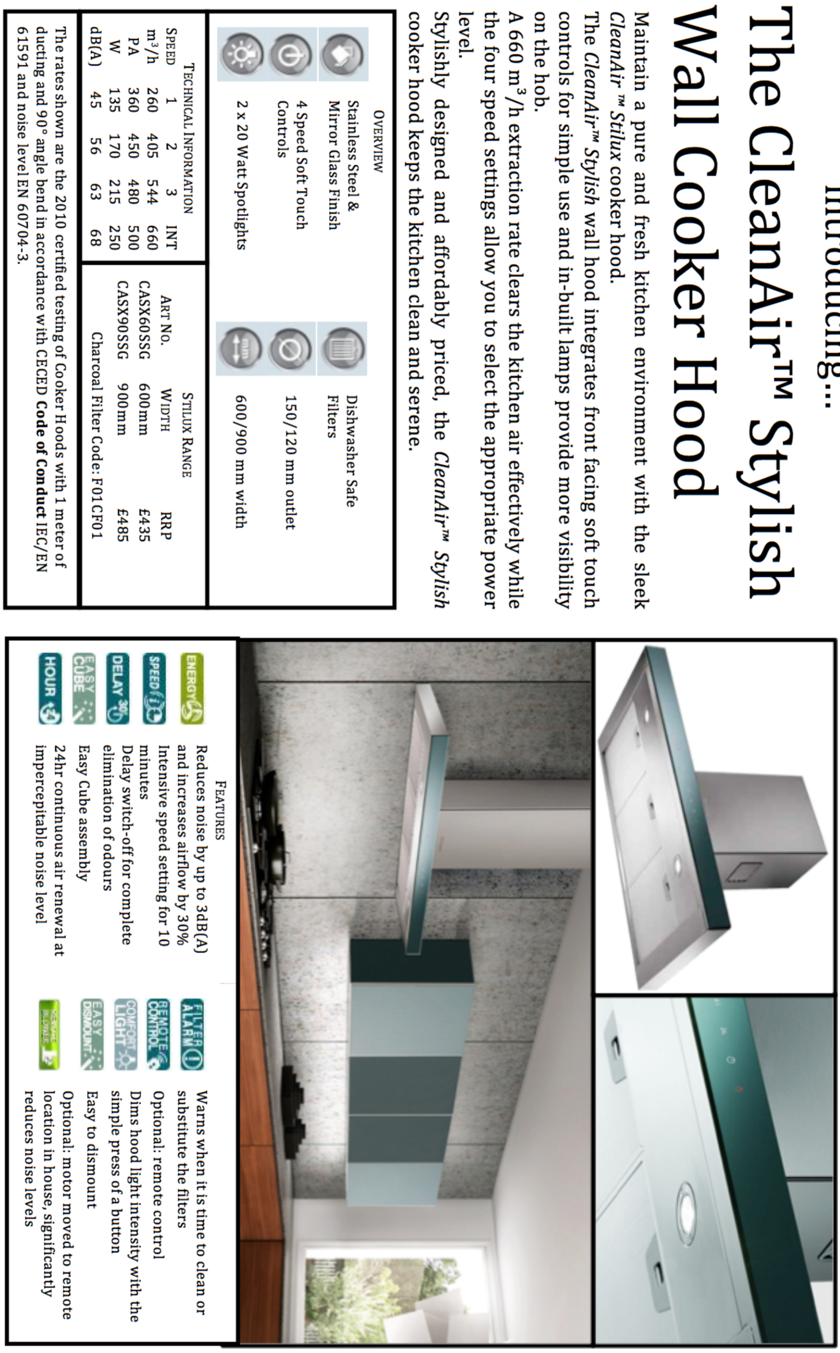
- Completed fill in sheet

The Exercise

You will be given up to 60 mins within which to complete the product re-design, after which you will sit down with the facilitator to talk through your cooker hood design and your development process. During the exercise the facilitator is not allowed to divulge extra information but can answer any questions that you have and offer clarifications. The facilitator will be asking you questions regarding what you are doing and you are encouraged to talk through any ideas that you have.

Appendix 6.2: Stylish Cookerhood Promotional Flyer

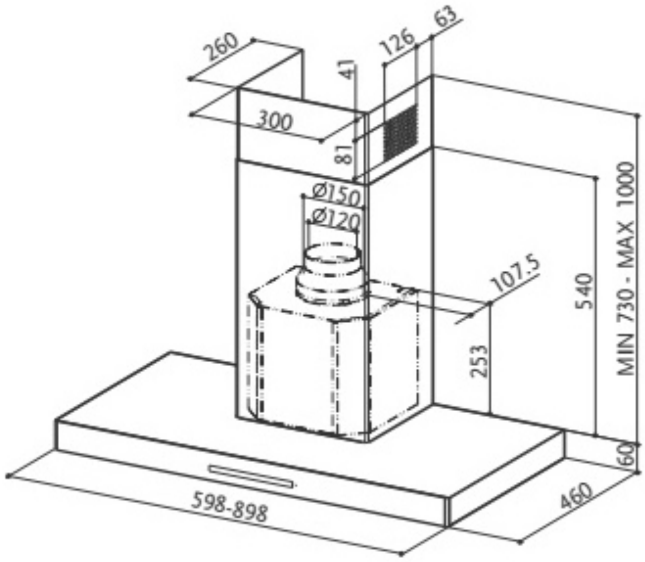
This appendix contains the promotional flyer that was created for the StylishEco Cookerhood during the controlled experiments.



Appendix 6.2: Stylish Cookerhood Technical Datasheet

This appendix contains the technical datasheet that was created for the StylishEco Cookerhood during the controlled experiments.

CleanAir™ Stylish Wall Cooker Hood Technical Data Sheet



Brand: CleanAir™

Product Code: 110.0255.547

Category: Cooker Hoods

EAN Code: 8015139039489

UPC Code: 8015139032428

Performance

Maximum extraxction power	660 m^3/h
Number of speeds	4
Intensive speed	
Noise level (low speed)	45 dB
Noise level (medium speed)	56 dB
Noise level (high speed)	63 dB

Design

Type	Wall-mounted
Lamps quantity	2
Lamp type	Halogen
Material	Glass, Stainless steel
Colour of product	Mirror, Stainless steel
Control type	Touch
Exhaust connection diameter	120 mm

Design

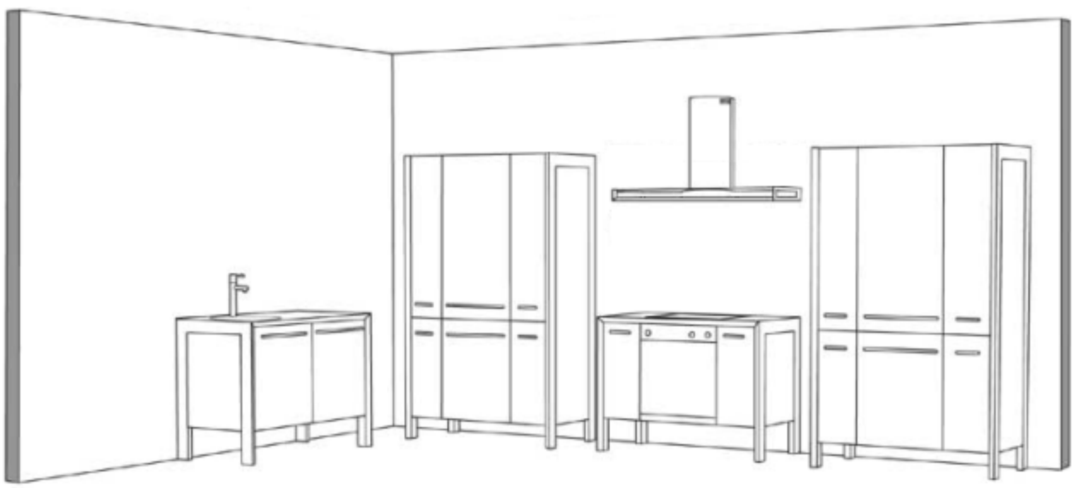
Number of motors	1
Filtering	
Grease filter type	Metal
Dishwasher proof filter	
Removable filter	

Power

Motor power	250 W
Lamp power	3 W

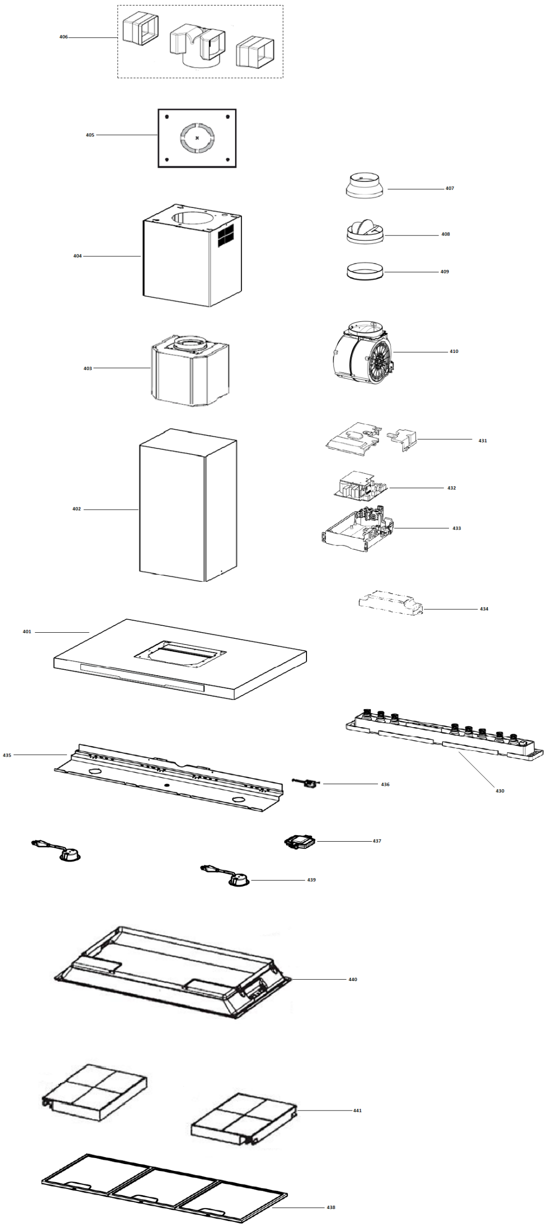
Weight and Dimensions

Witdth	898 mm
Depth	470 mm
Height (min)	790 mm
Height (max)	1060 mm
Height without chimney	60 mm



Appendix 6.3: Stylish Cookerhood Assembly Drawing

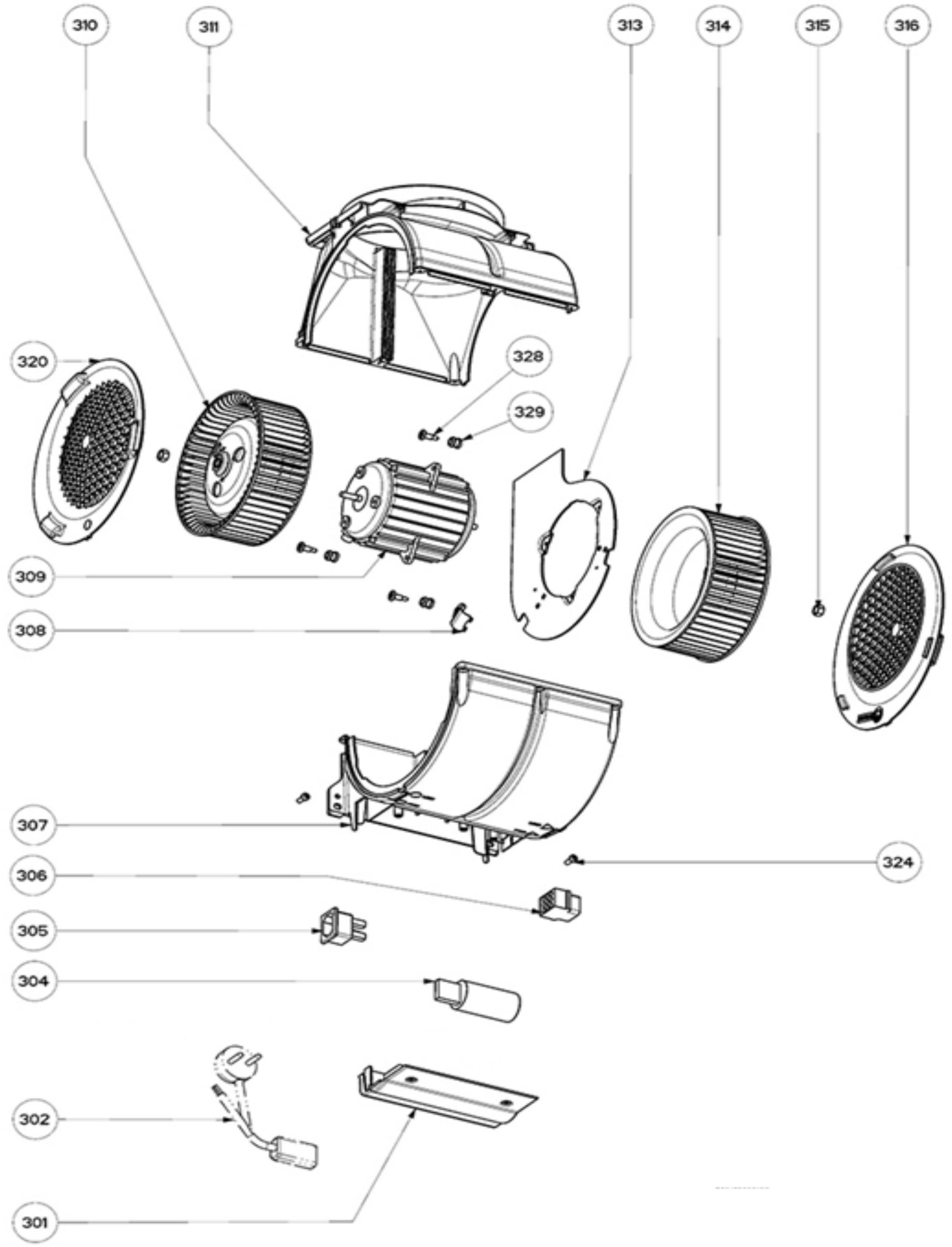
This appendix contains the assembly drawing that was created for the StylishEco Cookerhood during the controlled experiments.



Ref.	Name	Qu.
401	Base Unit Top	1
402	Chimney Lower	1
403	Easy Cube Casing	1
404	Chimney Upper	1
405	Chimney Cover	1
406	Filtering Kit Connection	1
407	Flange 1	1
408	No Return Valve + Flange	1
409	Flange 2	1
410	Electric Motor Assembly	1
430	Touch Panel	1
431	Card Casing Top	1
432	Assembly Card	1
433	Card Casing Bottom	1
434	LED Feeder	1
435	Spotlight Panel	1
436	Sensor	1
437	Sensor Connection Box	1
438	Grease Filter	3
439	Spotlight	2
440	Base Unit Bottom	1
441	Odour Filter	2

APPENDIX 6.4: ELECTRIC MOTOR ASSEMBLY DRAWING

This appendix contains the assembly drawing that was created for the StylishEco Cookerhood electric motor during the controlled experiments.



REF.	NAME	NO.	REF.	NAME	NO.	REF.	NAME	NO.	REF.		NO.
301	Cover Electric Wiring	1	**307**	Blower Bottom	1	**313**	Motor Bracket	1	**320**	Blower Left	1
302	Supply Cable	1	**308**	Motor Cable Clamp	1	**314**	Impeller Right	1	**324**	Blower Bolt	2
304	Capacitor	1	**309**	Electric Motor	1	**315**	Cap Nut Impeller	2	**328**	Motor Bolt	3
305	Connector	1	**310**	Impeller Left	1	**316**	Blower Right	1	**329**	Motor Nut	3
306	Female Connector	1	**311**	Blower Upper	1						

This appendix contains the simplified LCA report that was used for the StylishEco Cookerhood during the controlled experiments.

STYLISH COOKERHOOD SIMPLIFIED LCA REPORT

The following life cycle analysis was realised in accordance with ISO 14044:2006 requirements. It is a simplified LCA that aims to identify the environmental hotspots of the cooker hood.

Functional Unit – Draw air from the cooking area with a suction rate of 660m^3/hr. for two hours a day for a lifetime of nine years.

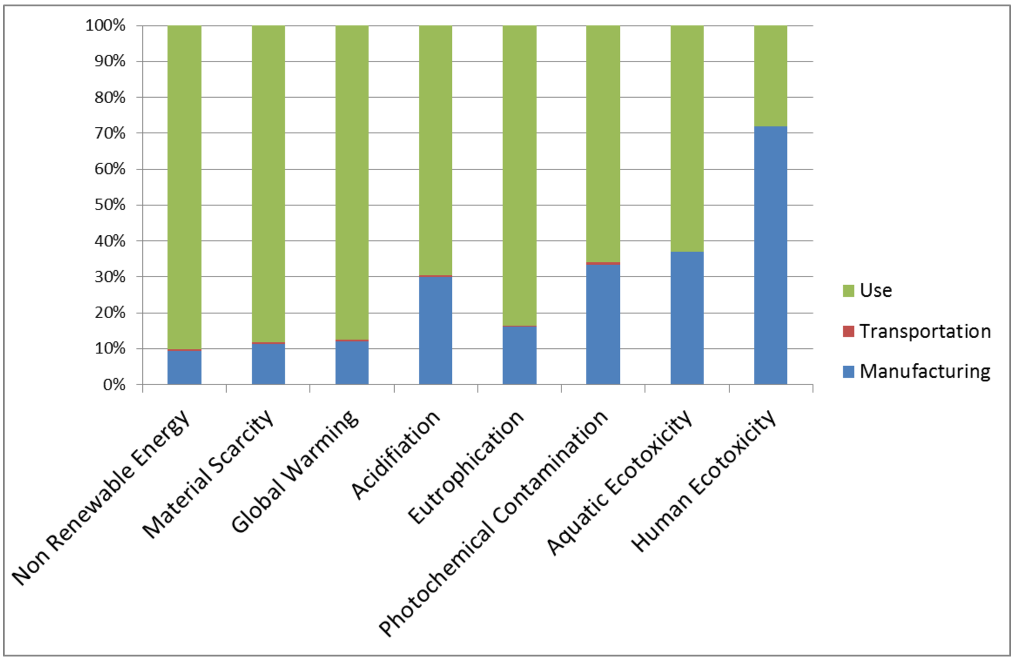
System Boundaries – Life cycle phases taken into account are as follows: manufacturing phase, distribution phase and use phase.

<u>Life Cycle Inventory</u>

The following is a list of the different elements that were taken into account during the modelling of the product lifecycle:

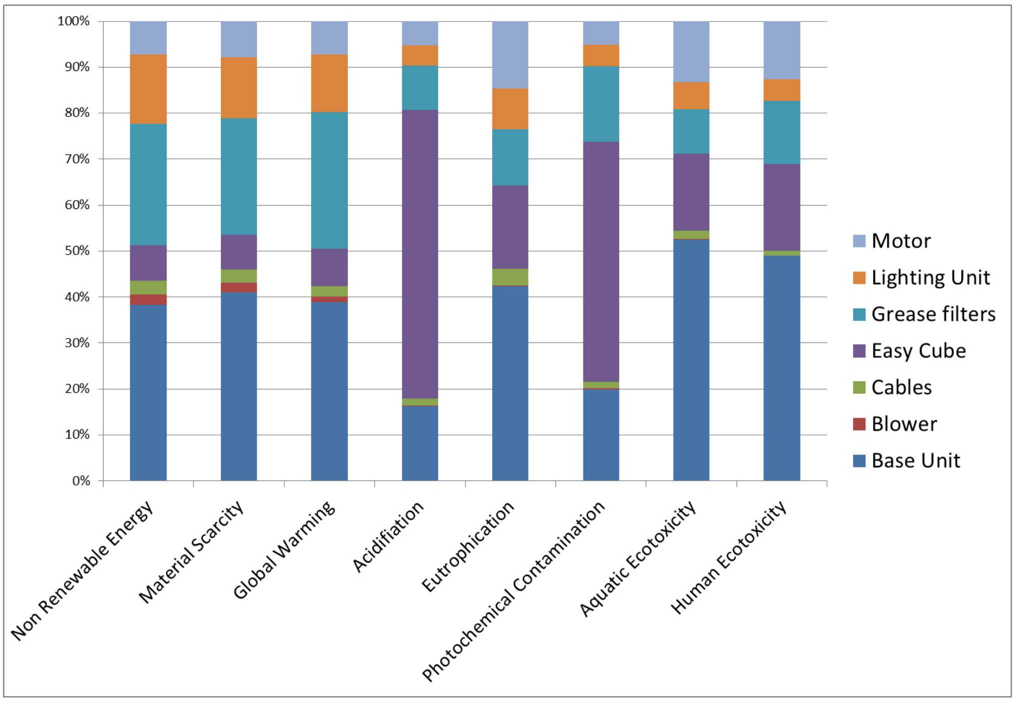
MANUFACTURING PHASE		
Component	Main Material + Components	Process
Base Unit (including Chimney)	Stainless Steel: 7.8kg	Stamping and Bending
Lighting Unit	Stainless Steel: 0.6kg + Halogen Lamps	Stamping and Bending Assembling
Grease Filters	Aluminium: 2.6kg	Sheet deep drawing
Easy Cube	Galvanised Steel: 2.11kg	Stamping and Bending Milling
Blower	Polypropylene (flame retardant): 0.46kg	Injection moulding
Motor	Stainless Steel: 1.26kg Copper: 0.38kg	Stamping and Bending Turning Thermoforming with Calendaring
TRANSPORTATION		
Sea freight for overseas sourcing 32-ton lorry for continental transporting (distance model based on product supply chain mapping of the cooker hood)		
USE PHASE		
Energy Consumption	Electric Motor: 1656 kWh Lamp: 129.6 kWh	
Lamps	6 halogen lamps (based on substitution over life cycle)	
Grease Filters	Cleaning every 6 months: 4/22 of a washing cycle in a typical European dishwasher	

Life Cycle Impact Assessment



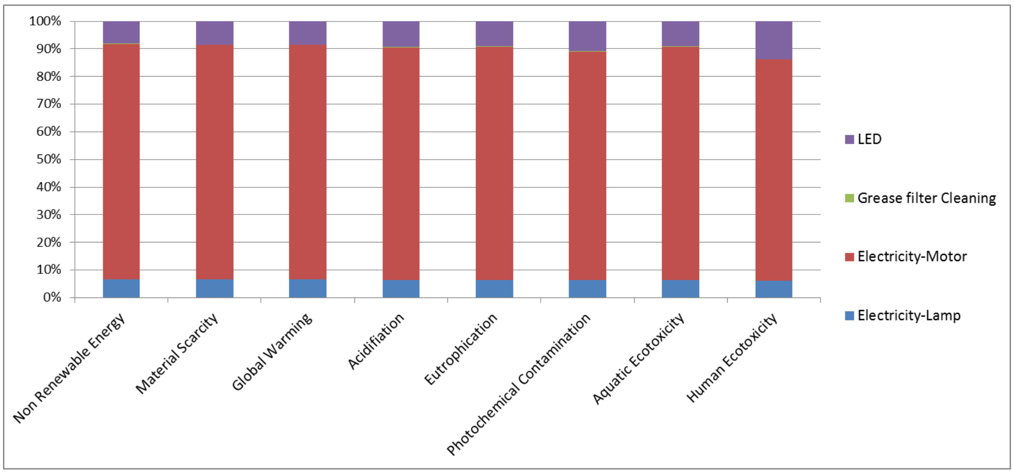
IMPACTS OF THE COOKER HOOD DURING ITS LIFE CYCLE

Manufacturing Phase



CONTRIBUTIONS TO ENVIRONMENTAL IMPACT DURING MANUFACTURING PHASE

Use Phase



CONTRIBUTIONS TO ENVIRONMENTAL IMPACT DURING USE PHASE

APPENDIX 6.6: COOKERHOOD PARTS CATALOGUE

This appendix contains the parts catalogue that was created for the StylishEco Cookerhood during the controlled experiments.

Lighting

TYPE	SHAPE	DESIGN	CAP	FINISH	WATTAGE	VOLTAGE	EQUIV. TO	LENGTH	WIDTH	RATED LIFE	BEAM ANGLE	LUMENS	ENERGY RATING	SUPPLIER	PRICE	OPTION
ENERGY SAVER HALOGEN	Spotlight	MR16	GU 5.3	Clear	20 W	12 V	35 W	46 mm	50 mm	4000 hrs	36°	300	B	Light A	£ 2.38	1
	Spotlight	MR16			20 W	12 V	35 W	45 mm	50 mm	4000 hrs	36°	300	B	Light B	£ 2.82	2
	Spotlight	MR16			20 W	12 V	35 W	44 mm	50 mm	5000 hrs	36°	300	C	Light D	£ 3.61	3
	Spotlight	MR16			20 W	12 V	35 W	45 mm	50 mm	5000 hrs	36°	300	C	Light C	£ 3.45	4
STANDARD LIFE DICHROIC HALOGEN	Spotlight	MR16	GU 5.3	Clear	35 W	12 V	35 W	48 mm	50 mm	2000 hrs	38°	430	F	Light A	£ 0.86	5
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	2000 hrs	38°	430	F	Light D	£ 1.30	6
	Spotlight	MR16			35 W	12 V	35 W	48 mm	50 mm	2000 hrs	38°	430	F	Light B	£ 0.69	7*
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	2000 hrs	38°	430	F	Light C	£ 1.10	8
LONG LIFE DICHROIC HALOGEN	Spotlight	MR16	GU 5.3	Clear	35 W	12 V	35 W	48 mm	50 mm	5000 hrs	38°	430	D	Light B	£ 1.34	9
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	5000 hrs	38°	430	D	Light C	£ 1.69	10
	Spotlight	MR16			35 W	12 V	35 W	48 mm	50 mm	5000 hrs	38°	430	D	Light D	£ 1.50	11
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	5000 hrs	38°	430	D	Light A	£ 1.45	12
COOL BACK HALOGEN	Spotlight	MR16	GU 5.3	Clear	35 W	12 V	35 W	45 mm	50 mm	3000 hrs	38°	350	D	Light A	£ 2.42	13
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	3000 hrs	36°	350	D	Light C	£ 3.05	14
	Spotlight	MR16			35 W	12 V	35 W	44 mm	50 mm	3000 hrs	38°	350	D	Light D	£ 2.75	15
	Spotlight	MR16			35 W	12 V	35 W	45 mm	50 mm	3000 hrs	38°	350	D	Light B	£ 2.53	16
LED	Spotlight	MR16	GU 5.3	Clear	7 W	12 V	35 W	45 mm	50 mm	15000 hrs	36°	350	A	Light E	£ 6.38	17
	Spotlight	MR16			5 W	12 V	35 W	48 mm	50 mm	15000 hrs	36°	380	A^+	Light G	£ 7.50	18
	Spotlight	MR16			5.5 W	12 V	35 W	49 mm	50 mm	25000 hrs	36°	330	A	Light H	£ 9.21	19
	Spotlight	MR16			7 W	12 V	35 W	49 mm	50 mm	25000 hrs	36°	370	A	Light F	£ 8.62	20

Electric Motor

Type	Power	Speed	Nominal Voltage	Airflow	Efficiency	Power to Shaft	Frequency	Supplier	Price	Option
Shaded-pole Single Phase Asynchronous Motor	230 W	1500 rpm	230 V	680 m/h^3	24 %	54.2 W	50 Hz	Motor A	£ 4. 67	1*
	230 W	1500 rpm	230 V	680 m/h^3	24 %	54.2 W	50 Hz	Motor B	£ 5.59	2
	200 W	1500 rpm	230 V	686 m/h^3	28 %	56 W	50 Hz	Motor C	£ 7.07	3
	200 W	1500 rpm	230 V	686 m/h^3	28 %	56 W	50 Hz	Motor D	£ 6.98	4
Single Phase Motor with Permanent Capacitor	160 W	1800 rpm	230 V	688.8 m/h^3	41 %	65.6 W	50 Hz	Motor B	£ 9.16	5
	160 W	1800 rpm	230 V	688.8 m/h^3	41 %	65.6 W	50 Hz	Motor A	£ 9. 90	6
	130 W	1800 rpm	230 V	680.4 m/h^3	48 %	64.8 W	50 Hz	Motor E	£ 10.12	7
	130 W	1800 rpm	230 V	680.4 m/h^3	48 %	64.8 W	50 Hz	Motor D	£ 10.20	8
Brushless Permanent Magnet Motor	150 W	2000 rpm	230 V	700 m/h^3	50 %	75 W	50 Hz	Motor A	£ 11.25	9
	150 W	2000 rpm	230 V	700 m/h^3	50 %	75 W	50 Hz	Motor C	£ 12.13	10
	110 W	2000 rpm	230 V	689 m/h^3	66 %	72.6 W	50 Hz	Motor E	£ 14.40	11
	110 W	2000 rpm	230 V	689 m/h^3	66 %	72.6 W	50 Hz	Motor F	£ 15.84	12

Grease Filter

Filter Type	Filter Medium	Frame Material	Retaining Mesh Material	Saturation Indicator	Washable	Disposable	Length	Width	Depth	Rated Air Flow	Supplier	Price	Option
mesh	Crimped Stainless Steel knitted wire mesh	Stainless Steel	Stainless Steel	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	1
		Stainless Steel	Aluminium	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	2
		Aluminium	Aluminium	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	3*
		Aluminium	Stainless Steel	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	4
		Stainless Steel	Stainless Steel	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	5
		Stainless Steel	Aluminium	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	6
		Aluminium	Aluminium	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	7
		Aluminium	Stainless Steel	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	8
	Crimped galvanised Steel knitted wire mesh	Stainless Steel	Stainless Steel	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	9
		Stainless Steel	Aluminium	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	10
		Aluminium	Aluminium	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	11
		Aluminium	Stainless Steel	Yes	Yes	No	420	260	20	700 m/h^3	Filter A	£ 3.20	12
		Stainless Steel	Stainless Steel	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	13
		Stainless Steel	Aluminium	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	14
		Aluminium	Aluminium	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	15
		Aluminium	Stainless Steel	Yes	Yes	No	420	260	10	700 m/h^3	Filter A	£ 4.40	16

Odour Filter

Filter Type	Washable	Disposable	Life	Length	Width	Depth	Rated Air Flow	Supplier	Price	Option
Carbon Filter	No	Yes	3-4 months	420	260	30	700 m/h^3	Filter A	£ 3.40	1
	No	Yes	3-4 months	420	260	15	700 m/h^3	Filter A	£ 4.15	2
	No	Yes	3-4 months	420	260	30	700 m/h^3	Filter B	£ 3.35	3
	No	Yes	3-4 months	420	260	15	700 m/h^3	Filter B	£ 4.00	4
Long Life Filter	Yes	No	3-4 years	420	260	30	700 m/h^3	Filter A	£ 6.50	5
	Yes	No	3-4 years	420	260	15	700 m/h^3	Filter A	£ 7.09	6
	Yes	No	3-4 years	420	260	30	700 m/h^3	Filter B	£ 5.90	7
	Yes	No	3-4 years	420	260	15	700 m/h^3	Filter B	£ 6.70	8

Blower

Material	Supplier	Price	Option
Galvanised Steel	Custom A	£ 1.69	1
	Custom B	£ 1.90	2
	Custom C	£ 1.35	3
Polypropylene	Custom D	£ 1.20	4
	Custom E	£ 0.67	5
	Custom F	£ 0.58	6

Impeller

Material	Supplier	Price	Option
Galvanised Steel	Custom A	£ 1.30	1
	Custom B	£ 1.45	2
	Custom C	£ 1.15	3
Polypropylene	Custom D	£ 0.90	4
	Custom E	£ 0.45	5
	Custom F	£ 0.40	6

Packaging

Filter Type	Supplier	Price	Option
Corrugated Cardboard Box	Box A	£ 0.65	1
	Box B	£ 0.60	2
	Box C	£ 0.66	3
	Box D	£ 0.96	4
	Box E	£ 0.30	5

APPENDIX 6.7: SUPPLIER DATABASE

This appendix contains the supplier database that was created for the StylishEco Cookerhood during the controlled experiments.

Light Bulb

SUPPLIER	PRODUCT RELATED	COMPANY RELATED									
	TRANSPORT SCENARIO	LOCATION	RAW MATERIAL USE	RENEWABLE RESOURCE USE	WASTE MANAGEMENT	RECYCLING AND REUSING	ENERGY CONSUMPTION	WATER CONSUMPTION	TRAVEL	CERTIFICATIONS	OVERAL SCORE
LIGHT A	Sea Freight 17 000 km 32 Ton Truck 230 km	China	6	5	6	6	6	5	9	ISO 9001, ISO14001, OSHAS 18001.	5.3
LIGHT B *	Sea Freight 17 000 km 32 Ton Truck 110 km	China	5	3	5	6	5	5	8	ISO 9001, OSHAS 18001.	4.5
LIGHT C	32 Ton Truck 56 km	Italy	7	7	6	7	6	6	5	ISO 9001, ISO14001, OSHAS 18001.	6.3
LIGHT D	32 Ton Truck 36 km	Italy	7	8	7	8	6	7	6	ISO 9001, OSHAS 18001.	7.4
LIGHT E	Sea Freight 17 000 km 32 Ton Truck 70 km	China	7	5	6	6	5	4	8	ISO 9001, OSHAS 18001.	5.9
LIGHT F	32 Ton Truck 430 km	France	5	6	8	2	6	7	6	ISO 9001, ISO14001, OSHAS 18001	5.7
LIGHT G	Sea Freight 17 000 km 32 Ton Truck 310 km	China	6	4	7	8	4	7	9	ISO 9001, ISO14001, OSHAS 18001	6.4
LIGHT H	32 Ton Truck 630 km	Italy	7	5	6	7	6	8	7	ISO 9001, OSHAS 18001	6.6

Electric Motor

Supplier	Product Related	Company Related									
	Transport Scenario	Location	Raw Material Use	Renewable Resource Use	Waste Management	Recycling and Reusing	Energy Consumption	Water Consumption	Travel	Certification	Overall Score
Motor A	Sea Freight 17 000 km 32 Ton Truck 110 km	China	6	5	6	6	7	6	5	ISO 9001, OSHAS 18001.	5.8
Motor B	32 Ton Truck 730 km	Italy	7	8	4	7	6	6	7	ISO 9001, OSHAS 18001.	6.4
Motor C	32 Ton Truck 1900 km	Romania	7	6	8	5	8	7	7	ISO 9001, ISO14001, OSHAS 18001.	6.9
Motor D	32 Ton Truck 2100 km	Romania	5	6	3	4	7	6	7	ISO 9001, OSHAS 18001.	5.4
Motor E	Sea Freight 17 000 km 32 Ton Truck 110 km	China	5	6	8	8	8	5	6	ISO 9001, ISO14001, OSHAS 18001.	6.6
Motor F	Sea Freight 200 km 32 Ton Truck 1300 km	UK	8	6	8	8	7	5	7	ISO 9001, ISO14001, OSHAS 18001.	7

Grease and Odour Filter

Supplier	Product Related	Company Related									
	Transport Scenario	Location	Raw Material Use	Renewable Resource Use	Waste Management	Recycling & Reusing	Energy Consumption	Water Consumptio n	Travel	Certification	Overal l Score
Filter A	Sea Freight 1 700 km 32 Ton Truck 72 km	Tunisia	6	4	7	7	7	6	8	ISO 9001, ISO14001, OSHAS 18001.	6.4
Filter B	32 Ton Truck 256 km	Italy	7	8	7	6	6	7	8	ISO 9001, ISO14001, OSHAS 18001.	7

Blower & Impeller

Supplier	Product Related	Company Related								
	Transport Scenario	Location	Raw Material Use	Renewable Resource Use	Waste Management	Recycling and Reusing	Energy Consumption	Water Consumption	Travel	Certification	Overall Score
Custom A	32 Ton Truck 22 km	Italy	7	8	9	7	7	8	8	ISO 9001, OSHAS 18001.	7.7
Custom B	32 Ton Truck 440 km	Italy	5	6	7	5	5	6	7	ISO 9001, ISO14001, OSHAS 18001.	5.8
Custom C	Sea Freight 18 000 km 32 Ton Truck 20 km	China	7	8	8	8	7	7	7	ISO 9001, ISO14001, OSHAS 18001.	7.4
Custom D	32 Ton Truck 90 km	Italy	7	7	7	8	8	6	8	ISO 9001, OSHAS 18001.	7.2
Custom E	Sea Freight 900 km 32 Ton Truck 72 km	Tunisia	6	5	8	5	6	6	6	ISO 9001, OSHAS 18001.	6
Custom F	Sea Freight 15000 km 32 Ton Truck 210 km	China	6	7	8	6	6	6	6	ISO 9001, ISO14001, OSHAS 18001.	6.4

Corrugated Box

Supplier	Product Related	Company Related									
	Transport Scenario	Location	Raw Material Use	Renewable Resource Use	Waste Management	Recycling and Reusing	Energy Consumption	Water Consumption	Travel	Certification	Overall Score
Box A	32 Ton Truck 75 km	Italy	8	9	7	7	7	8	7	ISO 9001, ISO14001, OSHAS 18001.	7.6
Box B	32 Ton Truck 20 km	Italy	7	7	8	8	9	7	6	ISO 9001, OSHAS 18001.	7.4
Box C	32 Ton Truck 23 km	Italy	5	6	7	8	8	8	8	ISO 9001, OSHAS 18001.	7
Box D	Sea Freight 200 km 32 Ton Truck 520 km	UK	9	9	8	9	8	8	7	ISO 9001, ISO14001, OSHAS 18001.	8.2
Box E	Sea Freight 17 000 km 32 Ton Truck 310 km	China	6	6	6	7	6	6	6	ISO 9001, OSHAS 18001.	6.1

Appendix 6.8: Stylish Cookerhood Detailed Transport Scenario

This appendix contains the detailed transport scenario that was used for the StylishEco Cookerhood during the controlled experiments.

Stylish Cookerhood Detailed Transport Scenario

The table below contains details of how parts of the cooker hood are transported.

Manufacturing Phase			
Part Transported	**Transportation Path**	**Transport Means**	**Distance (km)**
Chimney and Spotlight Bent	TAS Metals Fruili S.P.A to Fabriano (AN)	32 Ton Truck	390
Reduction Flange	Terni Polimeri to Fabriano (AN)	32 Ton Truck	160
Grease Filter	Tunisia to Porto di Ancona	Sea Freight	1 700
	Porto di Ancona to Fabriano (AN)	32 Ton Truck	72
Control Bracket	SabaPlast to Fabriano (AN)	32 Ton Truck	46
Easy Cube	Centro Lamiere S.R.L. to Fabriano (AN)	32 Ton Truck	440
Lamps	China to Porto di Ancona	Sea Freight	17 000
	Porto di Ancona to Fabriano (AN)	32 Ton Truck	110
Front Control Glass	Borgna Vetri to Fabriano (AN)	32 Ton Truck	670
Blower	Metalplast	32 Ton Truck	22
Electric Motor	China to Porto di Ancona	Sea Freight	17 000
	Porto di Ancona to Fossato di Vico (PG)	32 Ton Truck	72
	Fassoto di Vico to Fabriano (AN)	32 Ton Truck	23
Printed Wire Board	China to Porto di Ancona	Sea Freight	17 000
	Porto di Ancona to Fossato di Vico (PG)	32 Ton Truck	72
	Fassoto di Vico to Fabriano (AN)	32 Ton Truck	23
Capacitor	Ducati Energia a Fossato di Vito (PG)	32 Ton Truck	1 800
Cables	EMMEFFE Gaggioli to Fossato di Vico (PG)	32 Ton Truck	3
Impellor	LN2sl to Fossato di Vico (PG)	32 Ton Truck	90
Corrugated Box (Packaging)	Scatolificio Angeli to Fabriano (AN)	32 Ton Truck	75
Lateral Protection and Angular Protection	Pachart to Fabriano (AN)	32 Ton Truck	20
Chimney Protection	Icom SPA to Fabriano (AN)	32 Ton Truck	23
Distribution			
Cooker Hood + Packaging	Fabriano (AN) to Distribution Centre (EU)	32 Ton Truck	1579
End of Life			
Disassembled Cooker Hood	End user to Ecodom Plant	32 Ton Truck	100

APPENDIX 6.9: PARTS REPLACEMENT FILL-IN SHEET

This appendix contains the parts replacement fill-in sheet that was created for the StylishEco Cookerhood during the controlled experiments.

PART NO.	PART NAME	QUANTITY	STYLISH	OPTION	STYLISHECO
439	Spotlight	2	Standard Halogen	7	
309	Electric Motor	1	Single Phase	1	
438	Grease Filter	3	SS Mesh & AL	3	
114	Odour Filter	2	---	--	
310/314	Impeller	1	Galv. Steel	4	
307/11/16/120	Blower	1	Polypropylene	1	
	Packaging	1	Cardboard	1	

APPENDIX 6.10: CODE FOR 3-D MULTI-OBJECTIVE OPTIMISATION

This appendix contains the code that was written for 3-D multi-objective optimisation that aimed to determine the Pareto front during the controlled experiments.

```
#include <math.h>
#include "mex.h"

void paretofront(bool * front, double * M, unsigned int row, unsigned int col);

void mexFunction( int nlhs, mxArray *plhs[] , int nrhs, const mxArray *prhs[] )
{
   bool * front;
   double * M;
   unsigned int row, col;
   const int  *dims;

   if(nrhs == 0 || nlhs > 1)
   {
      printf("\nsynopsis:   front = paretofront(X)");
      plhs[0]    = mxCreateDoubleMatrix(0 , 0 ,  mxREAL);
      return;
   }

   M = mxGetPr(prhs[0]);
   dims = mxGetDimensions(prhs[0]);
   row = dims[0];
   col = dims[1];



   /* ----- output ----- */

   plhs[0]    = mxCreateLogicalMatrix (row , 1);
   front = (bool *) mxGetPr(plhs[0]);


   /* main call */
   paretofront(front,  M, row, col);
}

void paretofront(bool * front, double * M, unsigned int row, unsigned int col)
{
   unsigned int t,s,i,j,j1,j2;
   bool *checklist, coldominatedflag;

   checklist = (bool *)mxMalloc(row*sizeof(bool));
   for(t = 0; t<row; t++) checklist[t] = true;
   for(s = 0; s<row; s++) {
      t=s;
      if (!checklist[t]) continue;
      checklist[t]=false;
      coldominatedflag=true;
      for(i=t+1;i<row;i++) {
```

```
        if (!checklist[i]) continue;
        checklist[i]=false;
        for (j=0,j1=i,j2=t;j<col;j++,j1+=row,j2+=row) {
          if (M[j1] < M[j2]) {
            checklist[i]=true;
            break;
          }
        }
        if (!checklist[i]) continue;
        coldominatedflag=false;
        for (j=0,j1=i,j2=t;j<col;j++,j1+=row,j2+=row) {
          if (M[j1] > M[j2]) {
            coldominatedflag=true;
            break;
          }
        }
        if (!coldominatedflag) {    //swap active index continue checking
          front[t]=false;
          checklist[i]=false;
          coldominatedflag=true;
          t=i;
        }
      }
      front[t]=coldominatedflag;
      if (t>s) {
        for (i=s+1; i<t; i++) {
          if (!checklist[i]) continue;
          checklist[i]=false;
          for (j=0,j1=i,j2=t;j<col;j++,j1+=row,j2+=row) {
            if (M[j1] < M[j2]) {
              checklist[i]=true;
              break;
            }
          }
        }
      }
    }
    mxFree(checklist);
  }
```

Appendix 6.12: Analytic Memos Created during Analysis

This appendix contains the analytic memos that were created during the analysis of the controlled experiments.

When making decisions you need more than one factor to consider. Two factors seem to be the ideal number because once you have three balancing them out becomes harder.	The grease filter option seemed to trip a number of people up. All they had to do was carefully look through options to note the difference but a significant number failed to do so accurately.	In some of the cases, contrary to what most of the participants assumed, more expensive options did no translate to better environmental performance i.e. some grease filters
When told to improve the environmental performance and not given any other stringent constraints or a value to aim for, people found difficult to make decisions comfortably. It is important to quantify the improvements that you want. A good way of looking at it is '£X per % EP' or 'best possible EP for any cost' or 'best EP for this max cost' or '50% increase in EP' etc.	When they had no information on suppliers at all, not having to switch suppliers was always counted as a merit to sticking to the same supplier option. Sometimes they assumed that all other options were from different suppliers and discounted them. Sometimes this was not the case and they were from the same supplier and could have been viable choices.	There is common misconception that environmentally friendly products are more expensive. What people fail to do is to also acknowledge that the products also have a higher performance. It's not just that you are making something that is better for the environment, it is also that you are making something that performs better as a product so that is why the cost goes up. So it's important not to just based on just cost but more on cost per performance factor.
In some cases it is not worth improving the environmental performance if the product costs too much. Is this a healthy and progressive view to have?	Overarching assumption that people do not want to buy something that is expensive. They seem to not see the value that comes with having a better performing product.	When the environmental performance is the same, then knowing supplier information becomes important cause it will have an impact. This way those with supplier information will have greener supply chains attached to their products.
By making smarter decisions you can make gains. You can either pay more for a product with better operational performance or pay the same for a product with the same operational performance but better environmental profile i.e. filter.	Knowing supplier information does not seem to have much of an impact on the environmental performance of your product – this is because the impact of the transport phase is miniscule compared to use and manufacturing.	Knowing supplier information does not seem to have much of an impact on the environmental performance of your product – this is because the impact of the transport phase is miniscule compared to use and manufacturing.
When given cost information, overall you design a cheaper product.	You make decisions based on what you have in front of you or you end up making things up to fill in any gaps if you feel something is missing.	Condition D can be the ideal, a cross between C and B, if you educate them before as to what is available then they will have an idea of what is available to them.
You need understandable constraints otherwise people will self-impose constraints and usually they impose cost constraints even when not required or detrimental to other things.	While cost comes in as a constraint and viewed as something that has to be adhered to, when people add supplier considerations they always view them as desirables that they are in charge of	Designers are encouraged to adopt lifecycle thinking, to really put that into practice you need information relating to the different lifecycle stages and some of that information is supplier dependant.

	determining.	
Most participants decided to not include the odour filter as they felt that it would be unnecessary and just ramp up costs. There were some that decided to add it as they felt that it would be a worth-while selling point.	When you do not have cost you want it and say it would help you. When you have cost you say you don't have enough and you want more. When you have more you say you have too much.	While others use cost to go for the cheapest others do the opposite, so if it is too cheap it must not be environmentally friendly – maybe it is time to not associate the two so closely?
Those that only had cost wanted something else to help them decide if what they were paying for a certain level of performance was worth it. How do you quantify environmental gains?	Those in Condition B said they wanted more information and while those in Condition C did not say that they wanted less they did express that they had a lot of information. Maybe meet in the middle and be like Condition D where all the information is available but they chose.	Condition C produced the most consistent results. Condition D was very varied but on average they performed well. Condition B did not really have enough to go by.
Condition D had the best group results and they seem to the most balanced group so maybe it is best not to give people all the information up front but to tell them what is available to them and let them request the information that they feel they need.	Is value of environmental performance subjective? How can we make it objective so that two different people can look at two different products and decide that one is definitely better than the other?	Not only do you need information, you also need to be able to make the right informed decisions with that information. If you have software you can see the outputs directly but if not what do you do?

APPENDIX 6.13: PARTICIPANT PROCESS VIGNETTES

This appendix contains the process vignettes of participants P002-P016 in full.

P002

After the challenge was outlined and they had been given the catalogue to choose replacement parts from, P002 immediately remarked that they needed more information, specifically cost information.

P002 started off by looking at the spotlights, they referred to the functional unit used in the LCA report to calculate that the cookerhood had an in use life of approx. 6.5k hours and from there deduced that only the LED options would not need to be replaced if used in the new product. They supposed that because of their superior performance the LEDs would cost more however, they would have the added benefit of not requiring replacement and they would also use less electricity throughout them in-use life; not only would they be a better environmental choice but they would also have cost saving benefits for the end user which is a good selling point for the product as a whole. After that they immediately discounted the LEDs with 25k hours rated life and settled for 15k hours rated life option with an A+ energy rating.

Moving forward, P001 decided to focus solely on brushless permanent magnet motors as viable replacements for the current motor choice. This was because they felt that their better use of energy improved their environmental profile and also meant they could cut the end users electricity costs. They decided to select the most efficient (66%) brushless motor to include in the StylishEco.

For the grease filter, P002 took their time analysing the differences between the different choices and could outline what made the options different from one another and how that could have environmental performance implications. They noted that it was possible to have filters made from a single material, making them easier to recycle and that it was also possible to have a reduced filter thickness which would lessen the materials used in manufacturing the filters and potentially also reduce the size of certain aspect of the cooker hood that the filters would be housed in. Resultantly, they decided to select the thinnest possible all stainless steel grease filter.

When given the choice to add an odour filter to the StylishEco, they remarked that they did not see the point of having an odour filter and did not want to include it. From there, they moved on to the impeller and the blower where they surmised that polypropylene was cheaper than steel but could not comfortably make assertions regarding which material had a better environmental profile. Consequently, they did not make any changes and carried over the options that were included in the Stylish cookerhood.

For the packaging, where they did not have enough information to make an informed choice, they stuck to the current option and remarked that at least the supplier would not need to be changed and that could only be a positive.

Table 92 compares P002 results to the average Condition A results and average group results.

P002 VS. CONDITION A AND GROUP AVERAGE

	P002	Condition Average		All Cond. Average	
PEP	1.00	0.883	Better	0.792	Better
Cost	£47.14	£45.81	Worse	£38.77	Worse
Cost per % PEP	£0.47	£0.52	Better	£0.49	Better
SCG	2.049	2.046	Better	1.919	Better
Relative SCG	68%	68%	Same	64%	Better

During the entire exercise, P002 did not refer back to the LCA report's section on the impacts of the cookerhood. This could mean that they blindly decided to change the parts purely because they could and did not consider the impacts that the different parts had; however, it is also equally possible that though the initial run though of the problem, they mentally retained the information regarding impacts and knew that they had to make improvements.

Upon completion of the exercise, P002 remarked that not knowing anything beyond the performance of the parts and not having more stringent specifications regarding what was acceptable and what wasn't made making decisions harder. The exercise was designed such that a lot is left to the participant to decide e.g. there were no specifications as to how the new product had to perform environmentally beyond being better than the last one, how much it was better by was left to the participant's discretion. It is this that seemed to make the participant uncomfortable and less sure about the decisions they were making. They also commented that more information would have eased their discomfort, such as cost and manufacturing information. In the end, they acknowledged that eco-design is about more than just the product that you are designing so you need a vast amount of information to ensure you make informed decisions.

When looking at the way P002 approached and undertook the exercise, a strategy emerges; where they felt they had all the information required to make an informed choice, they went for the option that promise to deliver the best environmental performance, otherwise they kept the choices the same as in the predecessor cookerhood.

P003

After being told what was required of them during the exercise, P003 wasted no time in getting stuck in by deciding what spotlights would be included in the StylishEco. Halogens were discounted straight away on account of their inferior performance; this left them with LEDs that had 25k or 15k hours rated life or A or A+ energy ratings. To decide the most appropriate lights, they proceeded to calculate the life of the cookerhood to determine the minimum life required to ensure that they bulbs would not need to be replaced throughout the life of the cookerhood; this worked out to approx. 6.5k hours. This meant that by selecting the A+ rated LED with 15k hours rated life, the bulbs would not need to be replaced by the user and also because they had a better energy rating they would use less energy. Not only were they environmentally better; they also reduced operational cost, which would be a selling point.

When faced with making decision regarding the electric motor, they focused primarily on how efficient the motors were. After considering that the current option was only 24% efficient, they decided that doubling the efficiency would be a good enough increase and they did not need to go any higher. Resultantly they selected the 48% efficient single-phase motor with a permanent capacitor to be in the new StylishEco. As they worked through the exercise, P003 did not refer back to the LCA report but rather just focused on making choices based on what they were told they could change. Had they considered that it is the component with the biggest impact on the environmental performance of the overall product, they might have made a different choice regarding the motor and gone for one with a higher efficiency.

For the grease filter, P003 spent sufficient time getting familiar with the various options on offer that they were able to come to the conclusion that there were options that would offer environmental performance benefits. From there they decided to have an all stainless steel grease filter with the smallest thickness; they surmised that having the filter made from a single material would make it easier to recycle and would also make the manufacturing simpler and that having a thinner filter would result in less materials being used in the filter itself and in the whole cookerhood.

P003 decided to include the odour filter in the new cookerhood. They reasoned that including the odour filter would result in a cookerhood with added functionality and this could be a selling point. This added functionality could possibly offset the extra costs that were incurred due to the environmental improvements that were being made. Ultimately you could charge the end user more money to have a product that performs better environmentally and has extra functions compared to its predecessor while at the same time offsetting some of the costs you incurred when improving the environmental profile by having that added functionality because including the odour filter was unlikely to drastically increase costs. For the odour filter they decided to go for the thinnest long life filter, the option they felt had the best environmental performance. As they were trying to create a product that has a better environmental they were conscious of the fact that they were adding an extra part and that would have a negative impact on the overall environmental performance of the cookerhood, but had benefits in other areas, so it was important to reduce its impacts.

When confronted with the challenges within selecting the impeller and blower, they contemplated the differences between steel and polypropylene but ultimately decided that they were most comfortable keeping the parts that were in the Stylish as they felt they could not make a reasonably informed decision. And for the packaging, where they had no information to go by, they were happy to stick with the current option.

Table 93 compares P003 results to the average Condition A results and average group results.

P003 VS. CONDITION A AND GROUP AVERAGE

	P003	Condition Average		All Cond. Average	
PEP	0.776	0.883	Worse	0.792	Worse
Cost	£41.50	£45.81	Better	£38.77	Worse
Cost per % PEP	£0.53	£0.52	Worse	£0.49	Worse
SCG	1.960	2.046	Worse	1.919	Better
Relative SCG	65%	68%	Worse	64%	Worse

During the exercise P003 seemed to adopt a view that extended beyond the product that they were designing, they were very conscious of the how the product they were designing would be marketed and how the users would interact with it. Although they acknowledged that they needed to have market research to be sure, they figured that they could make improvements to the new product and it would be possible offset those costs through good product marketing that justified selling the new product at a higher price; it would be easy to justify the increased cost to the end users by highlighting how much lower the running costs of the StylishEco would be compared to the Stylish.

Upon completion of the exercise, along with market needs information, P003 mentioned that they felt they also needed information regarding how much the various options cost to help them make more informed decisions. The impact of not having the cost information manifested itself though P003 assuming that all the options with better environmental profiles would cost more; while this is usually the truth it is not always the case. For example various grease filters have similar costs but environmentally some are better than others and it is a case of understanding what makes some better than others.

When they felt that they had enough information to make a decision, P003 chose either the option with the best environmental performance or one that they deemed to offer good enough improvements on the predecessor; otherwise they did not change anything.

P004

When presented with the challenge P004 decided to take a systematic approach by using the information in the LCA report to calculate the impacts that the various components had during various stages of the life of the Stylish cookerhood. From this activity, they were able to deduce that the spotlights, electric motor and grease filter has some of the biggest environmental impacts. Starting off with the spotlights, they worked out the minimum life required to ensure that they would not be replaced. When this worked out to 6.5k hours, they were left the LEDs as the only viable replacement options and those with 15k hours rated life being the most suitable option. Of the two such lights on offer, they decided to go with the A+ rated option as that had the better environmental profile.

Moving on to the motor, which they had deduced had the biggest impacts during the use phase of the cookerhood and after looking though the available options, they decided that they would be satisfied with increasing the efficiency from 24% to 50%. This meant a move from a shaded-pole single-phase asynchronous motor to a brushless permanent magnet motor. Provided that they knew that the electric motor had the biggest impact, it is perhaps contrary that they chose it to be the one whose improvement would be limited. For the previous option, they had selected the option that they deemed to have the best performance, and as will become evident later, they had done the same for the grease filter, which is another of the high impact components. When contemplating the various options available for the electric motor, P004 remarked that the motor was likely to be most expensive part, this meant that improving it would have significant impacts on the overall cost so it would be better to have a good enough increase in efficiency as opposed to the best; this would not increase the overall cost too much but would still offer substantial environmental benefits.

As alluded to before, P004 took care with the grease filter, after examining the differences between the options they were able to select the thinnest all stainless steel grease filter for the StylishEco. This decision stemmed from the thoughts that having a filter material made from a single material would be better environmentally and for manufacturing and that a thinner filter would result in less materials being used.

They decided to pass up the option of adding odour filter to the new cookerhood citing that including it would be adding unnecessarily to the product when it performed well enough as it was. They were sure that if the previous cookerhood did not need a filter then this one would not need one either.

Due to the nature of the parts and decisions to be made, P004 decided to consider the impeller and the blower together. First, they thought that it would be good to ensure that both parts are made from the same materials as that would make recycling a bit easier. Second, they thought that there was an environmental case to be made for using steel as opposed to polypropylene. Resultantly they decided to have both parts made from steel. As for the packaging, there was nothing to differentiate the choices so they were happy to stick to the current choice.

Table 94 compares P004 results to the average Condition A results and average group results.

	P004	Condition Average		All Cond. Average	
PEP	0.801	0.883	Worse	0.792	Better
Cost	£47.63	£45.81	Worse	£38.77	Worse
Cost per % PEP	£0.59	£0.52	Worse	£0.49	Worse
SCG	2.1732	2.046	Better	1.919	Better
Relative SCG	72%	68%	Better	64%	Better

P004 started off well by referring to the LCA report and calculating the impacts that the various parts had but somehow, did not seem to translate it well when they started selecting options. It seemed that when faced with making the biggest improvement (the motor) they were also faced with the potential to include massive costs so they decided to go for a reasonable increase instead of the best on offer; without access to cost information there was no way for them to decide if the performance improvements would be worth it. This ties in with how they expressed that they would have liked to have had cost information during the exercise to help them make better decisions.

Reflecting upon how P004 conducted the exercise, they seemed to recognise the benefits that material homogeneity would have in when dealing with end-of-life issues such as disassembly for recycling. The strategy they adopted can be said to be one where they selected the option with the best performance or performance they deemed good enough when they felt they had sufficient information; when they were not well informed they kept the previous options. They made more changes than the other participants in their condition.

P005

When presented with the component selection exercise, P005 decided to start off by referring back to the LCA report. While initially they had gone through it, at the insistence of the facilitator, casually trying to decipher the information within the graphs, now they paid more attention and used the information within it to calculate the impacts that various components had on the overall cookerhood.

Identified as having the biggest impact, they decided to change the electric motor to the best option available. This meant that the shaded pole single phase asynchronous motor in the Stylish cookerhood would be upgraded to a brushless permanent magnet motor in the StylishEco. At 66% efficient, two of the four available brushless motors represented the best options performance wise and P001 opted for the cheaper of the two. When reflecting upon their choice, they remarked that they used cost as a tie breaker because to them, based on the information that they had, the two options were identical; they did however realise that when considering environmental differences, there had to be differences between the two but they did not have right information to help them discern the differences.

Next they moved on to the lights, which they had identified as having the second biggest impact during the use phase of the cookerhood. Here they declared that there was room for improvement and felt that doubling the rated life and having the energy rating go up 2 levels with would be a sufficiently good enough improvement. This left them with 8 different options to choose from and from these they selected the cheapest option, a long life dichroic halogen with a D energy rating and a rated life of 5000hrs. This meant that the new lights would only need to be changed once through the lifetime of the cooker hood, unlike twice as their predecessors, and while not the best rating, the improved rating would mean that operating costs would be reduced for the end user.

For the grease filter, P005 went thought the options on offer thoroughly and declared two of the options offered environmental improvements; these were two all stainless steel grease filters with differing thicknesses. While they recognise that the best option would be the thinner of the two, they decided to go with the thicker and cheaper one because they wanted to keep costs down then they felt that they had already sufficiently improved the environmental profile of the new cookerhood by the previous changes that they had made.

After concluding that they could not see a clear benefit, P005 decided not to include an odour filter in the StylishEco cookerhood. They said they were not prepared to add cost to include a feature whose functionality they were not sure about. From there, they fell back to the information that they had in the LCA report, and considering the impeller and blower together, they decided that they were going to use them to cut costs as they did not have very large lifecycle impacts. This resulted in both parts being the cheapest available polypropylene options. The same tactic was used for the packaging, where the selected the cheapest option on offer.

The table below compares P005 results to the average Condition B results and average group results.

P005 VS. CONDITION B AND GROUP AVERAGE

	P005	Condition Average		All Cond. Average	
PEP	0.876	0.746	Better	0.792	Better
Cost	£27.96	£31.99	Better	£38.77	Better
Cost per % PEP	£0.32	£0.43	Better	£0.49	Better
SCG	1.6316	1.652	Worse	1.919	Worse
Relative SCG	54%	55%	Worse	64%	Worse

During the exercise, P005 seemed to have a good grasp on the information that was in the LCA report and used it to inform the decisions that they made. These decisions did not however always result in being environmentally beneficial. This is to say they did not always make decisions to improve the environmental performance of the product, rather, in some cases they made choices based solely on cost.

When reflecting on the exercise, they remarked that while they used cost as a tie breaker in making decisions but to truly make environmentally conscious decisions they would have liked to have more information on the suppliers, transport, locations and manufacturing relating to the different products on offer. They also comment on how having the cost information made them more conscious of keeping costs down especially when they did not know the value of the product; they just could not tell if certain improvements were worth the money or not. As a result, when they were not sure if a certain improvement was worth it or not, they would just not have it.

Looking at how P001 tackled the exercise it can be said that when they came to the components with the highest environmental impacts they decided on performance improvements that they deemed to be appropriate and then selected the cheapest option that met the performance requirements. For the low impact parts, they completely disregarded any environmental benefits and went for the cheapest offering.

P006

Getting stuck into the exercise, P006 started off by calculating minimum rated life that would be required to ensure that the lights would not need to be replaced during the lifetime of the cookerhood. After getting the value of 6.5k hours, they decided that it was important to have lights with a minimum rated life of that value as it would not only mean that the cookerhood would be more environmentally friendly as it would consume less electricity, resulting in less waste, but also that it would also mean reduced costs incurred by the end user as they would not need to replace the bulbs and they would also not have to worry about replacing the bulbs. This resulted in two possible options, the 15k hour rated life LEDS with A and A+ energy ratings. From there they selected the one with the higher energy rating remarking that it was a worth it for the improvement in overall product performance and for the benefits that it offered to the users.

Throughout the exercise, P006 would refer back to the LCA report and by doing that they were able to note that the electric motor has the biggest impact of the environmental performance of the overall cookerhood. Upon looking at the available replacement options, they then decided that they wanted to go for a brushless motor, as it was superior in performance to the other available options. From the options available in the brushless motor section, they decided that selecting an option that increases the motor efficiency from 24% to 50% was more than good enough. Suddenly they were faced with having to make a choice between two motors that had the same performance but differing costs as different suppliers provided them. While initially they were reticent to go with the cheapest option, the expressed how they were suspicious of cheap items as it is usually because they come from far away and that would not be good for the environment. Ultimately they did decide to go for the cheaper option, the fact that the new motor would have the same supplier as its predecessor is what swung it.

When it came to selecting the grease filter, they seemed keen to make some environmental improvements. After evaluating the different offerings they decided that improvements could be had by switching to a thinner filter as it would result in less materials being used. They were certain that they wanted a thinner filter but they could not see how the various material options could lead to environmental improvements, as a result they decided to stick to the same material composition as the filter that was in the Stylish. P006 managed to make an improvement by using a thinner filter, however had they thought a bit more about the materials and end-of-life issues surrounding the recycling of the filters they might also have opted for a thinner filter made of the same material throughout.

When given the option to add a grease filter to the cookerhood, a component that is not in the Stylish cookerhood, P006 did not think that they could justify the added cost and were happy to not include it and remarked that it was something that people wouldn't really miss or wish to have.

Due to the similarities in the nature of decisions required, the blower and the impeller decisions were given the same treatment. For these, P006 mentioned that they could not see any real environmental performance differences between polypropylene and galvanised steel and as a result they would focus on the cheaper polypropylene options. They were however reluctant to go with the cheapest option; they just didn't seem to trust it because it was the cheapest. This meant that they were more comfortable selecting the mid-range polypropylene options for the blower and the impeller. For the final decision, regarding the packaging, as all they had to go by was the cost of different products from different suppliers they decided that it was best to stick to the current choice; they did not want to make a choice based solely on cost.

The table below compares P006 results to the average Condition B results and average group results.

P006 VS. CONDITION B AND GROUP AVERAGE

	P006	Condition Average		All Cond. Average	
PEP	0.778	0.746	Better	0.792	Worse
Cost	£40.95	£31.99	Worse	£38.77	Worse
Cost per % PEP	£0.53	£0.43	Worse	£0.49	Worse
SCG	1.6633	1.652	Better	1.919	Worse
Relative SCG	55%	55%	Same	64%	Worse

P006 proved to be very suspicious of the cheapest options that were on offer; without any other information to discern any differences between the suppliers, they seemed to assume that the suppliers who delivered the cheaper products were worse in some kind of way. When reflecting upon the exercise, they noted that they would have liked to have more information regarding the suppliers particularly their location. One can only surmise that had they had this information then maybe P006 would not have been so distrusting of the cheaper offering and instead would have evaluated the suppliers differently.

When tackling the exercise, where there was a clear environmental improvement to be made, P006 made sure they made an improvement; the choice was a balance between performance and cost but always with an improvement. However, for parts where they could not detect a clear environmental gain they either stayed with the same option as in the predecessor or they made a cost saving.

P007

From the get go, P007 held sticking to the right supplier in high regard; it started with the decision regarding the spotlight. After making it a point to note that the cheapest option was already in use, they proceeded to take note of the current supplier and to state that they would aim to stick to the same supplier wherever possible. The reason for having such a strong view was cited as a desire to work with a familiar supplier and to cut down on any costs that could be associated with sourcing new suppliers; they seemed to value maintain current relationships and where possible working within those. After noting the current supplier for the spotlight, they went through all the available options and isolate those that were from the same supplier. They were looking to stay with the same supplier but to upgrade to a light with a better rated life; upon comparing the available options and weighting up cost to rated life, they settled on a long life dichroic halogen that they were happy with. This resulted in the selection of a light with a rated life of 5k hours and a D energy rating. By adopting such a stringent supplier focus, P007 vastly limited the environmental improvements that they could have made; one problematic issue is that by sticking to Supplier B only they cut themselves off from any LEDs as Supplier B only sells halogen lamps. Following that, it could be said that P007 made another error by focusing solely on the rated life as a means of gauging environmental impact without calculating the life of the cookerhood. All of the lights provided by Supplier B, other than the one currently in use, would need to be replaced during the life of the cookerhood; this means that it would have been better to try and balance out the energy rating of the lights with the cost instead.

Carrying on as before, P007 decided that for the motor they would also like to stick to the same supplier. Upon reviewing the options available, they noted that Supplier A had a product in the three different motor type categories. To decide which motor to go with, they decided they wanted something that had low power and high efficiency; this would result in a significant increase in cost but they decided that it would be worth it. In the end, they settled for the 50% efficient brushless permanent magnet motor supplied by Supplier A.

After browsing the grease filter options, after some debating, P007 came to the conclusion that any differences were purely aesthetic and there was no benefit to be gained in changing from the current grease filter. Upon being given the option to include the odour filter, P007 rejected it remarking that the odour filter was not necessary and not worth the added cost.

The impeller, blower and packaging were given the same treatment; after deciding that their environmental contributions were relatively low, P007 decided to adopt some cost saving tactics. This meant that they selected the cheapest options all round; even their strategy to stick to the same supplier was abandoned.

The table below compares P007 results to the average Condition B results and average group results.

P007 VS. CONDITION B AND GROUP AVERAGE

	P007	Condition Average		All Cond. Average	
PEP	0.665	0.746	Worse	0.792	Better
Cost	£25.11	£31.99	Better	£38.77	Better
Cost per % PEP	£0.38	£0.43	Better	£0.49	Better
SCG	1.7527	1.652	Better	1.919	Worse
Relative SCG	58%	55%	Better	64%	Worse

Although they did adopt the 'same-supplier-first' approach, throughout most of the design process P007 kept referring back to the LCA report, which means they had a firm understanding on the impacts that various components had throughout the life of the Stylish cookerhood.

Reflecting upon the exercise, P007 stated that they would have liked to have more information regarding the suppliers of the products including their environmental impacts and manufacturing processes, as it was they had gone by the notion that if we used them before then they must be good so stick to them.

Looking at how P007 undertook this exercise, the same-supplier preference is evident. When faced with making decisions on parts that has substantial environmental implications, they looked at the suppliers that they wanted and then picked out what they thought was the best component on offer by balancing out cost and performance. For those parts that were deemed to have negligible impacts, the cheapest option was selected.

P008

When considering the environmental performance of spotlights, P008 found themselves debating the merits of having a higher rated life vs. having a better energy rating. Ultimately they came to the conclusion that rated life was a better indicator however what they failed to take realise is that when you choose to improve the environmental profile of a cookerhood by fitting it with a spotlight with a longer rated life, it is important to ensure that the extended life is sufficient enough to negate the need for a bulb replacement. P008 decided to select the long life dichroic halogen with a rated life of 5k hours and a D energy rating, this represented the cheapest option in the 5k-rated life range. They also remarked that by picking this choice they would be keeping the supplier constant.

They were keen to replace the current single-phase motor with a brushless one due to the superior performance offered by the brushless motors. From there they selected Option 9, as it was the cheapest brushless motor available; they would get 50% efficiency for £11.25 and they were happy with this. Once again, they remarked that this meant sticking with the same supplier and that this was an added bonus of choosing that motor.

After careful consideration of the grease filters on offer, P008 declared that there were three ways in which they could improve the environmental performance of the overall product. The first would be to use a filter with the same materials as this would make recycling easier and the second would be to go for a thinner filter and the third, implement all three changes. They remarked that since they felt that they had already made substantial environmental improvements, they would only implement one change so as to keep costs to a minimum. This resulted in the selection of the all stainless steel grease filter with the larger thickness. When given the option to add an odour filter they rejected it citing that it was just not necessary to add it.

P008 decided to have the impeller and blower made out of steel as they felt it had a better environmental profile than the alternative choice of polypropylene. They decided on steel from Custom 1, who they were currently purchasing from, as they felt that any cost savings that would be made by buying from a different supplier would not be worth having to switch suppliers.

However, this same sentiment was abandoned when it came to selecting the packaging because they opted to switch to a supplier who offered the cheapest product.

The table below compares P008 results to the average Condition B results and average group results.

P008 VS. CONDITION B AND GROUP AVERAGE

	P008	Condition Average		All Cond. Average	
PEP	0.665	0.746	Worse	0.792	Worse
Cost	£33.94	£31.99	Worse	£38.77	Better
Cost per % PEP	£0.51	£0.43	Worse	£0.49	Worse
SCG	1.5598	1.652	Worse	1.919	Worse
Relative SCG	52%	55%	Worse	64%	Worse

Throughout the design process, P008 seemed to put a lot of emphasis on keeping suppliers constant. After the exercise was completed, they commented that they would have liked more information on the suppliers to know what their environmental profiles were like because that would also have an impact on whether they insisted on staying with them or not. Additionally, they expressed a wish to have had information relating to the locations of the suppliers. While they expressly stated that cost was important but didn't want to fall into the trap on being too blinded by it, they seemed to fall back on it repeatedly.

When undertaking the exercise, P008 seemed to decide on what they classed as a good performance improvement and sought the cheapest way to implement that improvement. They went against this in the case of the blower and the impeller when they claimed that the cost savings were not worth switching suppliers.

P009

P009 started off the re-design process by looking at the spotlights. From the get go they decided to focus only on LEDs due to the superior performance that they offer; they remarked that these were also ideal as selecting any one of the ones on offer would mean they would not need to be replaced by the end user. While they were right this was an interesting remark to make, as they had not actually calculated the minimum life required to ensure that the bulbs would not need to be replaced. They felt that not having to replace the bulbs would not only be an environmental benefit but would also lead to customer satisfaction. For the LEDs on offer, they then proceeded to calculate the cost per hour of rated life and by comparing this to the profiles of the suppliers, they decided to select the LED with an A+ energy rating and a rated life of 15k hours. While they remarked that the supplier's location was not ideal, they were happy with the certifications and EMS scores that the supplier had.

For the electric motor they decided to focus on the efficiency and supplier profile. Immediately they discounted all single-phase motors in favour of the enhanced performance of the brushless motors. After considering the motor costs and profiles of their suppliers, P009 settles on the 50% efficient brushless motor that is supplied by Motor C. This was the result of trying to balance out the cost and supplier profile for the performance that they were getting.

After looking through the grease filters on offer, they declared that they could not see any differences in terms of environmental profile and as a result did not change the grease filter. When given the option to add an odour filter to their cookerhood, they stated that they liked the idea of offering a new feature with the new cookerhood and thought that it could be a great selling point. When deciding which odour filter to select, they calculated the number of times different filter options would need to be changed and how much that would cost. In the end, they selected the cheapest non-disposable long life filter.

For the blower and the impeller, P009 felt that they did not know enough about the materials and could not categorically say which one had the better environmental profile. They were happy to keep the options the same, as they were also happy with the current suppliers. For the last part, the packaging, they looked at the supplier profiles and tried to balance them out with the cost; this resulted in the selection of packaging from Box B.

The table below compares P009 results to the average Condition C results and average group results.

P009 VS. CONDITION C AND GROUP AVERAGE

	P009	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.766	0.760	Better	0.792	Worse
Cost	£39.83	£41.19	Better	£38.77	Worse
Cost per % PEP	£0.52	£0.54	Better	£0.49	Better
SCG	2.046	1.968	Better	1.919	Better
Relative SCG	68%	66%	Better	64%	Better

As they undertook the exercise, P009 seemed to like calculating the cost per unit performance; this is how they balanced out cost and performance. They remarked early on that it was very important to be weary of slight cost increases as they do add up very easily. Through their choices, it seemed they prioritised performance and supplier profile and then tried to get what they wanted for the best price possible.

Reflecting on the exercise as a whole, they felt that while they would have like more information on materials, the information depth of information that they had made it easier to make decisions. They cited the lighting decision as the easiest one to make as they felt they had all the information that they needed to make an informed choice.

As someone with a limited working knowledge of eco-design they remarked, “Instinctively you have an idea of things that you can do to improve the environmental profile of a product, this is reinforced when you get more information, like in the LCA report” and confessed that they as they got more information they felt more comfortable and confident. Whenever they were not confident, they decided that they would not change anything and stick to the original component.

In terms of the information they were given, they thought that they did have a lot to consider but by taking their time they were able to gain more confident in their decisions. While in some cases they would have liked more performance related information to guide them, they felt the supplier certifications that they were given were very important as they showed you which suppliers cared and had high standard.

P010

When initially faced with selecting lights for their new cookerhood, P010 immediately discounted the LEDs due to their increased cost, however once they started looking at performance numbers they decided to give them a second look. Ultimately they decided that their superior experience was worth the premium price tag and they decided to go for the one that they felt offered the best performance regardless of price. Once they had settled on the LED with a rated life of 25k hours and an A rating, they looked at the supplier who provided it and were satisfied with their profile.

For the electric motor, they decided to take a slightly different approach. The first thing that they did was to rank all the suppliers in terms of their environmental profiles and decided to only purchase a motor from one of the top 3. From there, they then stipulated that they were looking to pay approx. double cost of the current motor to double the efficiency of the motor in their new cookerhood; anything above this they felt was just too expensive. This resulted in the selection of the 48% efficient single-phase motor with capacitor supplied by Motor E.

It would be fair to say that P010 did not put much effort into trying to discern the differences between the different grease filters on offer. They were quick to claim that they could not really see how the options where different and that they were happy to stick to the current choice. It was also at this point in the exercise that they suddenly declared that they would be adopting cost saving tactics. It is interesting to note that while they explicitly said this, they did not seem to follow through. Instead, from this point onwards they made a lot of comments regarding making better environmental choices, as their conscience would not forgive them otherwise. It seemed that while they did want to keep the costs down, they did not was to do that at the detriment of the environment.

They readily took up the opportunity to add an odour filter to their design. They felt that the addition of the odour filter would result in a cookerhood with added functionality and this would be a great selling point. They decided on the thicker of the long life filters, and even though they had considered buying it from the same supplier as the grease filter they felt that switching suppliers offered cost savings that they could not pass up; the new supplier also had a better profile and that was an added benefit.

As they were working through the exercise, they did note that they realised that were not really utilising the LCA report that much. They did refer back to it here and there but its contents did not seem to influence the decisions that they were making. They also claimed that wherever possible they were trying to stick to Italian suppliers, as their closer proximity would lead to improved product environmental profile.

When considering which impeller to have in their product, they decided to keep the material the same for aesthetic reasons; from there they discounted two of the suppliers of galvanised steel impellers based on their profiles leaving the option from Custom A. For the blower, they decided that they didn't want to change the material, and after considering the option that they had left to pick from they decided that they were happy with part that was currently in use as it was reasonably priced and supplied by the best supplier. For the last part, the packaging, they were happy to go for a slightly cheaper option, although the supplier was not as good, they were happy with the compromise for cost benefits gained.

The table below compares P010 results to the average Condition C results and average group results.

P010 VS. CONDITION C AND GROUP AVERAGE

	P010	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.731	0.760	Worse	0.792	Better
Cost	£40.64	£41.19	Better	£38.77	Worse
Cost per % PEP	£0.56	£0.54	Worse	£0.49	Worse
SCG	1.992	1.968	Better	1.919	Better
Relative SCG	66%	66%	Same	64%	Worse

Upon completion of the exercise, they stated that overall they were happy with the information that they had been given. They remarked that since there was a lot for them to consider was easy to get overwhelmed or forget things, which meant that it was important concentrate.

Throughout the exercise, P010 asked a lot of questions and bounced their ideas off the facilitator, they said that this process of talking though their thoughts really helped them think about what they were doing in a bit more detail. P010 mainly selected parts by deciding which performance that they wanted and then choosing the best supplier or chose the supplier that they wanted first and then when for the best performing option that they offered.

P011

P011 kick started the design of the StylishEco by working out the minimum rated life required of the lights to ensure that they would not need to be replaced during the life of the cookerhood. This established that the lights with a rated life of 15k hours were the optimum; to select one of the two they considered the supplier profiles and settled on the one with the best supplier profile regardless of the fact that it was more expensive one. For the electric motors, they immediately discounted the single-phase ones and decided to focus solely on the brushless ones. They decided that they would be happy with increasing the efficiency to 50% and from there selected the motor that was provided by the supplier with the best profile, once again this proved to be the more expensive of the two option but they did not mind it.

Throughout the exercise P011 was conscious of being limited by price, to counter this they decided that they would decide on the performance that they wanted and would select it regardless of price. Throughout the exercise, the referred back to the LCA report and used it to inform their decisions. When faced with the grease filter selection, they could have taken more time to compare the options. With this part they felt that they could not discern any differences in the grease filters and would be more comfortable not changing anything. When given the choice, they felt that adding an odour filter to their cookerhood would result in added functionality that would be a good selling point. Resultantly, they selected the non-disposable long life grease filter with the bigger thickness and decided to purchase it from the supplier with the better profile and lower cost.

For both the impeller and the blower, they did not want to change the materials that were currently in use, as they could not confidently ay how the environmental performance would be affected. From there, they selected the suppliers with the best profiles regardless of cost. For the packaging, they decided to switch to a supplier who was located closer who also happened to offer a cheaper product.

The table below compares P011 results to the average Condition C results and average group results.

P011 VS. CONDITION C AND GROUP AVERAGE

	P011	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.766	0.760	Better	0.792	Worse
Cost	£43.25	£41.19	Worse	£38.77	Worse
Cost per % PEP	£0.56	£0.54	Worse	£0.49	Worse
SCG	1.9205	1.968	Worse	1.919	Better
Relative SCG	64%	66%	Worse	64%	Same

When reflecting upon the exercise, P011 remarked that they were given a lot of information and things to consider but this was good because this reflected the real life scenario that surrounds design and eco-design. For them, cost did not seem to be a major deciding factor. They liked to decide on the performance that they wanted and then select the option from the supplier with the better profile.

P012

When faced with the challenge of deciding which electric motor to use in their cookerhood design, P012 started off by working out the minimum light rated life required to ensure that the bulb would not need to be replaced throughout the life of the cookerhood. Once that was decided, the LED with 15k hours rated life and A+ energy rating was selected as the most appropriate choice not only because of its superior performance but also because the profile of its supplier.

For the electric motor, they decided that doubling the efficiency to 48% was an adequate improvement in performance. For this efficiency, P012 selected the single-phase motor with capacitor that came from the supplier with the better environmental profile, although they did remark that it was not ideal that the supplier was situated further away when compared to the other option.

After looking through the options for the grease filter, they decided to make all the improvements that they could. This resulted in the selection of the thinner all stainless steel grease filter regardless of the increased cost. When given the option of including an odour filter in their cookerhood, they rejected it as they claimed that they did not see a clear benefit of adding it and were more than happy to leave it out.

For the impeller, they decided to stick to the same material as before and decided that they were happy with the supplier who was currently providing it. They then decided to change the material of the blower to match the impeller, and this resulted in the blower and impeller being provided by the same supplier. A similar strategy was adopted for the packaging, they looked at the current supplier that they had and deemed it most appropriate to stick.

The table below compares P012 results to the average Condition C results and average group results.

P012 VS. CONDITION C AND GROUP AVERAGE

	P012	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.776	0.760	Better	0.792	Worse
Cost	£41.02	£41.19	Better	£38.77	Worse
Cost per % PEP	£0.53	£0.54	Better	£0.49	Worse
SCG	1.914	1.968	Worse	1.919	Worse
Relative SCG	64%	66%	Worse	64%	Same

While they did not seem to utilise the LCA report as much, they did seem to always think about the environmental impacts of the choices that they were making and tried to ensure that they made at least an improvement with each component selection.

Throughout the exercise, P012 did not seem to consider cost very much; they were more inclined to choose the product that they wanted and then accept the cost. They did remark that there was a lot of information and things to get their head round during the exercise, things that are not usually thought about. For example, usually it only matters where you get your component from because it affects the cost, but now the implications extended beyond that.

P013

Upon beginning the design of their cookerhood, P013 immediately asked for cost information related to all the products on offer. They then followed that up by asking for information on the outputs of the environmental management system (EMS) if they were available, only after that did they proceed with the design task. After referring to the LCA report they decided that they didn't really need to know any information regarding the location of the suppliers since the transport scenario had so little impact thorough the lifecycle of the cookerhood.

When selecting lights to include in their cookerhood, P013 wanted lights that would need to be replaced during the life of the cookerhood. To determine minimum rated life that they would require for this, they turned to the information that they had been given regarding the in use life of the cookerhood. With the minimum life decided to be 6.5k hours, they selected the light that would fulfil this while also providing the best energy rating and supplier profile. This turned out to be an LED with 15k hours rated life, an A+ energy rating and a supplier with a 6.4 EMS score and 3 certifications. For the motor, they took a similar approach by deciding that they wanted a performance of 48%, double what it was originally, and then selected the option that was provided by the supplier with the better profile. This resulted in the selection of a single-phase motor with a permanent capacitor.

For the grease filter, P013 readily switched to the all stainless steel option as they remarked that it would make recycling easier. They were not willing to spend extra money to have the thinner filter and stuck with the 20 mm thickness. When asked if they wanted to include an odour filter they declined as they felt that it did not offer sufficient benefits to warrant being included.

For the impeller and the blower, they decided that galvanised steel was the ideal material to use as it had a better environmental profile compared to polypropylene. After reviewing the various suppliers, they decided to stick to the current supplier due to their profile and the price that they were offering the product at. Much the same, they decided to stay with the same supplier for the packaging after taking into consideration the cost and the profile of the suppliers.

The table below compares P013 results to the average Condition D results and average group results.

P013 VS. CONDITION D AND GROUP AVERAGE

	P013	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.753	0.778	Worse	0.792	Worse
Cost	£38.31	£38.09	Worse	£38.77	Better
Cost per % PEP	£0.51	£0.46	Worse	£0.49	Worse
SCG	2.163	2.008	Better	1.919	Better
Relative SCG	72%	67%	Better	64%	Better

When reflecting on the exercise, P013 commented that there was a lot of information that they had to consider but it was nice having the option to ask for more information when they felt that they needed it; it made making informed decisions easier. They did express that they would have liked to have more information regarding materials and manufacturing processes. They felt that there was quite a lot of balancing out that had to be done to ensure that the best choice was made.

Overall, P013 selected components for their StylishEco cookerhood by deciding on the performance improvement that they wanted and selecting and option that fulfilled that while balancing supplier profile and cost.

P014

After being instructed to start the component selection exercise, P014 asked for information regarding the cost of the parts on offer and who the suppliers were. With this information in hand they proceeded to select what they deemed to be the most appropriate light to put into their StylishEco. As they were weighing up the various options, they remarked "Environmentally friendly things are always more expensive". This was right before they selected the long life halogen bulb with a rated life of 4k hours and a B energy rating. While they claim that they selected this light because it would not need to be replaced during the life of the cookerhood, this is incorrect as a minimum rated life of 6.5 hours would be required. They did however comment on how some of the other lights on offer had rated life hours that were well over the expected life of the cookerhood itself. One of the reasons they did select Option 1 was the low cost of the light. They also said that even though the lights they used were halogens, the fact that they were called energy saver halogens would be a good selling point.

When they moved on to the eclectic motor they decided that they would try and stick to the same supplier that they currently had. From there, they picked the brushless motor that offered the best performance. This proved to be the most expensive offering from Motor A but since they had consulted the LCA report they understood the importance of having an electric motor with high performance.

For the grease filter, they switched to the all stainless steel filter as they claimed that it had a better environmental profile, as it was a made from a single material. They felt that this was enough of an improvement and did not see the point of reducing the thickness of the filter. When given the option of including an odour filter in their design they turned it down as they did not wish to ramp up their costs.

For the impeller and the blower they decided to consider only the cost and go for the cheapest options available. Throughout the exercise P016 showed a lot of concern when it came to cost; there was a theme running through where they had to balance out the cost as they had gone for more expensive options in some cases. As a consequence of choosing an expensive component they felt the need to compensate. They also seemed very keep to stick with the same suppliers as they felt that would prevent any switching costs. When they changed to a better product, they always viewed it as a loss of money and did not seem to attach any gains to the change (they did not seem to realise that in some cases while they were paying more, they were also getting better performing products). Regarding the packaging, they decided to stick to the same supplier as before, they did however state that they try to negotiate for a lower price.

The table below compares P014 results to the average Condition D results and average group results.

P014 VS. CONDITION D AND GROUP AVERAGE

	P014	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.683	0.778	Worse	0.792	Worse
Cost	£27.19	£38.09	Better	£38.77	Better
Cost per % PEP	£0.40	£0.46	Better	£0.49	Better
SCG	1.8245	2.008	Worse	1.919	Worse
Relative SCG	61%	67%	Worse	64%	Worse

P014 summed up their experiences with the exercise by saying “There is a lot of stuff to think about, I just wasn’t thinking about it. I didn’t know what I could and could not ask for. I would have liked to know what things I can ask for then I will ask for them. So I missed the most interesting part of this then. There are too many things to weigh up. I’m more in design mode than looking at the whole picture mode. If I knew you had this, it would have affected the choices that I made. If you do not know that you can get something, then it is hard to ask for it.” They also expressed how having manufacturing information would also have allowed them to make more informed decisions.

In terms of how they tackled the exercise, they tried to go for the cheapest option wherever possible; for the more important parts they went for improved performance but for the other ones they were not concerned about that.

P015

When told to start the component selection exercise, P015 started off by requesting cost information. It was only when they were half way through the exercise that they realised that they probably had not made the most of the fact that they could ask for any information that they wanted. It was at this point that they asked for more information relating to the suppliers, including the outputs from the EMS. Armed with the new information, they decided to restart the exercise. When they got the extra information (distance, certifications and eco-score), they considered it but ultimately decided to stick to their original choices for the blower, grease filter, impeller and packaging.

They selected the all stainless steel grease filter as they felt that it had a better environmental profile, they were also please that they could make the switch without incurring any additional costs. They did not see the value the odour filter so when they were given the option to include it they turned it down as they felt that it was unnecessary. For the blower and the impeller they decided that they did not want to use any polymers but also wanted to reduce costs so they went for the cheapest steel available options. They had a similar cost view for the packaging but were conscious of not sacrificing the profile of the supplier too much so they went for cheaper packaging from a supplier with a better profile than the original one.

They referred back to the LCA report constantly during the process and commented that the motor and lights was where the potential to make major improvements was but that this was also where costs were likely to ramp up. As a result, they decided to make decisions regarding these last and started off by "trying to save cost in the less crucial components." They felt a comfort in the fact that by making certain performance improvements where it counted the most would likely result in a product that pays for itself throughout its lifecycle.

When they were making their choices, P015 tried to balance out the performance, supplier profile and cost. For the spotlight, they discounted supplier location as it had little impact and remarked that they were shocked to see that the transport phase had such a small overall impact. They tried to get the best balance between supplier profile, cost and performance and ended up selecting the LED with 15k hours rated life and an A+ energy rating. Moving on to the electric motor, they decided to go for the best efficiency available and from the two possible 66% efficient brushless motors to choose from they selected the one from the supplier with the better profile.

The table below compares P015 results to the average Condition D results and average group results.

P015 VS. CONDITION D AND GROUP AVERAGE

	P015	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.965	0.778	Better	0.792	Better
Cost	£42.77	£38.09	Worse	£38.77	Worse
Cost per % PEP	£0.44	£0.46	Better	£0.49	Better
SCG	1.949	2.008	Worse	1.919	Better
Relative SCG	65%	67%	Worse	64%	Better

Upon completing the exercise they stated that the aim was to try and optimise your choice and that meant trying to find a balance between improving the environmental performance and the cost. They found it interesting that it was left up to them to decide what information they wanted, in such a case they felt that they would have liked to have had commercial information like sales numbers. They also made a comment that sometimes when all you are faced with are numbers to help you compare items, it is hard to know how they actually translate in the real world; for example what would a 0.2 difference in EMS scores actually look like.

To summarise, P0015 tried to save money on the less crucial components and for the crucial ones tried to balance out cost, supplier profile and the best possible performance.

P016

When they started the exercise, P016 immediately asked for cost information and the names of who was supplying the parts. With this information they then proceeded to select parts for their cookerhood.

They were able to accurately calculate the minimum life required to ensure that the bulbs used in the cookerhood would not need to be replaced. Once they had this information, they then selected the cheapest light that was appropriate, the A rated LED with a rated life of 15k hours. In a similar fashion, for the electric motor they decided that doubling the efficiency to 48% would be a good enough improvement and they selected the cheapest single-phase motor with capacitor that had this performance.

When it came to sorting through the grease filter options, they were not able to discern any major differences between the choices and as a result of this they decided that it was best that they stuck with the selection that was in the current Stylish cookerhood. When they were given the option of including an odour filter in their cooker hood they turned it down, they said that they could not see the benefit and that it would be an unnecessary addition.

For the impeller and the blower, they decided to go with galvanised steel as they felt that it had a better environmental profile than polypropylene and for this they decided to stick with the supplier that they were familiar with. Lastly, for the packaging, they asked for the locations of the suppliers and decided to switch to a closer supplier who offered a lower cost. When they had various pieces of information to consider, supplier location was not something that they thought of. It was only when they had nothing but cost to go with that they asked for the supplier location and used it to help them make a decision.

The table below compares P016 results to the average Condition D results and average group results.

P016 VS. CONDITION D AND GROUP AVERAGE

	P016	Condition Average	Ranking	All Cond. Average	Ranking
PEP	0.71	0.778	Better	0.792	Better
Cost	£36.07	£38.09	Worse	£38.77	Worse
Cost per % PEP	£0.51	£0.46	Worse	£0.49	Better
SCG	2.0973	2.008	Better	1.919	Worse
Relative SCG	70%	67%	Better	64%	Better

Throughout the whole process, cost was a significant influencing factor for P016; they made several comments about going for the cheapest possible option. It is interesting to note that they never seemed to consider more than two factors at a time. Usually it would be performance and cost and in the one instance where performance was not a differentiator they turned to cost and supplier location. Overall, they tried to go for the cheapest option that met the performance standards that they determined.

After they completed the exercise, they commented that they did not really feel like they had made any environmental decisions and that they didn't really feel like they had the information that would have allowed them to do that (even though they could have asked for it). They would have liked to have manufacturing information and more information regarding the suppliers; more than transport information as that did not really have such a big impact. When asked why they didn't ask for all that extra information that they just had mentioned that would have allowed them to make better-informed environmental decisions, they said that they were not really sure what they could have asked for so they didn't bother doing it.

Appendix 7.1: Framework For Purchasing Involvement in Product Development

This appendix contains the framework for purchasing involvement in product development.

Areas	Activity
Development Management	Determining which technologies to keep/develop in-house in which ones to outsource the suppliers Formulating policies for the involvement of the suppliers Formulating policies for purchasing related activities of internal departments Communicating policies and procedures internally and externally
Supplier Interface Management	Monitoring supplier market for technological developments Preselecting suppliers for products development collaboration Motivating suppliers to build up/maintain specific knowledge or develop certain products Exploiting the technological capabilities of suppliers Evaluating suppliers' development performance
Project Management	*Planning* Determining specific develop-or-buy solutions Selecting suppliers for involvement in the development project Determining the extent (workload) of the supplier involvement Determining the moment of supplier involvement *Execution* Coordinating development activities between suppliers and manufacture Coordinating development activities between first-tier suppliers Coordinating development activities between first-tier suppliers and second-tier suppliers Ordering and chasing prototype
Product Management	*Extending Activities* Providing information on new products and technologies being developed or already available in markets Suggesting alternative suppliers, products and technologies that can result in a higher quality of the final product *Restrictive Activities* Evaluating products designs in terms of part availability, manufacturability, lead-time, quality and cost Promoting standardisation and simplification of designs and parts

From Wynstra et al 2000 Driving and enabling factors for purchasing involvement in product development

Appendix 8.1: A Checklist for Ethical Issues

This appendix contains a checklist of ethical issues that was used during the evaluation of the project:

Ethical Issue	Description
Privacy	The right not to participate. The right to be contacted at reasonable times and to withdraw at any time.
Promises and Reciprocity	What do participants gain from cooperating with the research? If promises are made keep them.
Risk Assessment	In what ways will the research put people under psychological stress, legal liabilities, ostracism by peers or others? Will there be political repercussions? How will you plan to deal with these risks?
Confidentiality	What constitutes the kinds of risks of reasonable promises of confidentiality that can be honoured in practice? Do not make promises that cannot be kept.
Informed Consent	What kind of formal consent is necessary and how will it be obtained?
Data access and ownership	Who will have access to the data and who owns it?
Researcher Mental Health	How will the researcher be affected by conducting the research? What will they see or hear that may require debriefing or counselling?
Advice	Who will the researcher use as a confidant(e) or counsellor on issues of ethics during the research?

Checklist available from (Gray, 2010)