THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

QUALITY MANAGEMENT
FOR
SUSTAINABLE PRODUCT DEVELOPMENT:
ADAPTATIONS
OF
PRACTICES AND TOOLS

VANAJAH SIVA

Division of Quality Sciences
Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2016

Quality Management for sustainable product development: Adaptations of practices and tools
VANAJAH SIVA
ISBN 978-91-7597-290-9

Doktorsavhandlingar vid Chalmers tekniska högskola.
Ny serie nr 3971
ISSN 0346-718X

Division of Quality Sciences
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0) 31-772 1000

Printed by Chalmers Reproservice
Gothenburg, Sweden 2016

ABSTRACT

Quality Management is a management approach that has been suggested to project a number of synergies with sustainable development in general, and environmental sustainability in particular. For example, the principles of customer focus and continuous improvement are applicable in practices supporting environmental sustainability, especially in product development. Such synergies could be used to the advantages of organizations who are faced with the challenges of current era, to develop and manufacture products with considerations, not only toward quality, cost and time but also, to the environment. However, the application of Quality Management practices and tools to support environmental sustainability in product development is neither straightforward nor simple. The purpose of this thesis is, therefore, to explore and identify the adaptations of Quality Management practices and tools to better support environmental sustainability. Specific focus is given to the integration of environmental requirements in product development, and to the adaptations of Robust Design Methodology, as one Quality Management methodology.

This thesis consists of five studies; one literature review, one conceptual study, and three case studies, addressing four research questions. The purpose of the literature review was to elaborate on the support of Quality Management for business approaches toward sustainable development. The findings show that there is a lack of adaptations of Quality Management practices and tools to exploit its potential contributions toward sustainable development. Further, the customer focus view requires expansion from focus on the user to include all stakeholders. The literature review precedes two case studies that explored the joint consideration of quality and environmental requirements in a product development setting. The first case was of a large manufacturing organization in Sweden. The second was a comparative study between the same Swedish organization, and a large manufacturer in The Netherlands. Results show that Quality Management can support the two sustainable product development approaches, namely the integration of environmental requirements in existing methodologies, and the implementation of dedicated environmental concepts and tools such as Design for Environment and Life Cycle Assessment. However, adaptations of current practices and tools were found necessary. This was conceptually exemplified in the next study that explores how Robust Design Methodology-based efforts may better contribute to sustainability and, more specifically, to sustainable product development. Based on a review of selected published cases on the Robust Design Methodology-based efforts to minimize environmental impacts, an adaptation area suggested was to expand the view of the noise factors in order to realize the potential to contribute to various life cycle stages of a product. This was exemplified in the final case study of a medium-sized Swedish manufacturer, where the adoption of a life cycle approach to noise factor identification was proposed as a new practice of Robust Design Methodology.

Quality Management contributes to sustainable product development where its practices and tools are shared in a co-organized product development setting. Additionally, Robust Design Methodology contributes to sustainable product development through the expansion of the customer focus view and the adoption of a life cycle approach. Further, the challenges in sustainable product development, such as the lack of integration of environmental requirements, differ according to the two approaches that could be adopted by managers in terms of the type of products manufactured in varying industries. This thesis points to more empirical investigations of Quality Management practices and tools to support sustainable product development, and of the usefulness of Quality Management to economic and social sustainability, for future research.

Keywords: Quality Management, adaptation, integration, environment, sustainability, sustainable product development, Robust Design Methodology.

LIST OF APPENDED PAPERS

Paper I Siva, V., Gremyr, I., Bergquist, B., Garvare, R., Zobel, T., and Isaksson, R. (2015). The support of Quality Management for sustainable development: A literature review. *Paper under revision for publication at Journal of Cleaner Production.* An earlier version was presented at the 17th European Roundtable on Sustainable Consumption and Production 2014, Portoroz.

The writing process was led by Siva. Chapters in the paper were divided among all authors.

Paper II Siva, V. (2015). A case of joint consideration of quality and environmental requirements in product development. *Paper submitted to a journal for the first-round of peer review.* An earlier version was presented at the 1st EurOMA Sustainable Operations and Supply Chain Forum 2012, Groningen.

Single authored by Siva.

Paper III Siva, V., and Peters, K. (2015). Challenges in sustainable product development – A comparative study. An earlier version was presented at the 22nd EurOMA Conference 2015, Neuchatel.

Authored jointly by Siva and Peters. Empirical material was collected by Siva in Sweden. Empirical material in The Netherlands was jointly collected by Siva and Peters.

Paper IV Gremyr, I., Siva, V., Raharjo, H., and Goh, TN. (2014). Adapting the Robust Design Methodology to support sustainable product development. *Journal of Cleaner Production*, 79, 231-238. An earlier version was presented at the IIE Asian Conference 2012, Singapore.

Writing process led by Gremyr, and supported by Siva. Chapters in paper were divided among all authors.

Paper V Siva, V., Gremyr, I., Raharjo, H., and Svensson, B. (2015). A life cycle approach to Robust Design Methodology. Accepted for publication, to be published in 2016, in *International Journal of Productivity and Quality Management.* Inderscience Publishers. The paper can be seen listed as forthcoming at: http://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijpqm. An earlier version was presented at the 14th QMOD Conference 2011, San Sebastian.

Writing process led by Siva. Empirical material collected by Siva and Raharjo. Feedback was provided by Gremyr and Svensson.

Contents

ACKNOWLEDGEMENTS

The five years of the PhD journey flashed in front of my eyes when I sat down to write this page. Some were joyous memories, and some not in the least. And here are the people I must thank for being a part of the joy, and for standing by me through the rest.

Ida Gremyr, not once have I imagined that I would find a best friend in a supervisor, but I did. You have been there for me every step of the way, every single day of the past five years, in and out of office. You made it possible for me to fulfil a dream, you are the reason I am still standing, and you will always be a symbol of my success. I thank you for everything, and I especially thank you for being you. I am forever indebted to you, and I hope you know that you have a best friend in me too.

Ann-Sofie Axelsson and Jutta Hildenbrand, the strong, intelligent, and amazing women, whom I've had the utmost pleasure in having as co-supervisors, I thank you for being an inspiration to me, and inspiration you both shall remain. Thank you, Hendry Raharjo, for your co-supervision efforts that has shaped me into a better researcher. To the kind and wonderful examiner and teacher, Bo Bergman, your support has always been a boost of confidence, and I thank you for the confidence you have in me.

Laughter, hugs, office 'fika' and dinners, seminars and meetings, conferences and wine, will never be the same again without you, Andreas Hellström, Henrik Eriksson, Erik Eriksson, Alexandra Ericsson, Sverker Alänge, Peter Hammersberg, Sara Dahlin, Susanne Gustavsson, Svante Lifvergren, Sofi J Edvardsson and all others who have walked through this corridor with me. Thank you for your relentless, encouraging support through the good times, and for putting up with the worst version of me through the hard times. Jan Bröchner, Anna Kadefors, Therese Eriksson, Ahmet Anil Sezer, and Pernilla Gluch, without Service Management, Quality Sciences wouldn't be what it is to me. Thank you for being a part of my every day. Arni Halldorsson, you are a gift to this department and the PhD students. I am certain that I speak for everyone when I say thank you for your genuine interest and involvement in our wellbeing. You have done more than your part in shaping my success today.

My brilliant co-authors, Ida, Hendry, Ann-Sofie, Jutta, TN Goh, Thomas Zobel, Bjarne Bergquist, Rickard Garvare, Raine Isaksson, Kristian Peters, and Bolennarth Svensson, with whom I have shared the joys and sorrows of journal publications, reviewer's (constructive) criticisms, and conference presentations, I owe my writing skills and publishing success to you. Bjarne, thank you for your time and effort in challenging me to an intellectual duel during my licentiate seminar. Thomas, your contribution as the discussant in my final seminar has made this thesis publishable. Thank you for your continuous support till this day. Bolennarth Svensson, Sören Knuts, Per Johansson and Mats Deleryd, thank you for opening your doors for my studies, and for this thesis. My sincere gratitude goes to Chalmersska Forskningsfonden for making the study-visit to Groningen University in the Netherlands become a reality. Kristian Peters, JC Hans Wortmann, and all the wonderful staff of Operations at the Faculty of Economics and Business, thank you for the valuable and memorable opportunity to work with you. And I gratefully acknowledge the Sustainable Production Initiative (SPI) and the Production Area of Advance (AoA) of Chalmers for the funding of this research and thesis.

I owe all the fun, and at times, blurry, nights out, celebrating the successes or drowning the sorrows to my friends in Gothenburg. You have changed my life. Usha, Shankini, Suda and Latha, the best girlfriends any girl could ask for, thank you for showing my own strength to me. Mohan, Param, John, Gopal and Raj, my best buddies from another life, thank you for the friendship of a lifetime. To my family, thank you for all your love and support. Ulla and Sven Carlsson, thank you for making me feel like the daughter that you never had. Mom and Dad, the highlights of my life are the moments I made you proud. I hope this is another one of those moments. You put aside your needs as parents and allowed me the freedom to choose a life that I want for myself. I will spend the rest of this amazing life that I have, thanking you for that freedom.

1 INTRODUCTION

In the early 1980s, W. Edwards Deming stated that quality is everyone's responsibility. Deming was an early proponent of Quality Management (QM), and created 14 points in order to improve it (Anderson et al., 1994). Some examples are consistent improvement of products and services, top management assuming leadership roles, eliminating mass inspection, and ensuring quality is everyone's responsibility. Despite numerous challenges over the years, QM has emerged as a management approach that has become a common language in everyday operations that can be characterized by its principles, practices, and tools (Dean Jr and Bowen, 1994). The main principles identified by Dean Jr and Bowen (1994) are customer focus, continuous improvement, and teamwork through employee involvement. The customer focus principle, for example, is supported through the practice of collecting information about customer needs, where customer surveys and focus groups can be used as tools (Dean Jr and Bowen, 1994).

Corbett and Klassen (2006) stated that, *the QM revolution has pushed the operations management community to adopt a broader perspective, including processes upstream and downstream, as well as the organizational context surrounding those processes … the principles of QM have become widely accepted in theory and practice* (p. 9). The definition of quality by Bergman and Klefsjö (2010), that is, *the quality of a product is its ability to satisfy, or preferably exceed, the needs and expectations of the customers* (p. 23), suits the context of this thesis, where QM is discussed in terms of development of products. Further, the definition of QM as, *an integrated approach to achieving and sustaining high quality output, focusing on the maintenance and continuous improvement of processes and defect prevention at all levels and in all functions of the organization, in order to meet or exceed customer expectations* (p. 342) (Flynn et al., 1994) aligns with the characterization of Dean Jr & Bowen (1994).

The discussion concerning QM's usefulness vis-à-vis sustainable development in general (Garvare and Isaksson, 2001, McAdam and Leonard, 2003, Isaksson, 2006, Klefsjö et al., 2008), and environmental sustainability in specific (Theyel, 2000, Rusinko, 2005) has lasted for more than a decade. This discussion is in line with a current global challenge of sustainable development, defined by the Brundtland Commission in 1987 as, *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (p. 43) (Brundtland, 1987). Sustainable development is often seen as built upon three pillars, namely environment, social, and economic. The objective of sustainable development has been described as maximizing the interconnected environmental, social and economic goals through careful considerations of trade-offs that may exist between them (Barbier, 1987). However, in the specific discussion of QM and its contribution to sustainable development, environmental goals often take center stage (Sarkis, 2001). Environmental sustainability here refers to minimizing or eliminating harmful impacts, such as reduction of wastes in terms of materials, resources, and energy (Daly, 1990, Goodland, 1995), in the development and manufacturing of products. Without minimizing the importance of the economic and social sustainability in the development of products identified by, for example, the cost of poor quality (Isaksson, 2005), and the growing research area of social life cycle impact assessment (Dreyer et al., 2006), the contribution of QM within the scope of this thesis is narrowed down to the environmental pillar of sustainable development.

In current times, the serious threats faced globally are the dwindling natural resources and increasing population. In such times, it has become relevant to paraphrase Deming's quote on quality, and argue that sustainable development has emerged rapidly as everyone's responsibility. As awareness of sustainable development grows worldwide, striving for sustainable solutions does not end with governments and policy makers. The responsibility has spread to all levels of society, with a heavy emphasis on organizations (Sarkis, 2001, Nidumolu et al., 2009), which, in this thesis, refers to manufacturing industries of any size. The growing challenge for organizations lies in addressing the demands for sustainable products and processes from stakeholders such as customers who are environment-conscious (Hetterich et al., 2012), policy makers and regulators who are environment-driven (Griggs et al., 2013), a supply chain that is environment-focused (Sarkis et al., 2010), and the demands of market and industries (Delmas and Toffel, 2004). In order to address such demands, product design and development must include environmental requirements, in addition to quality, cost and time-to-market requirements, bringing into focus the area of sustainable product development (SPD). A number of definitions and elaboration on the meaning of SPD have been addressed previously (Shrivastava, 1995, Van Weenen, 1995, Kaebernick et al., 2003, Gmelin and Seuring, 2014, Gmelin and Seuring, 2014). Referring to SPD, Gmelin and Seuring (2014) and Gmelin and Seuring (2014) touched upon the often-neglected social pillar of sustainability in the various interpretations of SPD. Referring to the purpose of this thesis where the focus is on the environmental pillar of sustainability, SPD is defined as the efforts made at the design and development stages of products aimed at fulfilling the needs of customers with the purpose of reducing the environmental impacts throughout the entire product's life cycle.

In the 1990s, the mainstream organizational efforts towards environmental sustainability were mainly reactive, where wastes were generated and then managed or controlled, for example, via recycling or pollution control (Gupta, 1995, Porter and Van Der Linde, 1995, Shrivastava, 1995, Hart and Ahuja, 1996). The move away from the end-of-pipe technologies and establishing proactive measures could be argued as the initial step toward SPD (Van Weenen, 1995). Van Weenen (1995) argued that, *what is required is a broader product oriented approach, that considers 'prevention' as a starting point, and moves on to integrated product development that achieves reduced impacts across the whole product life cycle* (p. 95). Since then, research and application of new knowledge have developed over the years suggesting organizations to take a more proactive role in the contribution toward environmental sustainability (Sarkis, 2001, Buysse and Verbeke, 2003), resulting in the introduction of concepts such as Design for Environment (DfE) (Fiksel, 2009) and tools such as Life Cycle Assessment (LCA) (Klöpffer, 1997). The application of these environmental design tools is identified as one approach to SPD. DfE and LCA, for examples, are applied in the design and development phases of products in order to reduce the impact on the environment throughout the product life cycle. Although these have their merits, they are not without challenges; for example, most of the DfE tools are conceptual, and only useful in specific product life cycle phases (Kota and Chakrabarti, 2007). Other challenges include the absence of proper guidelines for the application of LCA, and obtaining quality data (Sutherland et al., 2008, Jayal et al., 2010).

Another approach to SPD investigates the integration of environmental requirements into existing management approaches and methodologies (Paramanathan et al., 2004, Robinson, 2004, Lubin and Esty, 2010). One amenable approach is QM (Klassen and McLaughlin, 1993, Angell and Klassen, 1999, Ahmed, 2001). For example, the principles of customer focus and continuous improvement are applicable to support environmental sustainability, especially in product development (Hart, 1995, Sarkis, 2001, Wilkinson et al., 2001, Johansson, 2002, Calia et al., 2009). Such synergies could be exploited by organizations that are faced with designing and developing products with environmental requirements on par with quality, cost and time. Similarly, a number of QM tools, such as Qualify Function Deployment (QFD) (Masui et al., 2003) and Failure Mode and Effects Analysis (FMEA) (Bovea and Pérez-Belis, 2012) have been adapted to include environmental requirements in the product development stages. However, the application of QM practices and tools to support environmental sustainability in product development is neither straightforward nor simple, mainly owing to such challenges as lack of integration and product development organization (Ritzén and Beskow, 2001, Johansson et al., 2007, Dangelico and Pujari, 2010, Short et al., 2012, Lopes Silva et al., 2013, Pigosso et al., 2013). In the context of this thesis, the term "integration" is defined as, *continuous interdisciplinary sharing of data, knowledge and goals among project participants* (p. 31) (Fischer et al., 1998). There is a need to further explore the challenges in SPD by including the integration domain (Griffin and Hauser, 1996, Becker and Zirpoli, 2003).

Within the two approaches to SPD, a specific challenge faced by organizations consistently lays in the lack of integration of environmental requirements and tools in the product design and development (Sroufe et al., 2000, Kuo et al., 2001, Nielsen and Wenzel, 2002, Hauschild et al., 2004, Lindahl, 2006, Choi et al., 2008, Knight and Jenkins, 2009, Vinodh and Rathod, 2010, Bovea and Pérez-Belis, 2012, Brones et al., 2014, Hatcher et al., 2014, Hartmann and Germain, 2015). There are ample research pointing toward both approaches to SPD, namely the integration of environmental requirements in established methodologies, and the implementation of concepts and tools, such as DfE and LCA. Both SPD approaches suggest the application of QM practices and tools to address environmental requirements in product development (Vinodh and Rathod, 2010, Bovea and Pérez-Belis, 2012). However, research concerning their application is mainly conceptual (Kaebernick et al., 2003, Berchicci and Bodewes, 2005, Rusinko, 2005, Sakao, 2009, Bovea and Pérez-Belis, 2012). Therefore, the challenge continues to persist in organizations on how to operationalize the integration of environmental requirements in product development (Johansson et al., 2007, Short et al., 2012, Pigosso et al., 2013). In order to integrate environmental requirements in product development, it is necessary to critically examine current applications of QM practices and tools, and suggest ways to tackle, for example, organizational barriers.

1.1 Purpose

The purpose of this thesis is to explore and identify the adaptations of QM practices and tools to better support environmental sustainability. Specific focus is given to the integration of environmental requirements in product development, and to the adaptations of Robust Design Methodology (RDM), as one QM methodology.

1.2 Research Questions

Four research questions were formulated for this thesis. The first (RQ1) concerns the contribution of QM toward environmental sustainability in general. This question was formulated in order to identify and analyze the various arguments in literature supporting the use of QM as an existing management approach to contribute to environmental sustainability. A literature review was conducted to address RQ1.

RQ1: How can QM contribute to environmental sustainability? (Paper I)

The next step in addressing the purpose of the thesis was to focus on the product development setting in organizations. Therefore, the second research question (RQ2) was focused on the organization of the product development in order to support the integration of environmental requirements with the use of QM practices and tools, which was addressed by one case study.

RQ2: How can product development be organized in order to exploit QM to integrate environmental requirements? (Paper II)

The applications of QM practices and tools were found applicable in both SPD approaches identified in the literature. Therefore, the third research question (RQ3) was focused on the two SPD approaches, using a comparative study constituted of the same case from RQ2 and a new case.

RQ3: What are the differences in the challenges when adopting the two different SPD approaches? (Paper III)

The final step was to address the second focus area: the adaptations of RDM practices and tools in order to support SPD. Hence, the fourth research question (RQ4) was focused on the contribution of RDM to SPD. RQ4 was addressed in two studies, one conceptual study and a case study.

RQ4: How can RDM contribute to SPD? (Papers IV and V)

1.3 Relevance

The studies conducted in this thesis are found relevant to research and practice in a number of ways, and they are elaborated on in the following two sections.

1.3.1 Relevance to research

Various research has pointed toward QM's general applicability vis-à-vis environmental sustainability. The added contribution of this thesis on an academic level is the specific adaptations of QM that are suggested. Although the QM approach has been linked to environmental sustainability for many years, research is still in its infancy level in terms of exploiting and adapting the applicability of its practices and tools, for example. In this thesis, the mainly conceptual synergies identified between QM and environmental sustainability are further explored and exemplified empirically. The empirical investigations have, then, pointed to future research areas where the suggested adaptations of QM practices and tools can be investigated in various organizations, processes, and operations.

The application of QM practices and tools to facilitate the integration of environmental requirements in product development contribute to research by identifying concrete ways to apply QM at an operational level. This contributes to current research by taking a step further in the exploration of QM as an approach suitable for the integration of environmental requirements. In order to investigate the adaptations of QM practices and tools to better support environmental sustainability, it is necessary to understand the SPD approaches adopted in organizations, and the challenges in SPD based on these approaches. The contribution to research in the area of SPD, therefore, lays in further narrow categorization of the challenges in SPD according to specific approaches in terms of the types of products manufactured, for example. The relevance to the research areas of product development and SPD are also exemplified through adaptations of RDM practices and tools in facilitating SPD, in addition to the introduction of a new RDM practice.

1.3.2 Relevance to practice

This thesis contributes to practice by shedding some light to practitioners and managers who are faced by the challenges in SPD. The integration of environmental concepts, tools, and requirements in daily operations and product development has been a constant challenge faced by organizations. Practitioners are provided with some specificities in understanding the application of existing approaches such as QM to support integration efforts in product development. The discussion of a number of integration strategies also allows practitioners to analyze and adopt suitable strategies according to individual organization of product development. Further, the elaboration of the challenges in SPD based on industrial contexts provides practitioners the opportunity to view the challenges through a different lens.

Organizations applying RDM have faced many challenges in the past in relation to its complexity, and a lack of necessary expertise in subjects such as statistics. In this thesis, the application of the RDM practice of noise factor identification has been exemplified with the adoption of a life cycle approach in order to facilitate SPD, with minimal use of statistics. Practitioners are also shown that RDM is not only made up of statistical tools, but rather could be made useful by addressing the principles and practices as well.

Through jointly addressing the quality and environmental requirements in product development, product designers are provided with an opportunity to realize the potential synergies between QM and environmental sustainability. The best quality products don’t necessarily contribute positively to the environment, and vice versa. Therefore, practitioners need to be made aware that trade-offs have to be made when balancing quality and environment; one way to do so is by jointly addressing these requirements at the early stages of product development.

1.4 Thesis Structure

The structure of the rest of the thesis is as follows:

Chapter 2 contains a detailed description of the theoretical background surrounding the main areas of this thesis, namely QM, and SPD.

In chapter 3, the methods employed in all the studies are described and elaborated on.

Chapter 4 presents summaries of the five appended papers, and ends with a description of their common themes.

In chapter 5, the discussion of the thesis is presented by addressing the four research questions formulated.

Chapter 6, then, presents the conclusion of this thesis.

Finally, in chapter 7, the areas of future research directions are pointed out and discussed.

These chapters are followed by a Reference List and Appended Papers I to V.

2 THEORETICAL BACKGROUND

The two main theoretical areas in this thesis are QM and SPD. Further, the application of RDM in a product development setting is elaborated in order to exemplify the adaptation of QM practices and tools to support SPD.

2.1 Quality Management

QM has evolved from quality inspection at the end of a production line to a philosophy (Anderson and Rungtusanatham, 1994, Powell, 1995, Lengnick-Hall, 1996, Miller, 1996, Martinez-Lorente et al., 1998, Sousa and Voss, 2002), and is characterized by a set of mutually reinforcing principles, each of which is supported by a set of practices and tools (Dean and Bowen, 1994), where the main principles are customer focus, continuous improvement, and teamwork through employee involvement. QM stands firm on the basis of meeting and exceeding customer requirements; one specific practice is identifying and translating the voice of customer (VOC) into product characteristics with the use of QFD, for example (Griffin and Hauser, 1993). In a similar manner, Hart (1995) stated that the "voice of the environment" should be integrated into product development in his argument for product stewardship. Within the area of environmental sustainability in organizations, the product stewardship orientation is generally meant to consider the environmental impacts of products throughout their life cycle, from design and development, through manufacture, distribution, use, and disposal (De Bakker et al., 2002, Pujari et al., 2003, Fowler and Hope, 2007).

Various studies have addressed applying the practices and tools of QM, specifically QFD, to facilitate SPD, which could be seen in the works of Masui et al. (2003) for example, and others (Zhang et al., 1998, Kaebernick et al., 2003, Zhou and Schoenung, 2003, Vinodh and Rathod, 2010, Bovea and Pérez-Belis, 2012). Hart (1995) also stated that pollution prevention can be achieved in organizations through extensive employee involvement in the activities with the mindset of continuously improving current processes and products, where employee involvement and continuous improvement are two main principles of QM (Dean Jr and Bowen, 1994). Hart further argued that, *pollution prevention thus appears analogous, in many respects, to quality management* (p. 992).

QM, in the adoption of the ISO management system, has been a foundation for the industrial application of the environmental management system (EMS) (Miles and Russell, 1997, Bice et al., 1999). Linking environmental management to QM, Corbett and Klassen (2006) argued that, *to include environmental issues, the frame of reference offered by QM must be stretched in several directions* (p. 9). Examples are stretching the concept of "zero defects" in QM to "zero waste", applying statistical process control (SPC) to monitor emissions and identify control measures, and using process capability indices to measure environmental quality. Further, these authors argued that the notion of "customer" must encompass the environmental perspective by, for example, widening its meaning from a single user since a product's environmental impact concerns various stakeholders, including society in general, governmental and non-governmental organizations, legislators and environmental bodies. Corbett and Klassen (2006) also argued for the practices and tools of QM to apply equally to environmental issues since they are a natural extension of quality. Within the area of EMS, various studies have supported the contribution of QM principles, practices and tools (Corbett and Cutler, 2000, Curkovic et al., 2000, Giancarlo, 2005, Wiengarten and Pagell, 2012). However, the scope of this thesis is mainly on QM practices and tools, therefore the contribution of the management systems such as Quality Management System (QMS) and EMS toward environmental sustainability are not the focus of the thesis, although the subject is touched upon as it emerges in literature, specifically in the discussion of synergies between QM and environmental sustainability.

The potential synergies between QM and environmental sustainability have been explored in the past decade. However, a lack of empirical research in the area of product stewardship, which points to the integration of environmental requirements into product development has been raised (Hart and Dowell, 2011). The question of how to integrate environmental requirements into product development is a pressing challenge in organizations. The need for further research in examining new environmental tools and supportive existing tools in an organizational setting to ensure environmental sustainability in product development has been called for (Paramanathan et al., 2004). Within the area of QM, a number of researches have highlighted robust design tools such as the Taguchi method, and Design of Experiment (DoE) in the attempt to integrate environmental requirements into product development (Ben-Gal et al., 2008, Carrell et al., 2011, Cetin et al., 2011, Fratila and Caizar, 2011, Besseris, 2012, Hanafi et al., 2012, Camposeco-Negrete, 2013). A critical review of these studies (Gremyr et al., 2014) resulted in a research agenda toward required adaptations of RDM in order to better support SPD.

2.1.1 Robust Design Methodology

Genichi Taguchi, the proponent of RDM, defined quality loss as, *the loss a product causes to society after being shipped, other than any losses caused by its intrinsic function* (p. 1) (Taguchi, 1986), that is, by variability of function, and by harmful side effects. Robust design is optimized for performance, quality, and cost and is further characterized by Phadke (1989) as a method to make product performance insensitive to variations in raw material, manufacturing, and operating environment. It was further stated that robust design explicitly addresses how to economically reduce product functional variation. The definition of robust design, according to Genichi Taguchi, is, *the state where the technology, product, or process performance is minimally sensitive to factors causing variability (either in the manufacturing or user's environment) and aging at the lowest unit manufacturing cost* (p. 4) (Taguchi et al., 2000).

RDM is commonly described as an approach to reduce performance variation in products and processes (Shoemaker et al., 1991, Andersson, 1996, Goh, 2002). Performance variations are caused by the presence of various factors within the design and manufacturing environment, and beyond. Robustness of products is achieved by managing the factors causing variability, also known as noise factors (Kackar, 1989, Taguchi, 1986, Phadke, 1989). Noise factors during the manufacturing stage are, to a large extent, easily discerned; for example, variations in a production line, clean room manufacturing, or in an automated assembly line. The same does not apply to noise factors that may exist in user environments, where products are exposed to a variety of external conditions, such as differing temperatures and humidity, and the handling of products by various users (Johansson et al., 2006).

Similar to QM, RDM can also be characterized by its principles, practices, and tools. Arvidsson and Gremyr (2008) defined RDM as, *systematic efforts to achieve insensitivity to noise factors, founded on an awareness of variation and can be applied in all stages of product design* (p. 31). This definition was based upon three underlying principles of RDM; an awareness of variation, creating an insensitivity to noise factors, and the continuous applicability of RDM throughout all stages of product design. Further, a set of practices and supporting tools has been identified in connection to these principles (Hasenkamp et al., 2009).

The application of tools, such as the Taguchi method (Wu and Wu, 2000) and DoE (Roy, 1990), has been the common RDM research focus (Gu et al., 2004, Wu and Chang, 2004, Kovach and Cho, 2006, Lee and Park, 2006, Beyer and Sendhoff, 2007, Ilzarbe et al., 2008, Besseris, 2010, Yadav et al., 2010). Referring to research concerning RDM tools, the elaboration of RDM practices are often limited to the specific application of the tools, such as DoE (Montgomery, 1999). DoE has its merits in analyzing influences of control factors and possible noise factors in the system suitable for front-end application (Phadke, 1989, Roy, 1990). The application of DoE as a design tool has been quite popular among researchers (Ilzarbe et al., 2008), especially in the quality improvement and problem-solving methodology of Six Sigma (Goh, 2002, Kovach and Cho, 2006). Lifting the focus from tools to efforts centered on the underlying principles of RDM is argued to lead to additional opportunities to extend and adapt its application, specifically in contributing to new practices (Hasenkamp, 2009, Cabello et al., 2012).

Recent evidence has shown DoE as an effective tool to minimize or control environmental impacts (Carrell et al., 2011, Cetin et al., 2011, Fratila and Caizar, 2011, Besseris, 2012, Hanafi et al., 2012, Camposeco-Negrete, 2013). Hanafi et al. (2012) concluded that adopting a multi-criteria approach by using the Taguchi method is an effective way to handle the conflict between quality, cost, and environmental impact. Besseris (2012) stated that *[DoE] is concrete and reliable for environmental design just as it is for quality design* (p. 49). It was further implied that applying standard DoE experimental settings and using environmental requirements as response variables in the experiment, the environmental requirements are included in the design process, contributing to environmental quality improvement.

2.2 Sustainable product development

Aligned with sustainable development initiatives, environmental requirements have been interspersed in the development and manufacturing of products (Senge et al., 2001, Wilkinson et al., 2001, Anastas and Zimmerman, 2003, Nidumolu et al., 2009). Wilkinson et al. (2001) discussed the internal and external pressures faced by organizations in initiating practices supporting environmental sustainability, stating that governments alone are unable to solve the world's natural environment problems if the economic environment is unsupportive. By economic environment, the authors were referring to organizations and its contribution to environmental sustainability. Touching upon the motivation for organizations to contribute to environmental sustainability, Nidumolu et al. (2009) argued that, *sustainability is a mother lode of organizational and technological innovations that yield both bottom-line and top-line returns* (p. 57). They further stated that companies are able to reduce costs by reducing the inputs they use if they become environment-friendly.

Early sustainability initiatives focused on product end-of-life (EoL) strategies such as creating proper product disposal methods, increasing recycling options, controlling the hazardous waste of after-production and emissions from the disposal of products (Sarkis, 1995, Boks and Tempelman, 1998, Linton, 1999, Chiodo and Boks, 2002). From these early efforts, environmental requirements have moved upstream to the design stages of products (Sarkis, 1998, Johansson, 2002, Sun et al., 2003, Bhamra, 2004, Griese et al., 2005, Kleindorfer et al., 2005, Azapagic et al., 2006, Gehin et al., 2008). Sarkis (1998) argued that the DfE concept supports integrating environmental requirements into the early design of products, and Sun et al. (2003) discussed the concept of DfE where EoL strategies were described as an important decision-making enabler. EoL strategies consist of planning and integrating product take-back and disposal activities early in the design stage.

The cradle-to-grave perspective of SPD changed the focus from product EoL environmental impacts to reduced impacts across the life cycle of a product (Rydberg, 1995, Hanssen, 1999, Ljungberg, 2007, Gehin et al., 2008). A product life cycle refers to the product stages *followed from its 'cradle' where* *raw materials are extracted from natural resources through production and use to its 'grave'* (Baumann and Tillman, 2004) (p. 19). A systems approach is argued as necessary since reducing environmental impacts in only one life cycle stage while ignoring the remaining stages may result in negative contributions to environmental sustainability (Klöpffer, 2003). An example of reducing the environmental impact in the "raw material" stage, and ignoring the "end-of-life" stage could be explained thusly: An engine component of a car may be selected due to the weight and durability of its raw material, contributing to sustainability in terms of low fuel consumption. On the other hand, the disposal of the particular material may be hazardous to the environment at the end-of-life stage, which indicates that considerations made at one stage of a product life cycle may result in negative contributions at another stage. Klöpffer further added that, *a systems approach has to be taken. Only in this way, trade-offs can be recognized and avoided. Life cycle thinking is the prerequisite of any sound sustainability assessment* (p. 134).

Kaebernick et al., (2003) argued that *the introduction of environmental requirements into the product development process at all stages of a product's life leads to a new paradigm of sustainability, which is reflected in a new way of thinking, new application of tools and methodologies in every single step of product development* (p. 468). This argument indicates that integration of environmental requirements into product development must encompass all stages of products. The life cycle stages of a product are identified as raw materials, manufacturing, distribution, product use, and end of life (Choi et al., 2008).

Under one discourse of SPD, various research has suggested that environmental requirements should be integrated into existing management approach and methodologies (Klassen and McLaughlin, 1993, Kaebernick et al., 2003, Masui et al., 2003, Berchicci and Bodewes, 2005, Kleindorfer et al., 2005, Sakao, 2009). Referring to QM as an existing management approach, Klassen and McLaughlin (1993) stated that, *total quality management serves as a ready bridge to environmental excellence* (p. 21) by identifying the potential links between QM and the management of environmental requirements in the design of new products. Kaebernick et al. (2003) and Masui et al. (2003), for example, suggested Environmentally Conscious Quality Function Deployment (ECQFD) and Quality Function Deployment for Environment (QFDE), respectively, supporting integration into existing QM tools such as QFD. Berchicci and Bodewes (2005) presented a literature review in order to identify the challenges faced by product development teams in their effort to integrate environmental requirements into product development (further elaborated in section 2.2.2).

Overall, a vast amount of research and literature has been published concerning both approaches to SPD, namely the integration of environmental requirements into existing methodologies, and the implementation of environmental concepts and tools such as DfE and LCA. Both streams are further elaborated in the following sections.

2.2.1 Integration of environmental requirements into existing methodologies

The integration of environmental requirements into existing approaches such as QM is a rather common approach to SPD (Klassen and Mclaughlin, 1993, Angell and Klassen, 1999, Ahmed, 2001). Klassen and McLaughlin (1993) present a comparison between QM and environmental excellence. Relating to product development, robust design of products is argued as an integrated planning for all phases of product life cycle in terms of environmental excellence. It is stated that, *environmental excellence also begins during initial product design* (p. 19). Angell and Klassen (1999) suggested that quality practices such as the problem solving approach of Plan-Do-Check-Act (PDCA) and tools such as Pareto diagrams and control charts can be used to address environmental problems, as well as quality problems. These authors further identified that due to little general awareness of potential synergies between QM and environmental sustainability, the integration of environmental requirements remains a challenge. However, the emphasis in Klassen and McLaughlin (1993) and Angell and Klassen (1999) was on the environmental management system in general, and did not touch upon integration of specific product-related environmental requirements. Ahmed (2001) presented a framework called total quality environmental management (TQEM) based on the basic premise of TQM to attain customer satisfaction through continuous improvement, and stated that a significant opportunity may be represented by customer satisfaction vis-à-vis organizations address environmental requirements of products.

There are various studies supporting the integration of environmental requirements in existing QM practices and tools (Theyel, 2000, Kaebernick et al., 2003, Masui et al., 2003, Berchicci and Bodewes, 2005, Rusinko, 2005, Sakao, 2009, Vinodh and Rathod, 2010, Bovea and Pérez-Belis, 2012). Theyel (2000) identified, based on a survey of chemical plants, that QM is applicable in pollution prevention by involving production workers in the improvement of product quality through continuous improvement activities. Environmental performance of the chemical plants is also improved through employee training in pollution prevention, which is also a component of QM. Kaebernick et al. (2003) introduced the ECQFD in the attempt to capture the environmental requirements of products and translate them into design parameters. The authors argued that, *environmental requirements must be considered as equal partners to the traditional requirements of cost and quality* (p. 468), and showed the conceptual integration of environmental requirements via QFD. Similarly, Masui et al. (2003) applied QFD to translate the environmental VOC and environmental engineering metrics (EM) into product parameters as one way to handle the environmental and traditional quality requirements together. Rusinko (2005) argued that the QM principles of continuous improvement and employee participation are also acknowledged as an important element of environmental sustainability. She further argued that organizations need to adopt an integrated multifunctional approach, such as an expanded application of the PDCA (or Deming) cycle, in order to integrate environmental requirements into QM practices and tools to implement and manage environmental practices in organizations. Sakao (2009), on the other hand, demonstrated the application of the Kano model in order to adopt the QM approach to eco-design. The Kano model was used to reveal the environmental characteristics of products as indifferent, attractive, one-dimensional, must-be or reverse.

Vinodh and Rathod (2010) further presented an Environmentally Conscious QFD, integrated with LCA to enable SPD. They argued that the ECQFD is, *useful for evaluating different product concepts, and deploys environmental requirements throughout the development process* (p. 834). Environmental VOC, such as reduced material use, and environmental EM, such as reduced weight and volume, were used in the design of electronic switches in the exemplification of the ECQFD. In a different study, a number of tools, such as Environmental QFD, green QFD, QFDE, ECQFD and Environmental Failure Mode and Effects Analysis (EFMEA) were reviewed and classified (Bovea and Pérez-Belis, 2012). The description of EFMEA is, *the traditional FMEA is restructured to address environmental issues instead of potential failure of components with the aim of identifying and evaluating potential environmental impacts of all stages of the life cycle of a product during its development process. The objective is to minimize the product's environmental burden during its life cycle by taking corrective and preventive measures* (p. 67). However, Bovea and Pérez-Belis (2012) concluded that despite the availability of a wide variety of tools for the integration of environmental requirements into existing methodologies, organizations still face the challenge of applying them systematically.

2.2.2 Introduction and implementation of Design for Environment tools

The areas of DfE (Bras, 1997, Sarkis, 1998, Sun et al., 2003, Hauschild et al., 2004, Kurk and Eagan, 2008), eco-design (Bhamra, 2004, Griese et al., 2005, Luttropp and Lagerstedt, 2006), and Environmental New Product Development (ENPD) (Pujari et al., 2003, Pujari et al., 2004, Pujari, 2006) mainly employ LCA to assess products' environmental impacts throughout the life cycle. LCA is defined as *a technique for assessing the environmental aspects and potential impacts associated with a product by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts, and interpreting the results* (p. 22) (Baumann and Tillman, 2004).

The terms DfE and eco-design are commonly used interchangeably. The concept of DfE originated in the early 1990s, and is defined as, *the systematic consideration of design performance with respect to environmental, health, safety, and sustainability objectives over the full product and process life cycle* (p. 6) (Fiksel, 2011). A general description of eco-design, on the other hand, is given as, *actions taken in product development aimed at minimizing a product's environmental impact during its whole life cycle, without compromising other essential product criteria such as performance and cost* (p. 98) (Johansson, 2002). Pujari et al. (2003) define ENPD as, *product development into which environmental issues are explicitly integrated in order to create one of the least environmentally harmful products a firm has recently produced* (p. 658).

In addition to LCA as a DfE tool, a number of other tools have been suggested. For example, Bras (1997) included design guidelines and checklists as a basic tool applied in introducing environmental requirements in product design. Bras (1997), along with Bhamra (2004), discussed the Lifecycle Design Strategies (LiDS) Wheel, where organizations are able to assess their current state with respect to eight life cycle strategies. Further details of the LiDS Wheel could be found in van Hemel and Cramer (2002). In a list of DfE tools, Sarkis (1998) included TQEM, Green Supply Chain Management (GSCM), and ISO 14000 EMS, for example. Additionally, Design for Disassembly (DfD), which focuses on the improvement of a product design to enable disassembly with minimal cost and environmental impact, was discussed by Sun et al. (2003) and Hauschild et al. (2004).

As an example of the wide range of new tools that have been suggested as supportive of DfE (Azapagic et al., 2006, Byggeth and Hochschorner, 2006, Luttropp and Lagerstedt, 2006, Gehin et al., 2008, Knight and Jenkins, 2009, Birch et al., 2012), Azapagic et al. (2006) proposed a general methodology called process design for sustainability (PDfS) as one way to integrate environmental requirements into process design in the usual stages such as project initiation, preliminary, detailed, and final designs. Luttropp and Lagerstedt (2006) introduced the Ten Golden Rules in an attempt to merge environmental requirements into product development. Some of the Ten Golden Rules are non-use of toxic substances; minimize energy and resource consumption; minimize weight through material selection; promote long life, upgrading, and repair; and minimize use of joining elements of product design.

Byggeth and Hochschorner (2006) presented 15 DfE tools in order to identify and handle trade-offs in product development decision-making, whereas Birch et al. (2012) presented 22 eco-design tools and discussed the type of guidance provided by these tools. The tools listed are, namely, LiDS Wheel, the Ten Golden Rules, the Environmentally Responsible Product Assessment Matrix (ERPA), Material Energy Toxicity (MET), and Eco-Design Checklist. Gehin et al. (2008) introduced another new methodology called REPRO^2 (REmanufacturing PROduct PROfiles) where product profiles are evaluated based on the possibility for remanufacture. Further details could be found in Gehin at al. (2008). Knight and Jenkins (2009) discussed a variety of eco-design tools based on the practitioners' perspective, including checklists, Environmental Effect Analysis (EEA), MET, Environmental Impact Assessment (EIA), EQFD, LiDS Wheel, and Life Cycle Cost Analysis.

2.2.3 Management and organization of sustainable product development

Regardless of the terminology used, DfE or eco-design entail a number of organizational barriers (Baumann et al., 2002, Johansson, 2002, van Hemel and Cramer, 2002, Boks, 2006, Karlsson and Luttropp, 2006, Lindahl, 2006, Lofthouse, 2006). Baumann et al. (2002) argued that, *existence of tools is not sufficient, perhaps not even necessary. Management and organization seem to be more important than the tools* (p. 419), relating to the main challenge faced by organizations, which is the lack of integration of environmental requirements in product development. The reference of management and organization here point to product development, where successful integration of environmental requirements is dependent on how product development is organized, rather than the extensiveness of the tools applied. The lack of integration challenge was later raised by Boks (2006), Karlson and Luttropp (2006), Johansson (2007), and Lopes Silva et al. (2013).

Concerning the success factors for the integration of eco-design into product development, Johansson (2002) identified the integration of environmental requirements into the conventional product development process, introduction of environmental checkpoints, reviews and milestones, and performing eco-design in a cross-functional team, while Boks (2006) identified customization of eco-design tools to fit the company's needs, and the use of environmental checkpoints, reviews and milestones. On the other hand, in Van Hemel and Cramer (2002), the top barrier that was identified in their study of SME's was 'conflict with functional requirements', where a constant struggle is faced in product development decision making in terms of trade-offs. A number of obstacles identified by Boks (2006) point toward the lack of integration of the eco-design practices and tools in the product development. They are, large gap between eco-design proponents and those that implement it, the lack of appropriate organizational infrastructure, and the lack of cooperation between departments.

Berchicci and Bodewes (2005) identified "coordination and alignment within multifunctional product development teams" as relevant to the integration of environmental requirements into product development. This factor could, for example, be translated into coordination and alignment between quality and environmental specialists in the product development through shared practices and tools. Karlsson and Luttropp (2006) argued that, *the foundation* (in design and engineering work) *is that the synthesizing ability in design and product development processes is dependent on dialogue and cooperation that combine visionary, creative and analytic and experience based capabilities. Eco-design should support and promote proactive development of such synthesizing abilities* (p. 1292). This argument suits the description of a cross-functional product development team concerning the capabilities or competences of environmental and other specialists in terms of knowledge and experience to enable the integration of environmental requirements into product development. Lindahl (2006) identified the organizational obstacles to DfE tools, such as lack of training and education in the application of the tools. Further, the complexity of certain DfE tools was also identified as an obstacle. Lindahl identified one way of addressing these obstacles, *by using methods and tools and modifying them to fit into the company's context, knowledge and experience are integrated into the product development organization as a know-how backup* (p. 492).

3 RESEARCH METHODOLOGY

This chapter describes the research process of the studies conducted within the scope of the thesis. Appended paper I is based on a literature review, whereas papers II, III, and V are based on three cases, and paper IV is a conceptual study. The description and discussion of the empirical settings of the cases are included. This is followed by detailed description of the data collection and analysis methods of each of the five appended papers in separate sections. A discussion on the methodological choices and the justifications are also clarified. The chapter concludes with a discussion of the research quality and the limitations of the studies.

3.1 Research Process

The research process of the studies began in 2011 in the Division of Quality Sciences, Chalmers University of Technology. This division consists of researchers specializing in QM and its related subjects. One specific area of research within this division was RDM. In conjunction with the Sustainable Production Initiative (SPI) within Chalmers University of Technology, a focus of the Production Area of Advance (AoA) was to explore ways to achieve industrial competitiveness, and resource-efficient product and production development processes. Inspired by the Production AoA, the team at Quality Sciences was presented with a research proposal based on the notion that QM could be supportive of sustainable development, specifically in the area of SPD. Initially, the research had a narrow focus, namely RDM, as one of the methodologies under the umbrella of QM. The initial aim was to investigate how RDM could be supportive of SPD.

The first study that was conducted is now identified as Paper V. The organization studied was a medium-sized Swedish manufacturer, hereafter named "Component", with which the Division of Quality Sciences initiated a research collaboration. The collaboration initially was between the division and the contact person at Component, hereafter named BS, who had a long-term professional relationship with one of the professors within the division. BS possessed expertise on concept selection in product development and in the area of RDM. In accordance with the Production AoA focus and funding, Component suited the terms of a research collaboration with a medium-sized organization where the management was willing to discuss and move forward to improve the robustness of their products. During the initial discussions with BS, the organization's current issues were discussed. At Component, there was a vast amount of customer claims data available, and the concern was that there was a lack of initiatives to systematically analyze the claims data in order to support improvements in the product development activities. Therefore, the study described in Paper V focused on extracting and analyzing the claims data, along with semi-structured interviews with relevant personnel. After a number of brainstorming sessions with BS, and with the third author of Paper V, and a few iterations of the paper itself, the idea of analyzing the claims data based on a product life cycle approach was broached.

One of the challenges in conducting the studies was the limited number of organizations with fully formalized RDM initiatives. Another challenge was the limited number of organizations that are frontrunners in terms of environmental sustainability initiatives or SPD. Based on the limitations of the study that was conducted at Component, such as the lack of knowledge of RDM and SPD among employees, the next step was to make a conceptual standing of the initial assumptions. The second study is now identified as Paper IV, which was based on a literature review of studies concerning the application of RDM tools as DfE tools. Relevant scientific papers were found based on a literature search, conducted by the first three authors of Paper IV. A number of discussions were held with the fourth author of this paper, who is based at the National University of Singapore, a collaborating research partner with the Division of Quality Sciences.

The results described in papers IV and V led to the conclusion that RDM can be supportive of SPD; however, certain adaptations were needed. Hence, the discussion was lifted up a level to QM, raising the question whether adaptations are required for it to contribute to SPD. In 2013, an existing collaboration with a large Swedish manufacturer, named “Auto” was sought after due to their efforts based on organizational core values that included quality and environmental care. The product development team at Auto was co-organized consisting of various competences, namely quality and environment. In order to understand how QM practices and tools can be applied along with environmental requirements in a product development setting, a case study was initiated. This third study is now identified as Paper II.

There are potential synergies in play between QM and sustainable development; indeed, the research stream investigating SPD by the means of the integration of environmental requirements in management philosophies is posited on this idea. In order to further investigate the synergies and build a base for this thesis, it was decided that a literature review of research concerning the support of QM for sustainable development was in order. The justification to select the field of QM, and not being limited to product development specifically, was based on two reasons: first was that the application of RDM in specific to support SPD was already addressed in Paper IV. In order to expand the knowledge and findings of paper IV, it was found necessary to widen the research focus to the larger field of QM. The second reason was based on the understanding that only certain QM tools are applicable in the product development. Therefore, in order to capture as many QM tools as possible that may be applicable for the integration of environmental requirements, it was pertinent to investigate the entire field to discover other tools, or perhaps principles and practices that might be applicable. A team of researchers from Luleå University that conducts research within the fields of QM and environmental management was consulted and requested to collaborate in this study. This fourth study is now identified as Paper I.

At the end of year 2014, a two-month long study visit was arranged to the University of Groningen (RUG) in The Netherlands, where research collaboration was initiated. The contacts were established during a conference in 2013 with a research partner at RUG, who later became the co-author of the next paper. Paper III is based on the comparative case study. The researchers at RUG in the Faculty of Business and Economics are conducting studies in the area of SPD, namely the implementation of DfE tools in product development, where a total of six organizations were studied. During the study visit, the opportunity to visit and conduct interviews at one of the organizations, hereafter named “Electric” arose. Upon the many discussions with the co-author at RUG during the study visit, the idea to conduct a comparative study of the two organizations, Auto and Electric, materialized.

3.2 Empirical Setting

Three of the appended papers have employed the case study method. In order to address the questions regarding the organization of a product development in its natural setting and the applications of QM and RDM, a case research is found appropriate due to its exploratory approach (Benbasat et al., 1987, Voss et al., 2002). The studies within the context of this thesis could also be defined as extension or refinement of existing theory, where case research is also found suitable (Stuart et al., 2002) in the attempt to understand a current phenomenon where existing knowledge on QM and RDM could be extended in their applications to support SPD.

The three cases were based on the empirical settings of Component (Paper V), Auto (Paper II), and Electric (Paper III). In the following, the details of the organizations are to be found.

3.2.1 Component

Component is a part of an engineering group with wholly owned companies in Europe, the US, India and China, where Component is one division out of three comprising the entire group of companies. Through its own brands, Component aims to be a world-leading supplier of coupling equipment for trucks and heavy trailers. Component is the parent company in the engineering group with manufacturing and sales companies in Sweden, Germany, Belgium, and the Czech Republic and sales companies in Norway, Denmark, England, France, and the US. The manufacturing facility is located outside Gothenburg, where it employs a total of 256 employees.

Component was selected as a case for the empirical investigation of this thesis for a number of reasons. First was the intention and willingness to collaborate on a research project with the division of Quality Sciences brought forward by the main contact person at Component, BS. Second, Component aimed to address the environmental impacts of its products at all product life cycle stages, as per policy. Therefore, SPD was one of the focuses of Component moving forward. Finally, Component designed and manufactured couplings and components related to heavy trucks and trailers, where the product reliability and robustness are critical requirements in ensuring the safe application of the products. Accordingly, the intention to implement RDM practices and tools in the product development was also a main focus of Component.

3.2.2 Auto

Auto develops and manufactures one product brand as part of a large Swedish organization that is the world’s leading manufacturer of automotive vehicles. The aim of Auto within R&D is to become the world leader in sustainable transport solutions. Therefore, Auto is constantly involved in research in collaboration with public stakeholders, the industry, the academic community, and its customers. Their core values, namely quality, environmental care, and safety, have a long tradition and form the organization’s common base and corporate culture. The organizational aim is to maintain a leading position in these areas of core values. The specific product brand produced at Auto is supported by over 650 dealerships and 1,450 workshops in more than 140 countries, and a total of more than 2,700 employees work for this sector.

The organization of the product development was the main reason for the selection of Auto as one of the case organizations. The SPD approach that was adopted by Auto, which is the integration of environmental requirements in existing methodologies, was another. Since organizational challenges were the prime obstacle to SPD, such as the lack of integration of environmental requirements in product development, the organization of product development played an important role in the attempt to understand how these challenges can be addressed in an actual setting. Auto presented a suitable setting with its organization of specialists of competences from areas such as quality and environmental care, for example.

3.2.3 Electric

The group to which Electric belongs is a diversified power management company providing energy-efficient electrical, hydraulic, and mechanical solutions. Electric's electrical business is a global leader in power distribution, power quality, control and automation, and monitoring products and services. The organization was founded in Britain, but Electric is located in the Netherlands, with a total of 900 employees. Electric provides Smart Grid solutions that enable intelligent distribution and consumption of electrical power. Its comprehensive, innovative range of products and services can be used to reliably, efficiently and safely manage power across utility, commercial, industrial and residential markets. From power generation through to power consumption, Electric's solutions create smarter homes, buildings, factories, transportation, distribution and energy across the grid.

The initial motivation to select Electric as a suitable case for the studies related to SPD originated from the team of researchers at RUG, where Electric was one of the six Dutch manufacturers to become a part of a research project concerning SPD. The selection was based on organizations which were aiming to improve their SPD efforts in various stages, for example, frontrunners and beginners. Out of the six organizations, Electric was selected for the study in this thesis due to its position as a beginner in the efforts toward SPD, in order to match the efforts at Auto where the co-organization of the product development is also at a beginner's stage, namely, two years into implementation. Further, Electric also fitted the criteria of adopting the implementation of DfE approach in its SPD efforts.

3.3 Data Collection and Analysis

In this section, data collection methods and analyses of the five appended papers are described and discussed. The summary of research design, data collection and analysis are presented in Table 1.

Table 1: Summary of research design, data collection, and analysis

Paper	Research question	Research design	Main data collection method	Data analysis
I	RQ1 - How can QM contribute to environmental sustainability?	Literature review	Literature search in databases	Review data analysis, and thematic analysis
II	RQ2 - How can product development be organized in order to exploit QM to integrate environmental requirements?	Single case study	Interviews, document analysis	Qualitative data analysis using NVivo software
III	RQ3 - What are the differences in the challenges when adopting the two different SPD approaches?	Multiple case study	Interviews, document analysis	Qualitative data analysis using NVivo software
IV	RQ4 - How can RDM contribute to SPD?	Conceptual	Literature search in databases	Qualitative analysis of published case studies
V		Single case study	Interviews, document analysis, observations	Exploratory Data Analysis in the JMP software

Paper I – Literature review

The research question (RQ1) addressed in Paper I was as follows: "How can QM contribute to environmental sustainability?" A research design is often based on the question whether data should be generated to address a research question, or whether it can be addressed more effectively using existing literature or data (Vogt et al., 2012). In order to effectively answer RQ1, a review of existing literature was the first step. Further, this extensive literature review was identified as a research synthesis wherein results may be contradictory (Vogt et al., 2012). Treating this entire thesis as a single study, the literature review was treated as legwork to, first, make use of existing literature in the areas concerned, and second, as a foundation to build the rest of the thesis upon (Flick, 2009), although paper I was designed later.

The results that were found in existing literature, naturally, were not collected with RQ1 in mind. Therefore, in order to ensure the findings are valuable, substantial time was spent on the discussion and search of the correct databases to look into, appropriate journals to include, and relevant literature to review (Vogt et al., 2012). A number of meetings were held between the authors, one face-to-face meeting in Luleå in January 2014, and a number of Skype meetings for subsequent discussions throughout the duration of the review.

There were three main methodological steps for the review process, namely paper selection, coding of the data, and generation of themes from the results. Scopus and Web of Science were selected as the search databases due to their coverage of engineering-based publications. The search path used in Web of Science was [(sustainable development) OR (sustainability)] AND [(quality management) AND NOT (water quality management)]. Similarly, the search path used in Scopus was [(sustainable development) OR (sustainability) OR (environmental management)] AND [(quality management) AND NOT (water quality management)]. One slight difference between the search paths is the additional search word of "environmental management" in Scopus due to its wider coverage of multidisciplinary topics.

However, Scopus generated many articles within these search paths that did not relate to sustainable development. Therefore, an analysis of the search results, which is a feature available in Scopus, was performed, where results were analyzed based on "sources" indicating the journals in which the articles were published. The search was then narrowed down to the three journals with the most number of articles published within the search path. They were TQM Magazine (and its successor, the TQM Journal), Quality Progress, and the Journal of Environmental Management. The searches in the databases and subsequent reading of the abstracts of all the hits found were carried out by the first author. Based on the relevance to the review according to the abstracts, 58 and 38 articles were selected from Web of Science and Scopus respectively.

The 96 total articles were shared equally among all six authors for reviews, where 40 of them were relevant. Further, based on the snowball technique that allowed coverage of other journals not included in the initial selection, 52 other articles were identified as relevant. These articles were also distributed equally among the authors for reviews, where 29 were found relevant. As the review was summarized, two duplicates were found, resulting in 67 total reviewed articles.

A coding matrix was created in an Excel sheet for recording of the relevant findings from the contents of the articles, which was inspired by Barratt et al. (2011). The selected coding were "publication year", "type of article", "data collection method", "methodology", and "research strategy", to name a few. A calibration review was done initially to fine-tune the codes, where five random articles were chosen, which was outside the review list. A meeting was held after the calibration to ensure that the authors' classifications were understood by all. Some clarifications regarding the codes were warranted during the meeting, which resulted in adding or editing the codes, and a final coding matrix was created.

One specific coding criterion titled “conclusion/synopsis/contribution” was created to summarize each article. The summaries were then used to generate specific themes to categorize the review articles based on their individual contribution. An example is theme 1 titled “supporting sustainability through integration of management systems”, which was generated from 31 of the review articles discussing the integration of quality and environmental management systems as one way to support sustainability.

Two types of analyses were conducted for the review: data analysis, and thematic analysis. The review data analysis contained a graphical display of the publication timeline of the review articles, and categorization of their outcomes, such as descriptive insight, model, and framework. Further, graphical distribution of the methodologies applied in the articles was shown, and pie charts of the number of articles based on elements of QM and SD were also shown. The thematic analysis contained analysis of the four themes generated from the review results according to coding criteria such as outcome, type of paper, methodology, and focus on QM and the triple bottom line, and the main points of departure of the articles.

Paper II – Single case study (Auto)

A case analysis was found suitable for Paper II due to the nature of the research question to be addressed (RQ2), read as follows: ‘How can product development be organized in order to exploit QM to integrate environmental requirements?’ This Paper II case analysis involved the practices in a product development setting at Auto where a team of people with various competences addressed quality and environmental requirements. The study of the dynamics present within a single case setting such as this was found suitable due to the nature of the research question (RQ2) (Eisenhardt, 1989). In order to address RQ2, the organization of the product development (department) and the functions of the specialists (people) were found appropriate as units of analysis. Auto’s product development team was specifically chosen for this study due to the specific way it was organized, where a number of specialists from various competences have been organized as one team. The specific organization of the product development was of a large importance to address RQ2.

This study was based on interviews of all six members of the product development team at Auto. They were the product development team manager, and one specialist from each of these areas; Quality, Environment, Safety, Reliability, and Production. The interviews usually lasted between 45 minutes to an hour, and were done face-to-face, individually. All interviews were conducted in English, and recorded. The recordings were later sent to an external body for transcription. The interview questions were formulated in a semi-structured manner in order to stimulate open discussions and follow-up questions (Flick, 2009). The interview questions were, for example, “Can you describe the journey since you started working in a co-organized setting of the product development team?”, “Can you name the challenges that you faced in your role in the co-organized setting?”, and “What are the benefits in working in a co-organized setting?”

At Auto, the corporate culture of working with the core values of quality, environmental care, and safety was one motivation for the co-organization of the product development team. Therefore, it was found necessary to include a number of additional interviewees from different levels of hierarchy and product groups within the group of companies. Four additional interviews were conducted, in the same manner as before. The interviewees were the Manager of Quality and Environmental Management from the organization’s Operations group, the Director of Quality of Auto, an Environmental Manager of another product group, and the Vice President of Quality who sat at the group headquarters based in Gothenburg. The justification for the additional interviews was to gather relevant information on the dissemination of the core values as organizational strategy from the top management to the product development level in order to understand the extent of QM in the support toward SPD. Data collection extended to document analyses of a specific QM tool applied in product development and the organization's sustainability report of 2014.

NVivo 10 software, designed to support analysis of qualitative data (Richards, 1999) was used for data analysis. A number of codes were created in NVivo qualitative data software after reading the interview transcripts. The codes created were aligned with the purpose of the study where the joint consideration of quality and environmental requirements in product development was explored. The codes were also closely related to the semi-structured questions used in the interviews, such as "quality", "environment", "benefits", "challenges", and "improvement". The codes "benefits", "challenges" and "improvement" were tied to the organization of the product development in order to address quality and environmental requirements in a joint manner. Further, the findings were compared to a set of maturity levels containing five levels, where level 1 indicates a low level of maturity and level 5 indicating high (Bessant and Caffyn, 1997, Bessant and Francis, 1999, Chapman and Hyland, 2000).

Paper III – Multiple case study (Auto and Electric)

Paper III was designed to address RQ3: "What are the differences in the challenges when adopting the two different SPD approaches?" In order to analyze and compare the two SPD approaches adopted in these two cases, a cross-case comparative study was designed. The suitability of Auto and Electric for the comparative study is based on the SPD approaches that have been adopted by the two organizations. Auto's product development team is made up of a team of specialists from competences in the areas of quality and environmental care, for example. The SPD approach adopted by Auto mirrored the integration of environmental requirements in existing methodologies approach, where tools such as FMEA was used to integrate and address environmental requirements of the product development. By contrast, Electric has implemented the DfE approach in the product development.

Two cases, Auto and Electric, were studied in paper III. The data collection method and analysis of Auto was the same as described for paper II. As for the data collection at Electric, semi-structured interviews were conducted in similar manner. Two interviews were conducted in one day during a visit to the facility in the Netherlands in October 2014. Both interviews were done face-to-face and in English; each lasted an hour, where both the authors were present. The interviewees were the Portfolio Manager, and the Material Specialist, both working with the product development at Electric. The interviews were recorded and later transcribed. Two additional interviews were conducted via telephone by the first author, from Gothenburg in March and April of 2015. The interviewees were the Quality & Laboratory Manager and the Environment, Health and Safety Manager, also working with the product development. Similar interview questions were used as described for the case of Auto, but concerning the DfE implementation.

The data analysis for the comparative study was the same as described in the case of Auto in paper II. Further, the interview data from Electric was included in the analysis of the data from Auto in NVivo. The two authors have iterated on the cross-case analysis in a number of occasions through tele-conversations. The challenges in SPD were gathered from the existing literature, read and reviewed by both authors. The second author acted as an external investigator of the data analysis in NVivo performed by the first author. This strengthened the analysis and findings of the comparative study (Eisenhardt, 1989).

Paper IV – Conceptual study

This conceptual study was designed to address RQ4: "How can RDM contribute to SPD?", and was based on a method of integrating a number of different works on the same topic (Meredith, 1993), such as the application of RDM practices and tools in order to contribute to SPD. The method further summarizes the common elements found in the different works, and identifies the differences in order to extend the work (Meredith, 1993). There are four general conceptual goals: envisioning, explicating, relating, and debating (Macinnis, 2011).

The integration of RDM and SPD was based on each concept's underlying ideas, with the support of secondary data published as case studies. The reason for choosing to focus on secondary data from case studies was based on the attempt to understand how practical applications of RDM support SPD. A number of selected published case studies provided greater understanding of various approaches of RDM applications when compared to an analysis of a single case study that could be designed for the similar purpose within the capacity of this thesis. The case studies were searched for in several databases such as Scopus, Science Direct, Web of Science and Google Scholar. Two groups of search words were used in all databases. One group contained search words "robust design", "case study", "manufacturing", and "eco-design", where a total of 77 published cases were found. The second group of search words contained "robust design", "case study", "manufacturing", and "sustainability", which resulted in 84 published case studies. The words "eco-design" and "sustainability" were used in order to identify and extend the search to include as many related case studies concerning SPD.

The secondary data of case studies were further narrowed based on a number of criteria, namely, that the case studies must deal with RDM, the results of the cases establish the potential connections to sustainability benefits, and the cases were applied in, or concerned, a manufacturing setting. The abstracts of all 161 cases were reviewed based on these criteria, where five cases were selected for the analysis. Additionally, a directed search was conducted in the SPD-focused Journal of Cleaner Production, where two additional cases were found. The number of studies selected were, therefore, seven. The overview of the cases were used as the analysis of this study, and later discussed in the paper. The details of the analysis are shown in Table 2.

Table 2: Overview of the case analyses

Source	**Problem description**	**Robust design tools applied** [1)]	**Control factors**	**Noise factors** [2)]	**Response variables**	**Reported outcomes as described in case studies**	**Life cycle stage where RDM tools were applied**
Ben-Gal et al. (2008)	Minimizing the emission of air pollutants of a factory stack to guarantee an environmentally sound use of a system	Non-linear transfer function	Stack design parameters, i.e. height and diameter	Weather conditions, i.e., ambient temperature and wind speed	Emission of air pollutant	Design of factory stacks that emits regulated level of air pollutant	Design stage
Cetin et al. (2011)	Reduction of surface roughness, and cutting and feed forces during turning process of stainless steel	Taguchi's mixed level parameter design (L_{18}) orthogonal array as experimental design	Turning parameters - spindle speed, depth of cut, feed rate, viscosity	-	Surface roughness, cutting force, feed force	Optimal conditions of cutting parameters were identified to reduce cutting force and improve the surface finish	Design of the turning process
Carrell et al. (2011)	Simplifying disassembly by engineering a snap-fit for automatic release upon exposure to heat field to limit manual labor or machine operation for disassembly	Taguchi methods incorporated in a set of designed experiments	Method of heating (oil bath or air bath), temperatures for disassembly	Variable dimensions of the snap-fits (length, overhang, thickness, release angle)	Shortest time for disassembly	Minimal time for disassembly was achieved based on optimal process conditions	Design of end-of-life process
Fratila & Caizar (2011)	Optimizing cutting parameters for good surface finish (roughness) and minimum power consumption	Taguchi method using orthogonal arrays	Milling parameters – axial cutting depth, feed rate, cutting speed and lubricant flow rate	-	Finish surface roughness and cutting power	Optimum cutting conditions to successfully apply near-dry techniques for cutting processes were established	Design of milling process
Hanafi et al. (2012)	Optimize cutting parameters to achieve minimum power consumption and the best surface quality	Taguchi method coupled to grey relational analysis	Machining parameters – cutting speed, feed rate and depth of cut	-	Surface roughness and cutting power	Optimal conditions of cutting parameters were identified	Design of cutting process
Besseris (2012)	Minimize environmental quality indicators such as chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in milk wastewater treatment	Taguchi method, 8-run saturated orthogonal array	Acidity, dissolved oxygen, quantity of incoming wastes, sludge volume index and mixed liquor suspended solids	-	Values of COD and BOD	Minimum values for the quality indicators were identified	Design of wastewater treatment process
Camposeco -Negrete (2013)	Optimize cutting parameters for minimum energy consumption	Taguchi method, orthogonal array	Depth of cut, feed rate and cutting speed	-	Cutting power consumed, cutting energy consumed and surface roughness	Most significant factor for minimized energy consumption and improved surface roughness (feed rate) was identified	Design of cutting process

1) The methods and tools applied in these case studies are those specific to RDM. For detailed description of these tools, readers are referred to the book Taguchi Methods (Bendell, 1989).

2) Blank cells in the "Noise factors" column indicate that the experiments were designed to determine the main effects of the control factors to establish the optimal conditions.

Paper V – Single case study (Component)

Paper V was also designed to address the question "How can RDM contribute to SPD?" This study was based on customer claims data at Component, and the attempt to systematically improve the design stage of product development. Component intended to find ways to initiate robust design in product development, and contribute toward SPD. Therefore, the study used Exploratory Data Analysis (EDA) to identify most relevant root causes of the claims that could be connected to noise factors in the use stage of the products. Component specifically does business with component dealers, such as auto shops and mechanics, who distribute and service the end product for end-users. When components are replaced due to faulty parts, quality defects, or maintenance plans, the dealers are requested to return the old components to the organization for analysis and improvements. The availability of years of historical data on product claims made Component suitable for the study of noise factors which may cause defects in the use stage of the life cycle. The opportunity to analyze the defective products and the related noise factors presented by Component was fitting for the purpose of proposing a new RDM practice which could be supportive of SPD.

There were two parts of data collection and analysis, which included interviews and claims data. The interview questions were semi-structured, and involved personnel working with the customer claims database, and BS, as the main contact person, and the Quality Manager at Component. The two personnel interviewed were directly involved in handling the claims database, which included tasks such as data entry from claim forms into the database, processing of the claims, and ensuring the claim reports are closed upon actions taken by problem owners. All interviews were conducted in English, face-to-face, and the interview notes were transcribed. The interviews took between three to four hours each. The interview with the Quality Manager lasted for two hours, involving learning steps of how the results of the claims data could be applied in the improvement phases of product development. The meetings and interviews with BS extended over the span of several days, where lengthy discussions were held to learn the mechanisms of the products and to develop the understanding of faults identified in the claims report. The first author further spent a number of hours assisting BS in conducting hands-on inspection of defective products which were returned to Component by customers.

The claims data from years 2006 until 2010 were extracted from the database and imported into the statistical software JMP. The EDA (Tukey, 1962) was applied for the quantitative analysis of the claims data. The EDA contained three steps; display of data, identification of salient features, and interpretation of the salient features (De Mast and Trip, 2007). The claims data were displayed in the graphical forms of histograms to capture patterns and identify the salient features. Finally, product failures were inductively related to possible noise factors based on the information found in the remarks columns of the claims report describing the situation where the failures occurred. The failures and the related noise factors were then classified according to the life cycle stages of the products, namely raw material, manufacturing, distribution, product use, and end-of-life.

3.4 Research Quality

The research quality is discussed based on the trustworthiness of the data collection and analysis methods. Maxwell (1992) stated that, *validity, in a broad sense, pertains to the relationship between an account and something outside of that account, whether this something is construed as objective reality, the constructions of actors, or a variety of other possible interpretations* (p. 283). The descriptive validity (Burke, 1997) is addressed in this chapter pertaining to the studies in this thesis in order to strengthen the findings and qualitative analyses.

Burke (1997) stated that, *descriptive validity refers to the factual accuracy of the account as reported by the researchers* (p. 284). In the course of the studies within this thesis, during all interviews and meetings at the case organizations, notes were taken in addition to the recording of the sessions. All recordings were then transcribed, and where concerned stored in the NVivo database for analysis. In the case of Component, data triangulation (Flick, 2009) was adopted to further confirm accuracy. In addition to interviews, document analyses were conducted in accessing the customer claims database. The investigator triangulation (Flick, 2009) was also adopted in the case of Component, where the third author was present and involved during meetings with BS, and during analysis of the claims database which also involved export of the claims data into the JMP software.

In the case of Auto, the results of applying of FMEA in the product development were triangulated by studying documents such as templates and training materials. Further, the 2014 Sustainability Report as published by Auto was studied to further understand the reach of the core values as a corporate culture throughout the organization. The investigator triangulation was also applicable in the case of Electric, where the co-author has been involved for two years in several projects conducted prior to the cross-case analysis. The co-author was also present during both face-to-face interviews conducted at Electric.

Participant feedback (Burke, 1997) was another strategy to strengthen the descriptive validity at both Component and Auto. At Component, BS was consulted with regards to the claims database and reporting system, the claims data analysis, and findings. Concerning the Auto case, the product development manager was consulted with regards to the interview data. Further, the results and findings of the interview data analysis in NVivo were presented to all the team members and the manager in a separate session for their feedback.

Generalizability is commonly a concern in the design of a single case study, where it is claimed that, *single cases offer a poor basis for generalizing* (p. 43) (Yin, 2009). A longitudinal and in-depth study may provide support for generalizability of a single case study (Leonard-Barton, 1990). The case of Component was longitudinal, where the collaboration with the organization stretched between 2011 and 2013, yielding rich and vast data. The collaboration with Auto began in early 2014 and is ongoing, especially vis-à-vis the cross-case analysis with Electric. The outcome of these studies was communicated to the subjects involved, and has the potential of creating values for the organization in general, which is indicative of quality research (Karlsson, 2008). Further, the goal of certain qualitative research is argued to show the uniqueness of a certain group of specialists, such as the product development team in these cases, rather than generating results which are applied broadly (Burke, 1997). A certain degree of generalization can be aimed for when dealing with specific contexts or groups in the studies (Maxwell, 2005, Flick, 2009), for example, product development in organizations, and the specialists as product development team members, as explored in the cases of Auto and Electric.

3.5 Limitations

There are a number of limitations that come with the studies within this thesis. Generally, sustainable development is built upon three pillars, namely environment, social and economy. The contributions to the area of sustainable development, whether in the relevance to research or practice, encompasses all three pillars due to their interconnectedness. For example, the attempt to select a low environmental impact raw material in a product development stage may increase the cost of the product development effort due to the high priced raw material. Hence, it could be argued that the environmentally conscious decision is connected to the economic aspect of the development process. On another facet, organizations that outsource their operations to low-cost third world countries may contribute negatively to the social sustainability in terms of child labour and the lack of human rights law. However, because the focus of this thesis is on the adaptations of QM practices and tools within the context of product development, where the product requirements are limited to one pillar of sustainable development, the environment. The environmental requirements of products are added to the traditional quality, cost and time to market requirements of products. As the cost requirement is already addressed, and the economic pillar is therefore excluded. The social pillar is also excluded because the social sustainability indicators are outside the scope of the QM practices and tools.

Second, the studies are limited to the manufacturing industry, where QM practices and tools are widely applied. Although QM practices and tools are also famously applied within the service industries, the area of SPD is better suited to manufacturing. In the case of Auto, the study is limited to the specificity of one large automotive manufacturer. In comparison to other large automotive manufacturers around the globe, Auto may not fare as the most environmentally conscious in terms of emissions control, for example. However, Auto is famously known for its Corporate Social Responsibility (CSR) policies and activities, where it contributes to a high degree to the social and economic aspects of sustainability throughout its global network. The CSR efforts are, then, related to the first limitation addressed earlier. In terms of the SPD efforts within Auto, the environmental sustainability is the main concern, whereas the social and economic sustainability are addressed through the CSR efforts within the organization. However, the CSR efforts of Auto is outside the scope of this thesis.

Third, within the context of manufacturing, this thesis is focused on the product development efforts, and thus excludes the manufacturing processes and other upstream activities such as logistics, warehousing and distribution, and sales. Further, the upstream activities such as purchasing, marketing, and supply chains are also excluded. Although the discussion regarding SPD and RDM within the studies includes the entire life cycle of a product, the application and adaptations of QM practices and tools concern only the product development efforts. Within the area of QM, the focus is mainly on principles, practices and tools, and thus excludes other areas such as QMS ISO 9000 standards and audits, supplier quality selection, and incoming, in-process, and outgoing product quality inspections.

Finally, since the studies and discussions revolve around the integration strategies, the challenges in the integration efforts, the organization of the product development that supports the integration effort, and the applicability of QM practices and tools, the remaining aspects of SPD are excluded from this thesis, for example, project selection and prioritization, team selection and prototype testing.

4 SUMMARY OF APPENDED PAPERS

This thesis is based on five papers, as shown in Table 3. In this chapter, summaries of the five papers are presented. This is followed by the discussion of common themes.

Table 3: Overview of appended papers

Paper	**I: Literature review**	**II: Quality & Environment**	**III: Challenges in SPD**	**IV: RDM - SPD**	**V: Life cycle - Noise factor**
Type	Review	Single case	Multiple case	Conceptual	Single case
Purpose	Review and elaborate on the support of QM for business approaches toward sustainable development	Explore and analyze the joint consideration of quality and environmental requirements in a product development setting	Explore the two different SPD approaches and compare the challenges of the integration of environmental requirements in product development	Explore how efforts based on the RDM may better contribute to sustainability and, more specifically, to SPD	Propose a new practice of RDM by adopting a life cycle approach to noise factor identification

4.1 Paper I – The support of Quality Management to Sustainable Development: A literature review

Research has previously indicated that QM is suitable for the integration of environmental requirements into existing management approaches, based on its principle of meeting or exceeding customer requirements, where environmental requirements are viewed as customer requirements involving various stakeholders. The purpose of this paper was to review and elaborate on the support of QM for business approaches toward sustainable development. Business approaches, within the scope of this paper, refers to organizational efforts such as development and manufacturing of sustainable products, implementation of QMS, and EMS.

A literature review in Scopus and Web of Science databases resulted in a total of 67 review articles. Coding criteria were developed where themes were generated to classify all 67 articles. Four classification themes were generated: supporting sustainability through integration of management systems; QM as support to EMS implementation and to managing sustainability; supporting integration of sustainability considerations in daily work; and supporting stakeholder management and customer focus. The themes and their description are shown in Table 4.

Table 4: Description of the themes

Theme	Description
1. Supporting sustainability through integration of management systems (31 articles)	An integrated management system (IMS) is argued to be a means to reduce redundancies and manage resources efficiently. Further, an IMS is seen as one way to identify aspects of a QM system that could be supportive of sustainability in general.
2. QM as support to EMS implementation and to managing sustainability (22 articles)	The research reviewed argues that QM principles, practices and tools could be used for supporting the management of environmental considerations. Some articles translate the logic of principles, practices and tools to environmental management and sustainability. Most articles included in this theme deal with how the QM practices can be used to support the introduction of environmental management.
3. Supporting integration of sustainability considerations in daily work (6 articles)	This theme argues for integration of sustainability considerations into existing QM practices and tools. Some examples are combinations of QM practices and tools and LCA, and application of QM tools such as the House of Quality matrix and Design of Experiments "as is" and shown how they can support sustainability.
4. Supporting stakeholder management and customer focus (8 articles)	The articles reviewed emphasize the inherent focus on customers within QM and how that can assist in supporting necessary stakeholder management in sustainable development. This is argued to be achieved by broadening the sometimes narrow definition of a customer as a buyer, to a definition encompassing more stakeholders.

Three main findings of this paper pertain to the thesis. First, generally, there is a lack of research pointing towards adaptations of existing QM principles, practices, and tools vis-à-vis sustainability (Maxwell and Van Der Vorst, 2003, Luttropp and Lagerstedt, 2006). This is further supported by the second finding, which points to stakeholder management as a research area that may illuminate the synergies between QM and sustainability (Jørgensen et al., 2006). Since this is based on the understanding that stakeholders include customers among suppliers, policymakers, and society, for example, the QM principle of customer focus can no longer be limited to a single customer, but must include various stakeholders in the attempt to explore the potentials of QM in supporting sustainability. Third, QMS is only a part of QM that standardizes procedures and practices. Therefore, the support of QM toward sustainability should not be limited to management systems (Von Ahsen and Funck, 2001). Practices beyond management systems and standardization are needed in order to address the growing challenges of sustainability in organizations.

The QM adaptations are further explored and analyzed in Paper II, and Paper III. The expansion of the view of customer focus is explored in Paper IV, with a specific focus on RDM. A new practice, focused on RDM, is proposed in Paper V.

4.2 Paper II – A case of joint consideration of quality and environmental requirements in product development

Organizations have begun to shoulder the responsibility of ensuring development of sustainable products. This includes consideration of non-hazardous raw materials, and proactive end-of-life solutions in the early design phase, for example. Environmental requirements of products need to be considered equally with traditional requirements, such as quality, cost, and time. The challenge, however, lays in operationalizing the environmental requirements. A number of studies have suggested the use of existing management approaches as one way to integrate environmental requirements in daily operations, one being QM. The purpose of this paper was to explore and analyze the joint consideration of quality and environmental requirements in a product development setting.

In this paper, the integration strategies and mechanisms adapted from Becker and Zirpoli (2003), and Griffin and Hauser (1996) were applied to explore and analyze the joint consideration of quality and environmental requirements at a large Swedish organization, named “Auto”. The study involved interviews with a product development team and its manager. Later, the study was expanded to involve other levels of hierarchy and product groups within the organization.

The findings show that the application of QM tools, such as Failure Mode and Effects Analysis (FMEA), could enable the integration of environmental requirements in product development. The exemplification of the case according to the integration strategies, such as “organizational structures” and “co-location”, systematizes reviewing current product development practices, and increases understanding on environmental requirement operationalization. This case is also an example of the dissemination of organizational strategies from the top to bottom, where the core values of quality and environmental care are a common language throughout the organization. The paper concluded by suggesting that the co-organization effort is one way to support the adaptation of existing practices and tools from QM to facilitate environmental requirements in product development. The co-organization effort also addresses the challenges of lack of integration and systematic implementation for sustainability initiatives in product development.

This paper explores the adaptations of existing QM practices and tools in a product development setting in order to better align with the environmental requirements faced by organizations. The exemplification of a case contributes to the need for more empirical investigations for the benefits of practitioners in understanding how adaptations of QM practices and tools can be made to support the contribution to environmental sustainability.

4.3 Paper III – Challenges in sustainable product development – a comparative study

There are two main SPD approaches that have been identified over the years: integration of environmental requirements in existing methodologies, and implementation of environmental concepts and tools such as DfE and LCA. The challenges in SPD are oftentimes identified as general organizational and managerial issues related to the lack of integration of environmental requirements, concepts, and tools in product development. Examples include the lack of communication and cooperation between team members and departments, insufficient training and education related to the environmental knowledge, and lack of inappropriate measurement and control systems for environmental goals. However, the challenges can also be attributed to contextual factors, such as the complexity of the supply chain and the absence of business models for green products (Baumann et al., 2002). Therefore, the purpose of this paper was to explore the two different SPD approaches and compare the challenges of the integration of environmental requirements in product development. In doing so, the existing prevalent challenges in SPD could be further categorized according to the SPD approaches adopted by organizations.

The SPD efforts at Auto and Electric were studied due to their two different approaches. Auto has adopted the approach of integrating environmental requirements in existing methodologies by sharing QM practices and tools in the joint consideration of quality and environmental requirements. Electric, on the other hand, has implemented DfE and LCA to facilitate SPD. The organization of the product development to facilitate these two approaches was described. Further, the challenges in SPD as found in the existing literature were listed and used to identify and explore the challenges found at Auto and Electric. The summarized comparison of the SPD challenges is shown in Table 5.

Table 5: Summarized comparison of the challenges in SPD as observed at Auto and Electric

Challenge (Lack of)	**Auto**	**Electric**
Environmental goals and vision	Not observed	Observed challenge (not defined at Electric)
Strategy from top management/Top management support	Not observed	Observed challenge (short-term strategy conflicts with sustainable developments)
Business case for environmental products	Not observed	Observed challenge (lack of demand for green products with premium price)
Customer awareness of environmental products	Observed challenge (product features such as performance and speed dominate environmental awareness)	Observed challenge (awareness exists, but there are disputes on what is sustainable)
Clear product-related environmental requirements	Not observed	Observed challenge (environmental requirements are unclear because of VOC; reactive approach)
Cooperation between designers and environmental specialists	Not observed	Observed challenge (can be improved)
Cross-functional collaboration (between departments and external parties)	Observed challenge (knowledge sharing can be improved in the example of LCA application)	Observed challenge (can be improved)
Employee involvement/awareness	Not observed	Observed challenge (culture is to design new products, not to make existing products more sustainable)

The questions that were explored in this study were: “Do the SPD challenges, as identified in current literature, differ according to the SPD approaches adopted?” “If so, how do they differ?”

The findings show that Electric faced more challenges in its implementation of DfE and LCA than did Auto in the integration of environmental requirements in existing methodologies. This was attributed to the historical orientation of the organizations, where Auto has a long history of adhering to the core values of quality and environmental care. The differences can be further explained by the type of products manufactured. The automotive industry has stringent environmental requirements, and energy-efficient products are demanded by customers. Hence, the environmental requirements are linked to the development of the products per se, and has been instilled in everyday operations. Therefore, the challenges at Auto are more closely related to the implementation of SPD methodologies and DfE tools. Electric, on the other hand, with the SPD initiative being recent, is less mature and lacks the experience to better handle the challenges. The utility industry also adhere to stringent environmental requirements; however, they are product-dependent. In the case of the switchgears manufactured at Electric, there is a lack of requirements and demand for green products. Therefore, the challenges at Electric require addressing several strategic, managerial and organizational issues in its SPD approach.

4.4 Paper IV – Adapting the Robust Design Methodology to support sustainable product development

In recent years, RDM has been applied in cases where the Taguchi method was used for the eco-design of a factory smokestack (Ben-Gal et al., 2008), and reduced power consumption in machining processes (Fratila and Caizar, 2011, Hanafi et al., 2012), for example. However, the research on how RDM could contribute to environmental sustainability is not extensive. Hence, the potentials in the adaptation of the RDM to be applied in SPD remains unexplored. The purpose of this paper was to explore how efforts based on the RDM may better contribute to sustainability and, more specifically, to SPD.

Within the RDM literature, the understanding of variation is crucial, where uncontrollable noise factors may cause a product characteristic to deviate from its specified target, and therefore create variation among units of the same product (Phadke, 1989). The categorization of noise factors has developed over the years to reflect that outer disturbances are not limited to a single user of a product (Taguchi and Wu, 1979). Therefore, it was consistent in defining quality loss as losses to society. However, the consequent categorization of the same have become narrower in scope (Clausing, 1994, Davis, 2006). Further, although the need to apply the RDM early in the product design stage, proactively, has been raised in the past (Kackar, 1989, Taguchi and Clausing, 1990), evidence from cases show that this is lacking in organizations (Thornton et al., 2000). This shortfall may be found in previous research on RDM that focused on tools such as DoE, while neglecting the practices and the question of when to apply the tools (Arvidsson and Gremyr, 2008, Hasenkamp et al., 2009).

On the subject of SPD, much focus has been aimed at the inclusion of environmental requirements into existing tools, such as QFD (Masui et al., 2003). It has been argued that there are three key factors for adopting environmentally conscious designs; early integration of environmental aspects, adopting a life cycle approach, and a multi-criteria approach (Bovea and Pérez-Belis, 2012). Eco-design (Knight and Jenkins, 2009) and DfE (Fiksel, 2011) are two common approaches applied in product design stages to facilitate SPD; the life cycle perspective is considered pertinent to their adoption (Klöpffer, 1997, Knight and Jenkins, 2009). Five DfE strategies have been identified in research for each life cycle stage; raw material use optimization, clean manufacturing, efficient distribution, clean product use/operation, and end-of-life optimization (Choi et al., 2008).

This paper is based on a literature study of previous cases of RDM in a manufacturing setting. A total of seven cases were used for the review. The summarized overview of the cases are presented in table 6.

Table 6: Summarized overview of the case studies

Source	**Problem description**	**Response variables**	**Reported outcomes as described in case studies**	**Life cycle stage where RDM tools were applied**
Ben-Gal et al. (2008)	Minimize the emission of air pollutants of a factory stack	Emission of air pollutant	Stacks that emit regulated level of air pollutant	Design stage
Cetin et al. (2011)	Reduce surface roughness, and cutting and feed forces in turning process	Surface roughness, cutting and feed forces	Optimal conditions of cutting parameters	Process design
Carrell et al. (2011)	Simplify disassembly by engineering a snap-fit	Shortest time for disassembly	Minimal time for disassembly	Process design
Fratila & Caizar (2011)	Optimize cutting parameters for good surface roughness and minimum power consumption	Surface roughness and cutting power	Optimum cutting conditions	Process design
Hanafi et al. (2012)	Optimize cutting parameters for minimum power consumption and good surface quality	Surface roughness and cutting power	Optimal conditions of cutting parameters	Process design
Besseris (2012)	Minimize environmental quality indicators in milk wastewater treatment	Values of indicators	Minimum values for the quality indicators	Process design
Camposeco-Negrete (2013)	Optimize cutting parameters for minimum energy consumption	Power and energy consumption	Significant factor for minimized consumption	Process design

Practices and tools for upstream efforts are needed both in RDM and SPD. By including a sustainability indicator as a response, environmental impacts of a design can be highlighted. The adaptation of standard tools such as DoE to focus on the application of multiple responses, one being an eco-indicator, was suggested. Two adaptation areas of the RDM were suggested for further research. First, as RDM has the potential to contribute to all life cycle stages, it is important to have a broader view of the noise factors and more focus is needed on the early development stages, where the application of conceptual and qualitative tools is required. Second, there is a need to adapt existing RDM tools to include environmental requirements explicitly. The adapted RDM will fulfill the key criteria for the eco-design tools, namely an early integration of environmental aspects in the development processes, adopting a life cycle approach, and a multi-criteria approach.

This paper contributes, conceptually, to a deeper understanding of how RDM can be adapted to minimizing or eliminating environmental impacts in the design of products and processes. In order to fully exploit the potentials of QM, in general, and RDM, in specific, in supporting sustainability, adaptations such as broadening the view of customer focus and adopting life cycle approach are necessary.

4.5 Paper V – A life cycle approach to Robust Design Methodology

The concept of quality loss used as the loss a product imparts to the society, is indicative of product failures during the use stage and end-of-life strategies concerning product disposal. In order to design robust products, it is important to explore and identify failures that occur during product use. One way to accomplish this is by using the back-end data of product development, namely production data as well as claims data from customers that contains information regarding failures of products. The conditions related to or causing failures are, at times, referred to as noise factors. Analysis of claims data presents an opportunity to understand types of failure and the conditions in which the failures occurred. Hence, the opportunities to improve the design stage of the product development.

Concerning efforts on SPD, a life cycle approach is often adopted. The life cycle stages of a product are commonly categorized as extraction of raw material, manufacturing, distribution, use, and end-of-life. Customer claims data analysis can potentially identify failure modes that can be related to one or more stages of product life cycle. Hence, the noise factors related to the causes of failure could also be linked to one or more life cycle stages. The purpose of this paper is to propose a new practice of RDM by adopting a life cycle approach to noise factor identification.

This study is based on the analysis of claims data at Component. Interviews were conducted, and claims data were analyzed using Exploratory Data Analysis (EDA). The proposed practice is visualized in Figure 1.

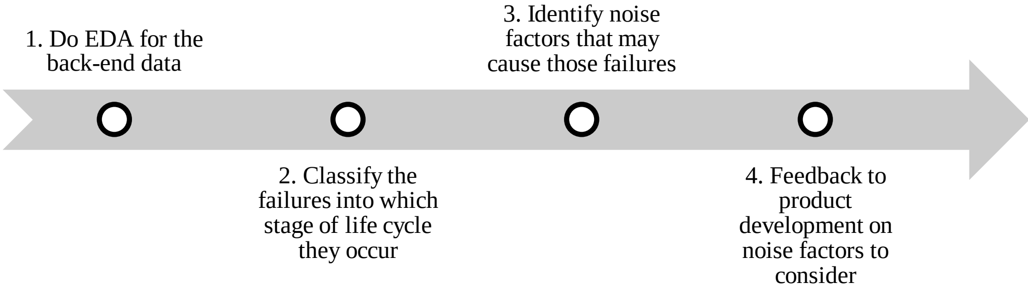

Figure 1: Proposed RDM practice for noise factor identification

In this paper, RDM has been applied to various product life cycle stages through the analysis of the claims data. The back-end data is a critical, yet untapped, source of information regarding the way products are used, and the conditions in which products fail; hence, a source of various noise factors across product life cycle stages. The paper proposed a new practice of RDM by adopting a life cycle approach to noise factor identification. The life cycle approach has two implications: it expands the focus of RDM to include all stages of a product instead of being limited to the product development process, and creates opportunities to identify contributions to stakeholders beyond a single customer. Focusing on the whole life cycle could capture long-term effects, for example, on the environment. Therefore, adopting the life cycle approach points to how RDM can be supportive of SPD. This paper specifically highlights the adaptations of RDM in the proposal of a new practice, which is an example of how QM can be supportive of SPD.

4.6 Common themes

Based on a general analysis of the appended papers, a set of common themes that emerged are described in this section. The common themes are categorized into two areas. One is the adaptations of QM practices and tools in order to support environmental sustainability in organizations, specifically in product development. The second is the adaptations of RDM practices and tools to facilitate SPD. Table 7 contains the summaries of the findings of the appended papers.

Table 7: Summaries of findings of appended papers

Paper	Summary of findings
I: Literature review	In order to enhance the support of QM toward sustainable development, three findings are relevant. 1) Adaptations of current QM principles, practices and tools, 2) Expanding the view of customer focus to include various stakeholders, and 3) The need for new practices beyond the implementation of IMS.
II: Quality & Environment	Co-organization of competences in the areas of quality and environmental care allows sharing and adapting of QM practices and tools to contribute towards SPD.
III: Challenges in SPD	The SPD challenges differ according to the approaches adopted with regards to the type of products manufactured in two varying industries.
IV: RDM - SPD	Adaptations of RDM is required in order to fulfill the key criteria for the eco-design tools, namely an early integration of environmental aspects in the development processes, adopting a life cycle approach and a multi-criteria approach.
V: Life cycle - Noise factor	A new practice of RDM is proposed, which is adopting of life-cycle approach to noise factor identification, which expands the focus of RDM to include all stages of a product's life, and creates opportunities to identify contributions to stakeholders beyond a single customer.

4.6.1 Adaptations of Quality Management practices and tools

Previous studies in the area of QM supporting sustainability are focused on management systems such as QMS and EMS. Various studies discuss the benefits of an IMS for reasons such as reducing redundancies in procedures and workflows, and decreased implementation times (Karapetrovic, 2002, Karapetrovic and Casadesús, 2009). However, the environmental sustainability potential of QM is not limited to IMS. The management standards that make up the ISO 9000 management system are one aspect of QM, whereas its principles, practices, and tools make up another aspect left to be explored. The QM principles, such as customer focus and continuous improvement, have been previously linked to environmental sustainability (Borri and Boccaletti, 1995, Curkovic et al., 2000). However, the linkages were related to the implementation of an EMS (Borri and Boccaletti, 1995), environmentally responsible manufacturing (ERM) (Curkovic et al., 2000), and general concepts such as sustainability management (Kuei and Lu, 2013) and environmental performance (King and Lenox, 2001, Bergenwall et al., 2012). Concerning QM tools, a number of studies have discussed QFD as a suitable tool for the integration of environmental requirements in the product development (Zhou and Schoenung, 2003, Sakao, 2004). However, the discussion focused on the applications of QM practices and tools as they are, whereas research on the adaptations of current practices and tools are scarce.

Theme 1: Customer focus principle of QM: Expanding the view of customer focus to include various stakeholders

The original view of customer focus as a QM principle points to understanding customer requirements and needs, explicit and implicit, in the early stages of product development in order to market satisfactory products (Bergman and Klefsjö, 2010). In current times, manufacturers are responsible for their products not only in the eyes of the end-users, but also to various other stakeholders, such as dealers, suppliers, policymakers, non-governmental organizations, and the society in which the organizations exist (Delmas and Toffel, 2004). Hence, the view of customer focus needs to be expanded, which includes the environmental requirements. One example is in the case of Auto, where the product development team included the approved raw material list during the selection of suppliers in the design stage. By doing so, they expanded the view of customer focus to include suppliers, and therefore ensure that only selected and approved raw materials are purchased.

Theme 2: Adaptations of QM practices: Co-organization of competences in product development to share QM practices

Environmental requirements of a product need to be considered at par with the quality, cost, and time requirements in the product development (Baumann et al., 2002, Bhamra, 2004). The integration of environmental requirements in product development becomes problematic when they are viewed upon as an add-on (Azapagic et al., 2006). One way to address this is to integrate requirements through sharing of existing practices. Boks (2006) identified practices such as adopting strong customer focus, and educating and training of product development team members on the environmental requirements of products as necessary for the successful integration. The action of the manager at Auto to co-organize the various competences as one product development team thus created the platform for sharing of existing practices, as exemplified in paper II. For example, practices such as creating a focus group in order to understand customer needs and wants could very well be applied for the environmental requirements of products. Conducting regular surveys with product dealers regarding the product quality and services, and with suppliers regarding the cost and delivery time, could also be useful. Quality and environmental specialists in the product development team, through sharing of practices, can find a common ground where knowledge could be exchanged, and communication could be enhanced between team members (Griffin and Hauser, 1996).

Theme 3: Adaptations of QM tools: FMEA for the integration of environmental requirements

There are a number of QM tools that have been applied to address the environmental requirements of products, such as QFD (Masui et al., 2003, Sakao, 2004), the Taguchi method (Ben-Gal et al., 2008), and FMEA (Bovea and Pérez-Belis, 2012). FMEA adaptations was one way of utilizing the QM tool to integrate environmental requirements in the product development, in addition to providing a platform for the co-organized team members to share a common tool, as found in paper II. Similar to sharing of practices, the sharing of the QM tool also allows for exchange of knowledge and increased communication. Therefore, the barriers of integration (Griffin and Hauser, 1996) among team members are addressed.

4.6.2 Adaptations of Robust Design Methodology practices and tools

Papers IV and V show that an existing methodology, such as RDM, contributes to SPD, but with necessary adaptations. In previous studies, the application of DoE and the Taguchi method have helped reduce environmental impacts of products (Ben-Gal et al., 2008, Carrell et al., 2011, Cetin et al., 2011, Fratila and Caizar, 2011, Besseris, 2012, Hanafi et al., 2012, Camposeco-Negrete, 2013). This was shown by adding environmental indicators as response variables in experiments where the impacts to the environment could be controlled or minimized. However, these studies lack an explicit connection between the fundamentals of RDM and its contribution toward environmental sustainability; hence, the lack of discussion regarding the adaptations of current applications. Going back to the fundamentals of RDM that point to awareness of variation (Arvidsson and Gremyr, 2008), and the concept of quality loss (Taguchi, 1986), the potential for contributing to sustainability is yet to be explored.

Theme 4: Adaptations of the fundamentals of RDM: Expanding the concept of quality loss to include environmental impacts

There are unexplored potentials to be realized if necessary adaptations are applied to existing RDM practices and tools. The example of the quality loss concept is an evident argument, where the impact of a product is not limited to a single user, but includes societal aspects such as impacts on the environment (Taguchi, 1986). In the case of the noise factors that cause unwanted manufacturing or use variation, the experience is not limited to the next process or a customer. Because the disturbances caused by noise factors may pose a harmful effect on the environment, the application of RDM practices and tools in daily operations should accommodate them. Awareness of variation is a fundamental principle of RDM (Arvidsson and Gremyr, 2008), where engineers and designers are able to estimate the design parameters based on assumptions made on known and unknown noise factors (Johansson et al., 2006).

These assumptions should be made based on the awareness of variation which may cause environmental damages in addition to quality related inconveniences to the users. The expansion of the quality loss to include environmental impacts to more than a single customer also allows the adoption of a life cycle approach, owing to the examination of end-of-life options, for example. Paper IV indicates that further adaptations of RDM tools such as Taguchi method and DoE is required in order to realize its potential as an eco-design tool. RDM, through adaptations, can be utilized to fulfill the key factors of an eco-design tool, namely early integration of environmental requirements, adopting a multi-criteria and a life cycle approach (Bovea and Pérez-Belis, 2012).

Theme 5: Adaptations of RDM practices: Adoption of lifecycle approach in noise factor identification

The identification of various noise factors remains a challenge in the application of RDM (Johansson et al., 2006, Johannesson et al., 2013). In paper V, a new practice was proposed for their identification by adopting a life cycle approach, which involves analysis of customer claims data. In doing so, the application of RDM is expanded beyond early stages of product design to include all life cycle stages, namely raw material, manufacturing, distribution, use, and end-of-life (Choi et al., 2008). Noise factors are not limited to design and manufacturing stages, but exist in all stages of product life cycle. Through the adoption of a life cycle approach, the identification of noise factors in all stages of product life cycle becomes possible. The analysis of claims data was intentionally used for the identification of possible failure causes and the life cycle stages it may have occurred. The connection of the life cycle stages to the probable noise factors creates an extended application of RDM, while possibly contributing to SPD.

5 DISCUSSION

This chapter elaborates on the discussion of the studies conducted in this thesis based on the purpose to explore and identify the adaptations of QM practices and tools to better support environmental sustainability. A specific focus of this thesis is given to the integration of environmental requirements in product development, and to the adaptations of RDM, as one QM methodology. The discussion is further sectionalized according to the four research questions.

There are two approaches to SPD which were found relevant to the studies in this thesis. One approach to SPD is the implementation of concepts such as DfE (Bras, 1997, Sarkis, 1998, Sun et al., 2003, Hauschild et al., 2004, Kurk and Eagan, 2008), eco-design (Bhamra, 2004, Griese et al., 2005, Luttropp and Lagerstedt, 2006), and tools such as LCA (Baumann and Tillman, 2004, Pujari, 2006). The other is the integration of environmental requirements in existing management approaches and methodologies (Angell and Klassen, 1999, Kaebernick et al., 2003, Masui et al., 2003, Berchicci and Bodewes, 2005, Kleindorfer et al., 2005, Sakao, 2009). However, in both these SPD approaches, the challenge remains to integrate environmental requirements in product development. Many studies have pointed to the challenging effort of integrating environmental requirements in product development (Kuo et al., 2001, Lindahl, 2006, Vinodh and Rathod, 2010, Bovea and Pérez-Belis, 2012). Some of the main challenges are attributed to the absence of integration strategies in organizations, and the obstacles found in existing integration strategies (Sroufe et al., 2000, Choi et al., 2008, Knight and Jenkins, 2009, Dangelico and Pujari, 2010, Pigosso et al., 2013). The obstacles are often related to organizational issues such as the lack of cooperation between product development team members and departments, lack of communication, and lack of knowledge sharing within the team (Ritzén and Beskow, 2001, Johansson et al., 2007, Short et al., 2012, Lopes Silva et al., 2013, Brones et al., 2014, Hatcher et al., 2014, Hartmann and Germain, 2015).

The potentials of QM could be materialized by taking advantage of the synergies that exist between QM and sustainable development. These synergies have been discussed based on four main themes in paper I, including the integration of management systems such as QMS and EMS. An IMS is argued as means to achieve internal organizational efficiency (Klefsjö et al., 2008) through reduced redundancy in the workflows and procedures of audits, for example. The second theme discusses the basic principles of QM such as customer focus, continuous improvement, and employee involvement, and its contribution to environmental sustainability in terms of product development (Sarkis, 2001, Johansson, 2002) and pollution prevention (Hart, 1995, Wilkinson et al., 2001, Calia et al., 2009). Additionally, the existing QM initiatives in organizations, such as Total Quality Management (TQM) practices, were viewed upon as the foundation for the implementation of EMS (Garvare and Isaksson, 2001, Mcadam and Leonard, 2003).

The third theme discussed was specific to environmental sustainability in terms of product development (Theyel, 2000, Rusinko, 2005). QM practices and tools are suitable for the integration of environmental requirements through understanding customers and stakeholders' requirements in the development and manufacturing of products, which is aligned with the findings in the case study at Auto (Klassen and Mclaughlin, 1993, Angell and Klassen, 1999, Ahmed, 2001). Further, QM practices and tools such as (D)FMEA and CTQ, could be adapted in order to address environmental requirements as shown in the cross-case analysis of Auto and Electric (Bovea and Pérez-Belis, 2012). The third theme is also found applicable in the exemplification of the other approach to SPD, namely the implementation of DfE tools (Kaebernick et al., 2003, Berchicci and Bodewes, 2005). The exemplification is found in the case of

Electric, where QM practices and tools, such as CTQ's and DFMEA, are adequately used to integrate environmental requirements in product development.

Theme four discusses the stakeholder perspective in terms of broadening the narrow view of customer focus of QM (Garvare and Isaksson, 2001, Klefsjö et al., 2008). Klefsjö et al. (2008) stated that, *by enlarging focus from customers to the wider concepts of stakeholders and interested parties, much of the QM theory should still be applicable, although modifications might be necessary* (p. 125). The broadening of the customer focus view is addressed in the conceptual study where adaptations to RDM, as one methodology in the QM area, have been suggested to better support SPD. The untapped potentials of RDM in its contribution to SPD could be materialized by returning to the original definition of quality loss (Taguchi, 1986), where losses include harmful side effects caused by products to the environment or the society. In order to do so, it is germane to adopt a life cycle approach when applying the practices and tools of RDM to realize the contribution to SPD (Van Weenen, 1995, Klöpffer, 2003, Baumann and Tillman, 2004). The adoption of life cycle approach in the noise factor identification has been proposed as one adaptation of RDM practices to support SPD, as exemplified in the case of Component. Further adaptations include tools such as Taguchi method and DoE, where it is viable to include environmental requirements as indicators to control or reduce the impacts to the environment, as shown in the cases reviewed in paper IV (Ben-Gal et al., 2008, Carrell et al., 2011, Cetin et al., 2011, Fratila and Caizar, 2011, Besseris, 2012, Hanafi et al., 2012, Camposeco-Negrete, 2013). The adaptations of RDM tools were suggested based on a critical review of these cases, where the environmental impacts were controlled using Taguchi method or DoE specific to a single process or product. The same tools could be adapted to include a number of environmental indicators, for example CO_2 emissions, in order to apply them as DfE or eco-design tools.

In the case of Auto, the integration of environmental requirements in product development was identified by addressing them jointly with quality. The case of Auto exemplifies the integration strategy identified as "organization structures" (Becker and Zirpoli, 2003), and "co-location" (Griffin and Hauser, 1996). Becker and Zirpoli (2003) referred to the example of multifunctional teams in product development for the "organization structures" integration strategy. Griffin and Hauser (1996), on the other hand, referred to the example of relocation of personnel in product development for the "co-location" integration mechanism. The co-organization of the environmental and quality specialists as product development team members reporting to one manager, as practiced at Auto, fits with the description of "organization structures" strategy and "co-location" mechanism. In doing so, some of the challenges of the integration of environmental requirements in product development are addressed (Sroufe et al., 2000). Further, the challenges related to organizational issues such as the control of information flow and management of resources within the product development team (Dangelico and Pujari, 2010) are also addressed. The co-organization of the specialists is found to increase communication and cooperation between team members (Johansson et al., 2007, Lopes Silva et al., 2013, Pigosso et al., 2013). The co-organization effort in the product development also allows for the sharing of QM practices and tools among the specialists, such as FMEA, in supporting SPD through integration of environmental tools and requirements in product development (Kuo et al., 2001, Lindahl, 2006, Vinodh and Rathod, 2010, Bovea and Pérez-Belis, 2012).

The challenges in SPD as described in the comparative case study were further categorized based on the SPD approaches adopted by the organizations. QM practices and tools were found useful in the two approaches to SPD as exemplified by Auto and Electric. It was found that QM practices and tools were applied for the integration of environmental requirements in both cases. However, the challenges faced by the organizations are no longer generic organizational issues as identified in the current literature (Ritzén and Beskow, 2001, Johansson et al., 2007, Lopes Silva et al., 2013). The comparative study showed how challenges differ according to the SPD approaches adopted based on further contextualization such as the type of products manufactured. Deeper understanding regarding the contribution of QM to environmental sustainability could be gained when research is focused on specific SPD adoption at organizations, where QM practices and tools could be adapted according to the approach. In terms of the product context, the required adaptations of QM practices and tools to support environmental sustainability may differ according to the regulations imposed on the products and the awareness of customers, even in industries which are considered mature with regards to environmental sustainability.

5.1 RQ1: How can Quality Management contribute to environmental sustainability?

Over the years, various studies have been conducted in order to establish the potential synergies between QM and sustainable development (Hart, 1995, Garvare and Isaksson, 2001, McAdam and Leonard, 2003, Corbett and Klassen, 2006). The synergies are especially established in the manufacturing industries in the implementation of management systems and in the design and development of products. The use of QM as an approach suitable for the integration of environmental requirements in product development has been argued by many (Klassen and McLaughlin, 1993, Angell and Klassen, 1999, Sarkis, 2001, Johansson, 2002, Calia et al., 2009, Lopes Silva et al., 2013). The literature review of paper I resulted in the identification of four themes where QM is found supportive of sustainable development. One of the themes was described as QM supportive of the integration of sustainability considerations in daily work. This theme was generated based on the reviews of previous research on studies pointing toward the use of QM practices and tools which are supportive of SPD (Sakao, 2004, Besseris, 2012), focused on addressing the environmental requirements of products in the product development. Research on the topic of SPD mainly concerns environmental requirements of products. Therefore, the phrase “sustainability considerations” as used in the description of the theme could be replaced with “environmental requirements”.

The literature review also identifies two themes concerning the support of QM for EMS. One theme discusses the integration of management systems such as QMS and EMS, where an IMS is argued as more efficient in terms of execution through reduction of redundant work concerning the maintenance of one management system instead of two (Karapetrovic, 2002, Karapetrovic and Casadesús, 2009). The other theme discusses the support of QM in the implementation of EMS in organizations, where QM principles, practices and tools are argued to be the foundations for the introduction of environmental management programs (Klassen and McLaughlin, 1993, Giancarlo, 2005, Wiengarten and Pagell, 2012). These two themes are made up of a majority of the literature reviewed, which indicates that a large number of previous studies have been focused on the synergies between QM and the EMS. However, the scope of this thesis is limited to product development, and therefore the investigation of the EMS is not relevant in addressing the purpose.

The final theme generated from the literature review is the support of QM in stakeholder management based on the customer focus principle of QM (Garvare and Isaksson, 2001, Klefsjö et al., 2008). In previous research under this theme, it was argued that by expanding the narrow view of customer focus from a single customer to encompass other stakeholders, QM can be supportive of sustainable development. Expanding the view of customer focus is also identified in the conceptual study of paper IV, where the definition of quality loss (Taguchi, 1986) was discussed. Within QM, focusing on customers has invariably been a strong foothold for continuous improvement, where organizations strive to understand existing and future customer needs and wants in order to improve the product offering and its quality to increase customer satisfaction and loyalty. According to Taguchi (1986), in his argument for robust design to manage variations in product performance, products cause losses to society after being shipped from the manufacturers. This prevalent definition of quality loss is found aligned with the expansion of the customer focus view to include other stakeholders such as policymakers, environmental bodies, and the society. When engineers and product designers begin considering these stakeholders, the requirements of a product also expands to include environmental requirements, for example, in addition to quality and other traditional product requirements, such as cost and time to market.

The broadening of the customer focus view will not be effective if the supporting practices and tools are not adapted to include environmental bodies and the society. The voice of customers is made explicit through practices such as focus groups or administering customer satisfaction surveys; this voice should then be accommodated. Similarly, the supportive tools such as QFD are also in need of adaptations to be translated into product specifications and characteristics.

5.2 RQ2: How can product development be organized in order to exploit Quality Management to integrate environmental requirements?

In paper II, the product development team at Auto was studied in the attempt to explore and analyze the joint consideration of quality and environmental requirements in a product development setting. Integration strategies and mechanisms were adapted from Becker and Zirpoli (2003) and Griffin and Hauser (1996) in order to analyze the joint consideration of quality and environmental requirements at Auto. The findings of the paper show that co-organization of the specialists from the areas of quality and environment is one way to address the challenges of integration. Two strategies were found fitting in the case of Auto. The co-organization of the product development team was identified as the "organization structures" strategy as per Becker and Zirpoli (2003), and as the "co-location" mechanism as identified by Griffin and Hauser (1996).

Based on the analysis of the interview data, it was found that co-organization of the specialists allows for the application of shared practices and tools of QM. The product development team members operate on a project basis and acquiesce to the requirements of the products and customers accordingly. Therefore, the principle of customer focus comes into play, where adhering to customer requirements in addition to other stakeholders such as the environmental regulators concerning the strict requirements of the automotive industry, allows the team members to jointly address the requirements in relation to quality and the environment. Auto is also driven by the organizational core values, namely quality, environmental care and safety, where strategies concerning the core values are disseminated from top-down by core value managers in each area. The FMEA is applied widely in the product development activities at Auto. The environmental requirements are used as inputs in the FMEA in order to inculcate them in the development of products.

In addressing RQ2, the findings of paper II provide a few answers. The co-organization of specialists within the product development team, namely in the areas of quality and environment is one way to apply existing QM practices and tools to support the integration of environmental requirements in product development. The findings in paper II also direct practitioners in addressing a number of the organizational challenges in relation to integration strategies such as lack of cooperation and communication among team members.

5.3 RQ3: What are the differences in the challenges when adopting the two different sustainable product development approaches?

In paper III, two cases of Auto and Electric were studied exemplifying the integration of environmental requirements in existing methodologies and the implementation of DfE and LCA. The SPD challenges as identified in current literature (Ritzén and Beskow, 2001, Johansson et al., 2007, Dangelico and Pujari, 2010, Lopes Silva et al., 2013, Pigosso et al., 2013) were used to address this research question. The current, and prevalent, SPD challenges are found to be generic strategic, managerial, and organizational issues. There is a need to further categorize the SPD challenges according to contexts, namely the type of products.

The SPD challenges were found to differ according to the SPD approaches adopted by Auto and Electric. The SPD approach of integrating environmental requirements in existing methodologies, as in the case of Auto, presented challenges which are specific to SPD methodologies and DfE tools, whereas, the approach of implementing DfE and LCA, as in the case of Electric, presented challenges related to strategic, organizational, and managerial issues. These differences were attributed to the type of products, although both organizations belonged to industries which are considered mature in terms of environmental sustainability.

5.4 RQ4: How can Robust Design Methodology contribute to sustainable product development?

In the area of RDM, to understand the losses caused by a product to the society, there is a need to adapt or create new practices that extends beyond the traditional design stage of products. RDM is found to be applicable in all stages of a product life cycle, as exemplified in paper V. In the case of Component, the customer claims dataset was utilized to create a new practice to identify noise factors in various life cycle stages of the product. This practice is an example of how the elements of RDM, such as noise factor identification, and the elements of SPD, such as adopting a life cycle approach, could be combined to explore the potentials of QM to support environmental sustainability. The outcome is twofold. The application of RDM is adapted and extended to enable its contribution to SPD, and the product life cycle perspective is usefully applied for the required adaptations of the practice of noise factor identification.

The analysis of published case studies where the Taguchi method and DoE have been applied to improve the environmental impacts of products and processes indicate that RDM practices and tools contribute to SPD. Further, the needed adaptations of RDM practices and tools have been identified in order to strengthen the usefulness of RDM in facilitating SPD. A new practice of RDM has been proposed in paper V where a life cycle perspective was adopted in the noise factor identification.

6 CONCLUSION

The purpose of this thesis is to explore and identify the adaptations of QM practices and tools to better support environmental sustainability. A specific focus was given to the integration of environmental requirements in product development, and to the adaptations of RDM, as one QM methodology. The findings of this thesis are based on five studies consisting of a literature review, a conceptual study, and three case studies. These studies have provided the answers to the four research questions formulated pertaining to the purpose of this thesis.

Previous research was categorized under four themes where QM is found contributing to environmental sustainability. However, adaptations to existing QM practices and tools were found necessary in order to utilize the full potential of QM in the support toward environmental sustainability. The adaptations included joint consideration of quality and environmental requirements in a product development setting, where the competence specialists were co-organized as a team and QM practices and tools were shared to achieve the integration of environmental requirements in product development. In doing so, a number of current SPD challenges were also addressed, such as the lack of communication and co-operation among team members, and the lack of knowledge sharing. The adaptations of QM practices and tools were shown to apply in both the SPD approaches identified in literature, namely the integration of environmental requirements into existing methodologies, and the implementation of DfE and LCA. However, it was found that the SPD challenges may differ based on the approaches adopted with regards to the type of product due to the extent of the environmental regulations imposed and the level of environmental awareness of customers. The adaptations of RDM in order to further support SPD was identified in the broadening of the customer focus view from a single user to the society in general. Therefore, there is a need to adopt a life cycle approach in the application of RDM such as noise factor identification. Further, tools such as DoE and Taguchi method could be further adapted by focusing on multiple responses, one being the environmental requirements.

The conclusion of this thesis hereby points to two main areas. The first is that the adaptations of QM practices and tools, for example sharing of tools such as FMEA in a co-organized product development competences of quality and environmental care, are useful in addressing a number of the organizational barriers contributing to the lack of integration of environmental requirements in product development. The second area points to the needed adaptations of RDM practices and tools in order to facilitate SPD. The contribution, in doing so, included expansion of the current applications of RDM by adopting a life cycle approach to noise factor identification, and an addition to the list of DfE tools supporting SPD.

7 FUTURE DIRECTIONS

The contribution of QM to environmental sustainability has been highlighted in the past decade. However, various contributions were highlighted conceptually, with most studies pointing toward a single application of the standard tool, as is, on a specific product. Further, the connection between such an application and the way the product development is organized, for example, is not explored. Another example is the application of multiple QM tools such as QFD, FMEA, RDM, and SPC for the integration of environmental requirements within a single setting of an organization and a variety of products and processes. Generally, there is a lack of empirical investigations into the application of QM principles, practices and tools and its contribution to environmental sustainability. There is also a need to further explore the stakeholder perspective on the adaptations of customer focus view to include more than a single user through empirical studies. Regarding the implementations of EMS and IMS, future research should be more focused on establishing links to business processes and the impact on business performance. At the current state, studies on EMS are mainly conceptual. In order to further understand the impact of an integrated system, more studies are required focusing on the links and impacts of such systems on process and product levels.

The integration of environmental requirements in product development is needed at all levels of organizations. Previous research focused on establishing environmental sustainability strategies in relation to organizational performances and financial outcome. However, in order to address the operational challenges downstream, there is a need to further study the dissemination of environmental strategies. For example, empirical investigations on the translation of environmental strategies to product requirements at product development, and process requirements at manufacturing are required. Further, the focus of this thesis has been partly on RDM and at the product development level, whereas environmental requirements play an important role at downstream processes as well. In addition, it will also be useful to further explore other strategies that could be applied in the integration of environmental requirements in product development and manufacturing. This will address various challenges that accompany integration efforts at the operational levels.

In the application of RDM, the contribution to SPD could be further enhanced by exploring the multi-criteria approach where environmental requirements are used along with traditional requirements, such as product functional and engineering parameters. Previous research in this area is not extensive, and only focuses on reducing the environmental impacts of selected products or processes. The multi-criteria approach is also useful in understanding the necessary trade-offs that could be made between environmental and traditional requirements. For example, for an optimal outcome of a product or process, various parameters are controlled based on a high or low levels. These experiments could be useful in understanding the effects one parameter has on the other, where opportunities to identify trade-offs are available in addition to further exploration on controlling the impacts on the environment. The life cycle perspective is a critical area that needs further exploration, not only in research within SPD, but also in the area of research on the contribution of QM practices and tools. Traditionally, QM practices and tools are applied specifically to single processes or stages of products, for example design or manufacturing. In order to further exploit the effect of a process downstream, it is important to adopt the life cycle perspective on the application of these practices and tools.

8 REFERENCES

Ahmed, N. U. (2001), "Incorporating environmental concerns into TQM", *Production and Inventory Management Journal,* Vol. 42**,** No. 1, pp. 25-30.

Anastas, P. T. & Zimmerman, J. B. (2003), "Design through the 12 principles of green engineering", *Engineering Management Review, IEEE,* Vol. 35**,** No. 3, pp. 95-101.

Anderson, J. C. & Rungtusanatham, M. (1994), "A theory of quality management underlying the Deming management method", *Academy of Management Review,* Vol. 19**,** No. 3, pp. 472-509.

Anderson, J. C., Rungtusanatham, M. & Schroeder, R. G. (1994), "A theory of quality management underlying the Deming management method", *Academy of Management Review,* Vol. 19**,** No. 3, pp. 472-509.

Andersson, P. (1996), "A semi-analytic approach to robust design in the conceptual design phase", *Research in Engineering Design,* Vol. 8**,** No. 4, pp. 229-239.

Angell, L. C. & Klassen, R. D. (1999), "Integrating environmental issues into the mainstream: an agenda for research in operations management", *Journal of Operations Management,* Vol. 17**,** No. 5, pp. 575-598.

Arvidsson, M. & Gremyr, I. (2008), "Principles of Robust Design Methodology", *Quality and Reliability Engineering International,* Vol. 24**,** No. 1, pp. 23-35.

Azapagic, A., Millington, A. & Collett, A. (2006), "A methodology for integrating sustainability considerations into process design", *Chemical Engineering Research and Design,* Vol. 84**,** No. 6, pp. 439-452.

Barbier, E. B. (1987), "The concept of sustainable economic development", *Environmental Conservation,* Vol. 14, No. 02, pp. 101-110.

Barratt, M., Choi, T. Y. & Li, M. (2011), "Qualitative case studies in operations management: Trends, research outcomes, and future research implications", *Journal of Operations Management,* Vol. 29**,** No. 4, pp. 329-342.

Baumann, H., Boons, F. & Bragd, A. (2002), "Mapping the green product development field: engineering, policy and business perspectives", *Journal of Cleaner Production,* Vol. 10**,** No. 5, pp. 409-425.

Baumann, H. & Tillman, A.-M. (2004), *The Hitch Hiker's Guide to LCA - An orientation in life cycle assessment methodology and application,* U.S.A., Studentlitteratur.

Becker, M. C. & Zirpoli, F. (2003), "Organizing new product development: Knowledge hollowing-out and knowledge integration - the FIAT auto case", *International Journal of Operations & Production Management,* Vol. 23**,** No. 9, pp. 1033-1061.

Ben-Gal, I., Katz, R. & Bukchin, Y. (2008), "Robust eco-design: A new application for air quality engineering", *IIE Transactions,* Vol. 40**,** No. 10, pp. 907-918.

Benbasat, I., et al. (1987), "The case research strategy in studies of information systems", *MIS Quarterly,* September 1987, pp. 369-386.

Bendell, T. (1989), *Taguchi Methods,* England, Elsevier Science Publishers Ltd.

Berchicci, L. & Bodewes, W. (2005), "Bridging environmental issues with new product development", *Business Strategy and the Environment,* Vol. 14**,** No. 5, pp. 272-285.

Bergenwall, A. L., Chen, C. & White, R. E. (2012), "TPS's process design in American automotive plants and its effects on the triple bottom line and sustainability", *International Journal of Production Economics,* Vol. 140**,** No. 1, pp. 374-384.

Bergman, B. & Klefsjö, B. (2010), *Quality from customer needs to customer satisfaction,* 3rd. Lund, Studentlitteratur.

Bessant, J. & Caffyn, S. (1997), "High-involvement innovation through continuous improvement", *International Journal of Technology Management,* Vol. 14**,** No. 1, pp. 7-28.

Bessant, J. & Francis, D. (1999), "Developing strategic continuous improvement capability", *International Journal of Operations & Production Management,* Vol. 19**,** No. 11, pp. 1106-1119.

Besseris, G. J. (2010), "A methodology for product reliability enhancement via saturated–unreplicated fractional factorial designs", *Reliability Engineering & System Safety,* Vol. 95**,** No. 7, pp. 742-749.

Besseris, G. J. (2012), "Eco-design in total environmental quality management: Design for environment in milk-products industry", *The TQM Journal,* Vol. 24**,** No. 1, pp. 47-58.

Beyer, H.-G. & Sendhoff, B. (2007), "Robust optimization – A comprehensive survey", *Computer Methods in Applied Mechanics and Engineering,* Vol. 196**,** No. 33-34, pp. 3190-3218.

Bhamra, T. (2004), "Ecodesign: the search for new strategies in product development", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* Vol. 218**,** No. 5, pp. 557-569.

Bice, A. E., Block, M. R., Caillibot, P. & Cascio, J. (1999), "What they're saying about standards", *Quality Progress,* Vol. 32**,** No. 7, pp. 28.

Birch, A., Hon, K. & Short, T. (2012), "Structure and output mechanisms in Design for Environment (DfE) tools", *Journal of Cleaner Production,* Vol. 35**,** pp. 50-58.

Boks, C. (2006), "The soft side of ecodesign", *Journal of Cleaner Production,* Vol. 14**,** No. 15, pp. 1346-1356.

Boks, C. & Tempelman, E. (1998), "Future disassembly and recycling technology: Results of a Delphi study", *Futures,* Vol. 30**,** No. 5, pp. 425-442.

Borri, F. & Boccaletti, G. (1995), "From total quality management to total quality environmental management", *The TQM Magazine,* Vol. 7**,** No. 5, pp. 38-42.

Bovea, M. D. & Pérez-Belis, V. (2012), "A taxonomy of ecodesign tools for integrating environmental requirements into the product design process", *Journal of Cleaner Production,* Vol. 20**,** No. 1, pp. 61-71.

Bras, B. (1997), "Incorporating environmental issues in product design and realization", *Industry and Environment,* Vol. 20**,** No. 1, pp. 7-13.

Brones, F., de Carvalho, M. M. & de Senzi Zancul, E. (2014), "Ecodesign in project management: a missing link for the integration of sustainability in product development?", *Journal of Cleaner Production,* Vol. 80**,** pp. 106-118.

Brundtland, G. H. (1987), *Our Common Future,* New York, Oxford University Press.

Burke, J. (1997), "Examining the validity structure of qualitative research", *Education,* Vol. 118**,** No. 2, pp. 282-293.

Buysse, K. & Verbeke, A. (2003), "Proactive environmental strategies: a stakeholder management perspective", *Strategic Management Journal,* Vol. 24**,** No. 5, pp. 453-470.

Byggeth, S. & Hochschorner, E. (2006), "Handling trade-offs in ecodesign tools for sustainable product development and procurement", *Journal of Cleaner Production,* Vol. 14**,** No. 15-16, pp. 1420-1430.

Cabello, A., Flores, K., Flores, M., Khan, M. & Al-Ashaab, A. An analysis of methods to achieve robustness towards a lean product development process. 18th International Conference on Engineering, Technology and Innovation (ICE), 2012. IEEE, 1-10.

Calia, R. C., Guerrini, F. M. & de Castro, M. (2009), "The impact of Six Sigma in the performance of a pollution prevention program", *Journal of Cleaner Production,* Vol. 17**,** No. 15, pp. 1303-1310.

Camposeco-Negrete, C. (2013), "Optimization of cutting parameters for minimizing energy consumption in turning of AISI 6061 T6 using Taguchi methodology and ANOVA", *Journal of Cleaner Production,* Vol. 53**,** pp. 195-203.

Carrell, J., Tate, D., Wang, S. & Zhang, H. C. (2011), "Shape memory polymer snap-fits for active disassembly", *Journal of Cleaner Production,* Vol. 19**,** No. 17, pp. 2066-2074.

Cetin, M. H., Ozcelik, B., Kuram, E. & Demirbas, E. (2011), "Evaluation of vegetable based cutting fluids with extreme pressure and cutting parameters in turning of AISI 304L by Taguchi method", *Journal of Cleaner Production,* Vol. 19**,** No. 17, pp. 2049-2056.

Chapman, R. & Hyland, P. (2000), "Strategy and continuous improvement in small-to-medium Australian manufacturers", *Integrated Manufacturing Systems,* Vol. 11**,** No. 3, pp. 171-179.

Chiodo, J. D. & Boks, C. (2002), "Assessment of end-of-life strategies with active disassembly using smart materials", *The Journal of Sustainable Product Design,* Vol. 2**,** No. 1-2, pp. 69-82.

Choi, J., Nies, L. & Ramani, K. (2008), "A framework for the integration of environmental and business aspects toward sustainable product development", *Journal of Engineering Design,* Vol. 19**,** No. 5, pp. 431-446.

Clausing, D. (1994), "Total Quality Development: A Step-By-Step Guide to World Class Concurrent Engineering", *American Society of Mechanical Engineers, Cambridge Massachusetts,* ASME Press, New York.

Corbett, C. J. & Klassen, R. D. (2006), "Extending the horizons: environmental excellence as key to improving operations", *Manufacturing & Service Operations Management,* Vol. 8**,** No. 1, pp. 5-22.

Corbett, L. M. & Cutler, D. J. (2000), “Environmental management systems in the New Zealand plastics industry”, *International Journal of Operations & Production Management,* Vol. 20**,** No. 2, pp. 204-224.
Curkovic, S., Melnyk, S., Handfield, R. B. & Calantone, R. (2000), “Investigating the linkage between total quality management and environmentally responsible manufacturing”, *Engineering Management, IEEE Transactions on,* Vol. 47**,** No. 4, pp. 444-464.
Daly, H. E. (1990), “Toward some operational principles of sustainable development”, *Ecological Economics,* Vol. 2**,** No. 1, pp. 1-6.
Dangelico, R. M. & Pujari, D. (2010), “Mainstreaming green product innovation: why and how companies integrate environmental sustainability”, *Journal of Business Ethics,* Vol. 95**,** No. 3, pp. 471-486.
Davis, T. P. (2006), “Science, engineering, and statistics”, *Applied Stochastic Models in Business and Industry,* Vol. 22**,** No. 5-6, pp. 401-430.
De Bakker, F. G., Fisscher, O. A. & Brack, A. J. (2002), “Organizing product-oriented environmental management from a firm’s perspective”, *Journal of Cleaner Production,* Vol. 10**,** No. 5, pp. 455-464.
De Mast, J. & Trip, A. (2007), “Exploratory data analysis in quality-improvement projects”, *Journal of Quality Technology,* Vol. 39**,** No. 4, pp. 301-311.
Dean Jr, J. W. & Bowen, D. E. (1994), “Management theory and total quality: Improving research and practice through theory development”, *Academy of Management Review,* Vol. 19**,** No. 3, pp. 392-418.
Delmas, M. & Toffel, M. W. (2004), “Stakeholders and environmental management practices: an institutional framework”, *Business Strategy and the Environment,* Vol. 13**,** No. 4, pp. 209-222.
Dreyer, L., et al. (2006), “A framework for social life cycle impact assessment (10 pp)”, *The International Journal of Life Cycle Assessment,* Vol. 11, No. 2, pp. 88-97.
Eisenhardt, K. M. (1989), “Building theories from case study research”, *Academy of Management Review,* Vol. 14**,** No. 4, pp. 532-550.
Fiksel, J. (2009), *Design for environment: a guide to sustainable product development*, New York, McGraw-Hill Professional.
Fiksel, J. (2011), *Design for Environment, Second Edition*, New York, McGraw-Hill.
Fischer, M. A., Waugh, L. M. & Axworthy, A. (1998), “IT support of single project, multi-project and industry-wide integration”, *Computers in Industry,* Vol. 35**,** No. 1, pp. 31-45.
Flick, U. (2009), *An Introduction to Qualitative Research,* Fourth Edition, London, Sage Publications Ltd.
Flynn, B. B., Schroeder, R. G. & Sakakibara, S. (1994), “A framework for quality management research and an associated measurement instrument”, *Journal of Operations Management,* Vol. 11**,** No. 4, pp. 339-366.
Fowler, S. J. & Hope, C. (2007), “Incorporating sustainable business practices into company strategy”, *Business Strategy and the Environment,* Vol. 16**,** No. 1, pp. 26-38.
Fratila, D. & Caizar, C. (2011), “Application of Taguchi method to selection of optimal lubrication and cutting conditions in face milling of AlMg3”, *Journal of Cleaner Production,* Vol. 19**,** No. 6-7, pp. 640-645.
Garvare, R. & Isaksson, R. (2001), “Sustainable development: Extending the scope of business excellence models”, *Measuring Business Excellence,* Vol. 5**,** No. 3, pp. 11-15.
Gehin, A., Zwolinski, P. & Brissaud, D. (2008), “A tool to implement sustainable end-of-life strategies in the product development phase”, *Journal of Cleaner Production,* Vol. 16**,** No. 5, pp. 566-576.
Giancarlo, B. (2005), “Matching “environmental performance” and “quality performance” A new competitive business strategy through global efficiency improvement”, *The TQM Magazine,* Vol. 17**,** No. 6, pp. 497-508.
Gmelin, H. and S. Seuring (2014), “Achieving sustainable new product development by integrating product life-cycle management capabilities”, *International Journal of Production Economics,* Vol. 154, pp. 166-177.
Gmelin, H. and S. Seuring (2014), “Determinants of a sustainable new product development”, *Journal of Cleaner Production*, Vol. 69, pp. 1-9.

Goh, T. (2002), “The role of statistical design of experiments in Six Sigma: Perspectives of a practitioner”, *Quality Engineering,* Vol. 14**,** No. 4, pp. 659-671.

Goodland, R. (1995), “The concept of environmental sustainability”, *Annual Review of Ecology and Systematics,* Vol. 26**,** pp. 1-24.

Gremyr, I., Siva, V., Raharjo, H. & Goh, T. N. (2014), “Adapting the Robust Design Methodology to support sustainable product development”, *Journal of Cleaner Production,* Vol. 79**,** pp. 231-238.

Griese, H., Stobbe, L., Reichl, H. & Stevels, A. Eco-design and beyond - Key requirements for a global Sustainable Development. 2005. IEEE, 37-41.

Griffin, A. & Hauser, J. R. (1993), “The voice of the customer”, *Marketing Science,* Vol. 12**,** No. 1, pp. 1-27.

Griffin, A. & Hauser, J. R. (1996), “Integrating R&D and marketing: a review and analysis of the literature”, *Journal of Product Innovation Management,* Vol. 13**,** No. 3, pp. 191-215.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N. & Noble, I. (2013), “Policy: Sustainable development goals for people and planet”, *Nature,* Vol. 495**,** No. 7441, pp. 305-307.

Gu, P., Lu, B. & Spiewak, S. (2004), “A new approach for robust design of mechanical systems”, *CIRP Annals-Manufacturing Technology,* Vol. 53**,** No. 1, pp. 129-133.

Gupta, M. C. (1995), “Environmental management and its impact on the operations function”, *International Journal of Operations & Production Management,* Vol. 15**,** No. 8, pp. 34-51.

Hanafi, I., Khamlichi, A., Cabrera, F. M., Almansa, E. & Jabbouri, A. (2012), “Optimization of cutting conditions for sustainable machining of PEEK-CF30 using TiN tools”, *Journal of Cleaner Production,* Vol. 33**,** pp. 1-9.

Hanssen, O. (1999), “Sustainable product systems—experiences based on case projects in sustainable product development”, *Journal of Cleaner Production,* Vol. 7**,** No. 1, pp. 27-41.

Hart, S. L. (1995), “A natural-resource-based view of the firm”, *Academy of Management Review,* Vol. 20**,** No. 4, pp. 986-1014.

Hart, S. L. & Ahuja, G. (1996), “Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance”, *Business Strategy and the Environment,* Vol. 5**,** No. 1, pp. 30-37.

Hart, S. L. & Dowell, G. (2011), “Invited editorial: A natural-resource-based view of the firm fifteen years after”, *Journal of Management,* Vol. 37**,** No. 5, pp. 1464-1479.

Hartmann, J. & Germain, R. (2015), “Understanding the relationships of integration capabilities, ecological product design, and manufacturing performance”, *Journal of Cleaner Production,* Vol. 92**,** pp. 196-205.

Hasenkamp, T. 2009. *Designing for robustness.* PhD Doctoral Chalmers University of Technology.

Hasenkamp, T., Arvidsson, M. & Gremyr, I. (2009), “A review of practices for robust design methodology”, *Journal of Engineering Design,* Vol. 20**,** No. 6, pp. 645-657.

Hatcher, G., Ijomah, W. & Windmill, J. (2014), “A network model to assist ‘design for remanufacture’integration into the design process”, *Journal of Cleaner Production,* Vol. 64**,** pp. 244-253.

Hauschild, M. Z., Jeswiet, J. & Alting, L. (2004), “Design for environment—do we get the focus right?”, *CIRP Annals-Manufacturing Technology,* Vol. 53**,** No. 1, pp. 1-4.

Hetterich, J., Bonnemeier, S., Pritzke, M. & Georgiadis, A. (2012), “Ecological sustainability–a customer requirement? Evidence from the automotive industry”, *Journal of Environmental Planning and Management,* Vol. 55**,** No. 9, pp. 1111-1133.

Ilzarbe, L., Álvarez, M. J., Viles, E. & Tanco, M. (2008), “Practical applications of design of experiments in the field of engineering: a bibliographical review”, *Quality and Reliability Engineering International,* Vol. 24**,** No. 4, pp. 417-428.

Isaksson, R. (2005), “Economic sustainability and the cost of poor quality", *Corporate Social Responsibility and Environmental Management,* Vol. 12, No. 4, pp. 197-209.

Isaksson, R. (2006), “Total quality management for sustainable development: Process based system models”, *Business Process Management Journal,* Vol. 12**,** No. 5, pp. 632-645.

Jayal, A., Badurdeen, F., Dillon, O. & Jawahir, I. (2010), “Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels”, *CIRP Journal of Manufacturing Science and Technology,* Vol. 2**,** No. 3, pp. 144-152.

Johannesson, P., Bergman, B., Svensson, T., Arvidsson, M., Lönnqvist, Å., Barone, S. & Maré, J. (2013), "A robustness approach to reliability", *Quality and Reliability Engineering International,* Vol. 29**,** No. 1, pp. 17-32.

Johansson, G. (2002), "Success factors for integration of ecodesign in product development: a review of state of the art", *Environmental Management and Health,* Vol. 13**,** No. 1, pp. 98-107.

Johansson, G., Greif, A. & Fleischer, G. (2007), "Managing the design/environment interface: studies of integration mechanisms", *International Journal of Production Research,* Vol. 45**,** No. 18-19, pp. 4041-4055.

Johansson, P., Chakhunashvili, A., Barone, S. & Bergman, B. (2006), "Variation mode and effect analysis: A practical tool for quality improvement", *Quality and Reliability Engineering International,* Vol. 22**,** No. 8, pp. 865-876.

Jørgensen, T. H., Remmen, A. & Mellado, M. D. (2006), "Integrated management systems–three different levels of integration", *Journal of Cleaner Production,* Vol. 14**,** No. 8, pp. 713-722.

Kackar, R. N. (1989), *Off-line quality control, parameter design, and the Taguchi method,* Edited by Dehnad, K., California, Wadsworth & Brooks/Cole.

Kaebernick, H., Kara, S. & Sun, M. (2003), "Sustainable product development and manufacturing by considering environmental requirements", *Robotics and Computer-Integrated Manufacturing,* Vol. 19**,** No. 6, pp. 461-468.

Karapetrovic, S. (2002), "Strategies for the integration of management systems and standards", *The TQM Magazine,* Vol. 14**,** No. 1, pp. 61-67.

Karapetrovic, S. & Casadesús, M. (2009), "Implementing environmental with other standardized management systems: scope, sequence, time and integration", *Journal of Cleaner Production,* Vol. 17**,** No. 5, pp. 533-540.

Karlsson, C. (2008), *Researching operations management,* New York, Routledge.

Karlsson, R. & Luttropp, C. (2006), "EcoDesign: what's happening? An overview of the subject area of EcoDesign and of the papers in this special issue", *Journal of Cleaner Production,* Vol. 14**,** No. 15, pp. 1291-1298.

King, A. A. & Lenox, M. J. (2001), "Lean and green? An empirical examination of the relationship between lean production and environmental performance", *Production and Operations Management,* Vol. 10**,** No. 3, pp. 244-256.

Klassen, R. D. & McLaughlin, C. P. (1993), "TQM and environmental excellence in manufacturing", *Industrial Management & Data Systems,* Vol. 93**,** No. 6, pp. 14-22.

Klefsjö, B., Bergquist, B. & Garvare, R. (2008), "Quality management and business excellence, customers and stakeholders: Do we agree on what we are talking about, and does it matter?", *The TQM Journal,* Vol. 20**,** No. 2, pp. 120-129.

Kleindorfer, P. R., Singhal, K. & Wassenhove, L. N. (2005), "Sustainable operations management", *Production and Operations Management,* Vol. 14**,** No. 4, pp. 482-492.

Klöpffer, W. (1997), "Life cycle assessment", *Environmental Science and Pollution Research,* Vol. 4**,** No. 4, pp. 223-228.

Klöpffer, W. (2003), "Life-cycle based methods for sustainable product development", *The International Journal of Life Cycle Assessment,* Vol. 8**,** No. 3, pp. 157-159.

Knight, P. & Jenkins, J. O. (2009), "Adopting and applying eco-design techniques: a practitioners perspective", *Journal of Cleaner Production,* Vol. 17**,** No. 5, pp. 549-558.

Kota, S. & Chakrabarti, A. Use of DfE methodologies and tools–major barriers and challenges. International Conference On Engineering Design, 2007, Paris, France.

Kovach, J. & Cho, B. R. (2006), "A D-optimal design approach to robust design under constraints: a new design for Six Sigma tool", *International Journal of Six Sigma and Competitive Advantage,* Vol. 2**,** No. 4, pp. 389-403.

Kuei, C.-h. & Lu, M. H. (2013), "Integrating quality management principles into sustainability management", *Total Quality Management & Business Excellence,* Vol. 24**,** No. 1-2, pp. 62-78.

Kuo, T.-C., Huang, S. H. & Zhang, H.-C. (2001), "Design for manufacture and design for 'X': concepts, applications, and perspectives", *Computers & Industrial Engineering,* Vol. 41**,** No. 3, pp. 241-260.

Kurk, F. & Eagan, P. (2008), "The value of adding design-for-the-environment to pollution prevention assistance options", *Journal of Cleaner Production,* Vol. 16**,** No. 6, pp. 722-726.

Lee, S. B. & Park, C. (2006), "Development of robust design optimization using incomplete data", *Computers & Industrial Engineering,* Vol. 50**,** No. 3, pp. 345-356.
Lengnick-Hall, C. A. (1996), "Customer contributions to quality: A different view of the customer-oriented firm", *Academy of Management Review,* Vol. 21**,** No. 3, pp. 791-824.
Leonard-Barton, D. (1990), "A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites", *Organization Science,* Vol. 1**,** No. 3, pp. 248-266.
Lindahl, M. (2006), "Engineering designers' experience of design for environment methods and tools–Requirement definitions from an interview study", *Journal of Cleaner Production,* Vol. 14**,** No. 5, pp. 487-496.
Linton, J. (1999), "Electronic products at their end-of-life: options and obstacles", *Journal of Electronics Manufacturing,* Vol. 9**,** No. 01, pp. 29-40.
Ljungberg, L. Y. (2007), "Materials selection and design for development of sustainable products", *Materials & Design,* Vol. 28**,** No. 2, pp. 466-479.
Lofthouse, V. (2006), "Ecodesign tools for designers: defining the requirements", *Journal of Cleaner Production,* Vol. 14**,** No. 15, pp. 1386-1395.
Lopes Silva, D. A., Delai, I., de Castro, M. A. S. & Ometto, A. R. (2013), "Quality tools applied to Cleaner Production programs: a first approach toward a new methodology", *Journal of Cleaner Production,* Vol. 47**,** pp. 174-187.
Lubin, D. A. & Esty, D. C. (2010), "The sustainability imperative", *Harvard Business Review,* Vol. 88**,** No. 5, pp. 42-50.
Luttropp, C. & Lagerstedt, J. (2006), "EcoDesign and The Ten Golden Rules: Generic advice for merging environmental aspects into product development", *Journal of Cleaner Production,* Vol. 14**,** No. 15-16, pp. 1396-1408.
MacInnis, D. J. (2011), "A Framework for Conceptual Contributions in Marketing", *Journal of Marketing,* Vol. 75**,** No. 4, pp. 136-154.
Martinez-Lorente, A. R., Dewhurst, F. & Dale, B. G. (1998), "Total quality management: Origins and evolution of the term", *The TQM Magazine,* Vol. 10**,** No. 5, pp. 378-386.
Masui, K., Sakao, T., Kobayashi, M. & Inaba, A. (2003), "Applying quality function deployment to environmentally conscious design", *International Journal of Quality & Reliability Management,* Vol. 20**,** No. 1, pp. 90-106.
Maxwell, D. & Van der Vorst, R. (2003), "Developing sustainable products and services", *Journal of Cleaner Production,* Vol. 11**,** No. 8, pp. 883-895.
Maxwell, J. A. (1992), "Understanding and Validity in Qualitative Research", *Harvard Educational Review,* Vol. 62, No. 3, pp. 279-300.
Maxwell, J. A. (2005), *Qualitative Research Design: An interactive approach*, California, Sage Publications, Inc.
McAdam, R. & Leonard, D. (2003), "Corporate social responsibility in a total quality management context: Opportunities for sustainable growth", *Corporate Governance,* Vol. 3**,** No. 4, pp. 36-45.
Meredith, J. (1993), "Theory building through conceptual methods", *International Journal of Operations & Production Management,* Vol. 13**,** No. 5, pp. 3-11.
Miles, M. P. & Russell, G. R. (1997), "ISO 14000 total quality environmental management: the integration of environmental marketing, total quality management, and corporate environmental policy", *Journal of Quality Management,* Vol. 2**,** No. 1, pp. 151-168.
Miller, W. J. (1996), "A working definition for total quality management (TQM) researchers", *Journal of Quality Management,* Vol. 1**,** No. 2, pp. 149-159.
Montgomery, D. C. (1999), "Experimental design for product and process design and development", *Journal of the Royal Statistical Society: Series D (The Statistician),* Vol. 48**,** No. 2, pp. 159-177.
Nidumolu, R., Prahalad, C. K. & Rangaswami, M. (2009), "Why sustainability is now the key driver of innovation", *Harvard Business Review,* Vol. 87**,** No. 9, pp. 56-64.
Nielsen, P. H. & Wenzel, H. (2002), "Integration of environmental aspects in product development: a stepwise procedure based on quantitative life cycle assessment", *Journal of Cleaner Production,* Vol. 10**,** No. 3, pp. 247-257.
Paramanathan, S., Farrukh, C., Phaal, R. & Probert, D. (2004), "Implementing industrial sustainability: The research issues in technology management", *R&D Management,* Vol. 34**,** No. 5, pp. 527-537.

Phadke, M. S. (1989), *Quality Engineering using Robust Design*, New Jersey, USA, PTR Prentice-Hall Inc.
Pigosso, D. C., Rozenfeld, H. & McAloone, T. C. (2013), “Ecodesign maturity model: a management framework to support ecodesign implementation into manufacturing companies”, *Journal of Cleaner Production,* Vol. 59**,** pp. 160-173.
Porter, M. E. & Van der Linde, C. (1995), “Green and competitive: ending the stalemate”, *Harvard Business Review,* Vol. 73**,** No. 5, pp. 120-134.
Powell, T. C. (1995), “Total quality management as competitive advantage: A review and empirical study”, *Strategic Management Journal,* Vol. 16**,** No. 1, pp. 15-37.
Pujari, D. (2006), “Eco-innovation and new product development: Understanding the influences on market performance”, *Technovation,* Vol. 26**,** No. 1, pp. 76-85.
Pujari, D., Peattie, K. & Wright, G. (2004), “Organizational antecedents of environmental responsiveness in industrial new product development”, *Industrial Marketing Management,* Vol. 33**,** No. 5, pp. 381-391.
Pujari, D., Wright, G. & Peattie, K. (2003), “Green and competitive: influences on environmental new product development performance”, *Journal of Business Research,* Vol. 56**,** No. 8, pp. 657-671.
Richards, L. (1999), “Data alive! The thinking behind NVivo”, *Qualitative Health Research,* Vol. 9**,** No. 3, pp. 412-428.
Ritzén, S. & Beskow, C. (2001), “Actions for integrating environmental aspects into product development”, *The Journal of Sustainable Product Design,* Vol. 1**,** No. 2, pp. 91-102.
Robinson, J. (2004), “Squaring the circle? Some thoughts on the idea of sustainable development”, *Ecological Economics,* Vol. 48**,** No. 4, pp. 369-384.
Roy, R. K. (1990), *A primer on the Taguchi Method*, USA, Van Nostrand Reinhold.
Rusinko, C. A. (2005), “Using quality management as a bridge to environmental sustainability in organizations”, *SAM Advanced Management Journal,* Vol. 70**,** No. 4, pp. 54-60.
Rydberg, T. (1995), “Cleaner products in the Nordic countries based on the life cycle assessment approach: The Swedish product ecology project and the Nordic project for sustainable product development”, *Journal of Cleaner Production,* Vol. 3**,** No. 1, pp. 101-105.
Sakao, T. (2004), “Analysis of the Characteristics of QFDE and LCA for Eco design support”, *Electronic Goes Green 2004.*
Sakao, T. (2009), “Quality engineering for early stage of environmentally conscious design”, *The TQM Journal,* Vol. 21**,** No. 2, pp. 182-193.
Sarkis, J. (1995), “Manufacturing strategy and environmental consciousness”, *Technovation,* Vol. 15**,** No. 2, pp. 79-97.
Sarkis, J. (1998), “Evaluating environmentally conscious business practices”, *European Journal of Operational Research,* Vol. 107**,** No. 1, pp. 159-174.
Sarkis, J. (2001), “Manufacturing’s role in corporate environmental sustainability-Concerns for the new millennium”, *International Journal of Operations & Production Management,* Vol. 21**,** No. 5/6, pp. 666-686.
Sarkis, J., Shaw, S., Grant, D. B. & Mangan, J. (2010), “Developing environmental supply chain performance measures”, *Benchmarking: An International Journal,* Vol. 17**,** No. 3, pp. 320-339.
Senge, P. M., Carstedt, G. & Porter, P. L. (2001), “Next Industrial Revolution”, *MIT Sloan Management Review,* Vol. 42**,** No. 2, pp. 24-38.
Shoemaker, A. C., Tsui, K. L. & Wu, C. F. J. (1991), “Economical experimentation methods for robust design”, *Technometrics,* Vol. 33**,** No. 4, pp. 415-427.
Short, T., Lee-Mortimer, A., Luttropp, C. & Johansson, G. (2012), “Manufacturing, sustainability, ecodesign and risk: lessons learned from a study of Swedish and English companies”, *Journal of Cleaner Production,* Vol. 37**,** pp. 342-352.
Shrivastava, P. (1995), "Environmental technologies and competitive advantage", *Strategic Management Journal,* Vol. 16, No. S1, pp. 183-200.
Shrivastava, P. (1995), “The role of corporations in achieving ecological sustainability”, *Academy of Management Review,* Vol. 20**,** No. 4, pp. 936-960.
Sousa, R. & Voss, C. A. (2002), “Quality management re-visited: a reflective review and agenda for future research”, *Journal of Operations Management,* Vol. 20**,** No. 1, pp. 91-109.

Sroufe, R., Curkovic, S., Montabon, F. & Melnyk, S. A. (2000), “The new product design process and design for environment: “Crossing the chasm”“, *International Journal of Operations & Production Management,* Vol. 20**,** No. 2, pp. 267-291.
Stuart, I., et al. (2002), "Effective case research in operations management: a process perspective", *Journal of Operations Management*, Vol. 20, No. 5, pp. 419-433.
Sun, J., Han, B., Ekwaro-Osire, S. & Zhang, H.-C. (2003), “Design for environment: methodologies, tools, and implementation”, *Journal of Integrated Design and Process Science,* Vol. 7**,** No. 1, pp. 59-75.
Sutherland, J., Rivera, J., Brown, K., Law, M., Hutchins, M., Jenkins, T. & Haapala, K. 2008. Challenges for the manufacturing enterprise to achieve sustainable development, The 41st CIRP Conference on Manufacturing Systems, 2008, Tokyo, Japan.
Taguchi, G. (1986), *Introduction to Quality Engineering: Designing quality into products and processes*, Tokyo, Asian Productivity Organization.
Taguchi, G., Chowdhury, S. & Taguchi, S. (2000), *Robust Engineering: Learn how to boost quality while reducing costs & time to market,* New York, McGraw-Hill Education.
Taguchi, G. & Clausing, D. (1990), “Robust Quality”, *Harvard Business Review,* Vol. 68**,** No. 1, pp. 65-75.
Taguchi, G. & Wu, Y. (1979), *Introduction to off-line quality control,* Central Japan Quality Control Association.
Theyel, G. (2000), “Management practices for environmental innovation and performance”, *International Journal of Operations & Production Management,* Vol. 20**,** No. 2, pp. 249-266.
Thornton, A. C., Donnelly, S. & Ertan, B. (2000), “More than just robust design: Why product development organizations still contend with variation and its impact on quality”, *Research in Engineering Design,* Vol. 12**,** No. 3, pp. 127-143.
Tukey, J. W. (1962), “The future of data analysis”, *The Annals of Mathematical Statistics,* Vol. 33**,** No. 1, pp. 1-67.
Van Hemel, C. & Cramer, J. (2002), “Barriers and stimuli for ecodesign in SMEs”, *Journal of Cleaner Production,* Vol. 10**,** No. 5, pp. 439-453.
Van Weenen, J. (1995), “Towards Sustainable Product Development”, *Journal of Cleaner Production,* Vol. 3**,** No. 1-2, pp. 95-100.
Vinodh, S. & Rathod, G. (2010), “Integration of ECQFD and LCA for sustainable product design”, *Journal of Cleaner Production,* Vol. 18**,** No. 8, pp. 833-842.
Vogt, W. P., Gardner, D. C. & Haeffele, L. M. (2012), *When to use what research design*, New York, Guilford Press.
von Ahsen, A. & Funck, D. (2001), “Integrated management systems—opportunities and risks for corporate environmental protection”, *Corporate Environmental Strategy,* Vol. 8**,** No. 2, pp. 165-176.
Voss, C., et al. (2002), "Case research in operations management", *International Journal of Operations & Production Management*, Vol. 22, No. 2, pp. 195-219.
Wiengarten, F. & Pagell, M. (2012), “The importance of quality management for the success of environmental management initiatives”, International Journal of Production Economics, Vol. 140, No. 1, pp. 407-415.
Wilkinson, A., Hill, M. & Gollan, P. (2001), “The sustainability debate”, International Journal of Operations & Production Management, Vol. 21, No. 12, pp. 1492-1502.
Wu, D. H. & Chang, M. S. (2004), “Use of Taguchi method to develop a robust design for the magnesium alloy die casting process”, *Materials Science and Engineering: A,* Vol. 379**,** No. 1, pp. 366-371.
Wu, Y. & Wu, A. (2000), *Taguchi methods for robust design*, New York, ASME Press.
Yadav, O. P., Bhamare, S. S. & Rathore, A. (2010), “Reliability-based robust design optimization: A multi-objective framework using hybrid quality loss function”, *Quality and Reliability Engineering International,* Vol. 26**,** No. 1, pp. 27-41.
Yin, R. K. (2009), *Case study research: Design and methods,* Fourth edition. California, Sage Inc.
Zhang, Y., Wang, H. & Zhang, C. (1998), “Product concept evaluation using GQFD-II and AHP”, *International Journal of Environmentally Conscious Design & Manufacturing,* Vol. 7**,** No. 3, pp. 1-15.

Zhou, X. & Schoenung, J. Application of a modified production quality tool for environmental impact assessment of lead-free solders. AICHE Sustainability and Life Cycle Topical Conference, 2003, California, 72-79.