The new product design process and design for environment

"Crossing the chasm"

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Abstract *This paper examines the role played by environmental issues during the new product design process. These issues are studied through an exploratory research project based on case studies of ten companies. The firms studied can be categorized into one of five major groups: innovators, early adopters, early majority, late majority and laggards. These groups strongly parallel the model of new product acceptance initially developed in the computer industry, as presented by Moore (1991). Of interest is the gap that exists between the early adopters and early majority users. This gap forms a chasm. Those factors that account for acceptance of environmentally responsible manufacturing in the innovators and early adopters are significantly different from those factors observed in the early majority, late majority, and laggards. This paper examines these and other differences, and the impact of these differences on the acceptance and use of environmental concerns within the new product design process.*

Introduction

Environmentally responsible manufacturing (ERM) is a relatively new concept that can be viewed as a product of the 1990s. ERM has been defined as an economically-driven, system-wide and integrated approach to the reduction and elimination of all waste streams associated with the design, manufacture, use and/or disposal of products and materials (Handfield *et al.*, 1997). Fundamental to ERM is the recognition that pollution, irrespective of its type and form, is waste. As seen in the concepts of just-in-time (JIT), total quality management (TQM), and time-based competition (TBC), waste is any activity or product which consumes resources or creates costs without generating any form of offsetting value stream (Porter, 1991; Porter and Van der Linde, 1995a, 1995b). The authors posit that firms can minimize waste by changing the way new products are designed. Those firms which include environmental issues in

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the design process have the opportunity to reduce disposal costs and permit requirements, avoid environmental fines, better utilize raw materials, boost profits, discover new business opportunities, rejuvenate employee morale, and improve the state of the environment.

Ideally, the most appropriate place for considering ERM issues is in the design phase since the amount of waste generated is a direct consequence of decisions made during product design (Van Weenen and Eeckles, 1989; Bowman, 1996; Fiskel, 1993, 1996; Melnyk *et al.*, 1996). As it is generally used, the term "design for environment" (DfE) is a component of ERM and involves making environmental considerations an integral part in the design of a product (Allenby, 1993; Coddington, 1993). Most of the research aimed at the development and evaluation of new environmental tools and procedures has been targeted towards the design stage. This emphasis recognizes the importance of DfE to the overall success of pollution reduction and elimination. As has been shown in other studies (e.g. Van Weenen and Eeckles, 1989; Allenby, 1993; Fiskel, 1993, 1996), we now realize that product design, while actually responsible for a relatively small percentage (approx. 5-10 percent) of the total costs, has a significant impact on the actual costs incurred within the system. Fabrycky (1987) estimated that up to 85 percent of life cycle costs are committed by the end of the preliminary design stages. Additionally, Ulrich and Pearson (1993), from a field research study, found that at least 50 percent of the costs for a class of mature products are design-determined and that up to 70 percent of costs are affected by manufacturing process decisions.

When viewed in this light, it is expected that more managers would be interested in the implementation and use of DfE procedures and tools. Managers may also want to look at DfE issues during the redesign or re-engineering of a product or process. Redesign and re-engineering typically occur during the maturity or decline phase of the product life cycle, however the time in which a firm is rethinking a product or process is not the only opportunity for DfE practices. After all, DfE involves the identification and elimination of in-process waste streams before they actually occur. However, for most firms, DfE has not achieved the same degree of acceptance as have JIT, TQM, and TBC (Makower, 1993; Epstein, 1996). Some examples and case studies of successful implementation exist, but these are isolated and limited to a very few companies (Franke and Monroe, 1995; Shelton, 1995). Our research in this area has shown that the level of acceptance of ERM practices and principles remains very uneven. Some firms such as 3M and Dow Chemical have tried to incorporate these concerns into the design process and evaluate product performance not only in terms of costs and profit but also in terms of environmental outcomes. For other firms, DfE remains a constraint – perceived as something that adversely affects the ability of the firm to design and deliver better products to the marketplace.

Given this uneven rate of acceptance and use of ERM-related principles and practices, especially within the design process, there is an opportunity for theory development through the in-depth study of new product design (NPD).

This study examines the factors affecting DfE, and the role played by DfE tools, metrics, and personnel within the new product design process. This study was specifically designed to address the following issues:

- How do ERM concepts influence NPD?
- What types of environment-related product hazards do firms face and does this impact the NPD process?
- When in the design process are environmental issues most evident?
- What ERM metrics, if any, are used in NPD performance?
- What tools are available for firms attempting DfE and ERM?

This study examines these questions using examples from managerial experiences. The focus of this study is not to explore why DfE lacks acceptance. Instead, we attempt to understand what constitutes ERM and look at firms which have adopted design for environment practices under the rubric of ERM and more specifically within the NPD process. The next section reviews the DfE literature and discusses why the usage of DfE has been uneven. Case studies are discussed and a classification model of DfE- and ERM-related practices is presented. The final section summarizes the conclusions and insights from the study.

Literature review

The objective of this study was to construct a sample of firms that would be diverse enough to capture the variance of ERM attributes across firms and products that may be overlooked in a single industry or product sample. To describe the range of responses to DfE, the researchers explored a number of frameworks as summarized in Table I. The evaluation of these competing frameworks revealed that many lacked a categorization schema that represented the types of firms and DfE attributes revealed in our research. Of the empirical studies reviewed, there seemed to be a split between the strategic choice perspective and developmental progression stages. Our research found environmental attributes that lent themselves well to both strategic choice and different stages of development. After this review, it was determined that, at an aggregate level, the Moore (1991) chasm model was the most appropriate because it bridged the gap between the before-mentioned dichotomy in the literature while simultaneously containing relevant attributes of the firms studied in this multi-industry setting. Furthermore, Moore's model was theoretically appropriate for explaining and understanding the observed behavior. Fundamentally, the firms studied very closely paralleled or reflected the same types of categories of firms originally described by Moore's model of new technology adoption. Recognizing that the application of similar frameworks from adjacent bodies of theory is a valid step in grounded theory (Strauss and Corbin, 1990), the chasm model was a theoretical "analogy" that worked.

Table I.
Empirical studies characterizing ERM

	Stages
Strategic choice perspective	
Mahon, J.F. (1983)	(1) avoid/neglect; (2) resistance; (3) accommodative; (4) compromise; and (5) collaborative
Lodgson, J.M. (1985)	(1) resisting; and (2) accepting
Miles, R.T. (1987)	(1) collaborative/problem-solving; and (2) individualistic/adversarial
Scholt, J. (1991)	(1) dependent; (2) defensive; (3) offensive; (4) aware; and (5) adapted
Arnfalk, P. and Thidell, A. (1992)	(1) passive; (2) authority-controlled; (3) law-optimized; (4) aware; and (5) adapted
Dillon, P.S. and Fisher, K. (1992)	(1) good environmental actors; and (2) bad environmental actors
Klassen, R.D. (1995)	(1) reactive; (2) defensive; (3) accommodative; and (4) proactive
Vastag, G., Kerekes, S. and Rondinelli, D.A. (1996)	(1) reactive; (2) proactive; (3) strategic; and (4) crisis preventive
Handfield, R.B., Walton, S.V., Seegers, L.K. and Melnyk, S.A. (1997)	(1) resistance adaptation; (2) embracing w/o innovating; (3) reactive; (4) receptive; (5) constructive and (6) proactive
Development progression perspective	
Petulla, J.M. (1987)	(1) crisis oriented; (2) cost oriented; and (3) enlightened
Arthur, D. Little, Inc. (1989)	(1) problem-solving; (2) managing; and (3) managing for assurance
Hunt, C.B. and Auster, E.R. (1990)	(1) beginner; (2) fire-fighter; (3) concerned citizen; (4) pragmatist; and (5) proactivist
Clarkson, M. (1991)	(1) reactive; (2) defensive; (3) accommodative; and (4) proactive
Marguglio, B.W. (1991)	(1) insensitivity; (2) awareness; (3) enlightenment; and (4) certainty
Moore, G. (1991)	(1) innovators; (2) early adopters; (3) early majority; (4) late majority; (5) laggards
Greening, D.W. (1992)	(1) high involvement; and (2) low involvement
Post, J.E. and Altman, B.W. (1992)	(1) adjustment; (2) adaptation; and (3) innovation
Flannery, B. and May, D.R. (1994)	(1) individual and (2) organizational
Greenberg, R. and Unger, C. (1994)	(1) innocence; (2) awareness; (3) understanding; (4) competence; and (5) excellence
Epstein, M.J. (1996)	(1) corporate environmental leaders – (7) corporate environmental laggard

Moore's model has five categories: innovators, early adopters, early majority, late majority, and laggards (see Figure 1). In Moore's original work, the five categories are used to discuss the acceptance of new technology. This model was chosen because the firms studied could also be categorized into these same types of categories on the basis of environmental categories. Additionally, the categories of firms studied very closely paralleled the categories of firms originally described by Moore (i.e. innovators appear to be more technologically advanced and laggards may actually have to be forced into adopting DfE concepts and practices). Thus, firms were assigned to

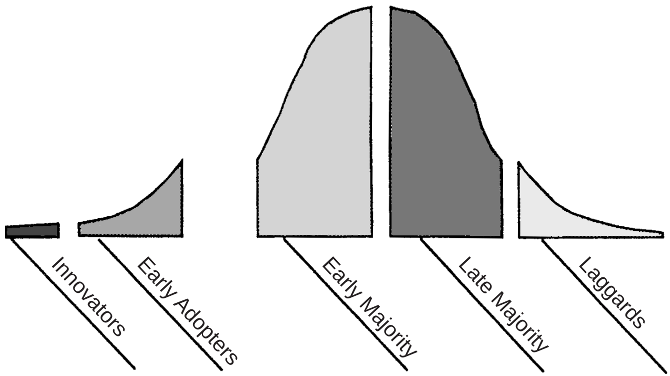

Figure 1.
The chasm model

different chasm categories because they exhibited some of the same characteristics organizations display when seeking to adopt a new technology. With an emphasis on environmental attributes, the researchers also found distinct attributes only present within certain chasm model categories. The attributes include innovators pursuing new environmental technology before the technology has been formally marketed, and laggards only adopting an environmental technology when it is actually buried within a mandated requirement. The application of the Moore categories will be described in greater detail in subsequent sections of this paper. The remainder of the literature review focuses on the concept of design for environment and the new product design process.

Design for environment (DfE)
The concept of DfE originated from industry's effort to target specific environmental objectives for design engineers to incorporate when creating a new product. DfE basically involves the incorporation of environmental considerations into the design and redesign of products, processes, and technical and management systems. The goals of ERM can more easily be achieved when environmental issues are identified and resolved during early stages of product and process design, when changes can be made to reduce or eliminate environmental waste (Allenby, 1993).

To date, few case studies look at methods for achieving DfE goals within manufacturing process techniques (McCormack and Jin, 1995; Sheng *et al.*, 1995). Research on manufacturing processes characterizes waste streams from specific processes (such as machining), and makes assessments of alternative processes. As such, specific DfE models have been developed and made available to practitioners. While it appears that much progress has been made in developing these models, they have not been integrated with one another to create a system that allows for assessment of overall DfE performance and the trade-offs therein. Most of these studies argue that the greatest opportunities for waste minimization exist during the design process. Therefore, product designers need to understand the ERM process and be able to influence "green" process design. Instead, top management neglect, cost and regulatory constraints, the slow corporate decision-making process, and cost rather than engineering-based design evaluations are cited as obstructing environmental issues from being an integral part of product design (Bhat, 1993).

Product design and DFE

The design process is one of the major tasks for any firm, responsible for two major types of design activities: new product design and development, and process design and development. Both product and process designs are closely interrelated and greatly influence each other while simultaneously impacting the environment. Both aspects must be considered to ensure that the firm has developed and implemented effective and efficient designs and processes. These design activities, in general, present opportunities for firms to find solutions to environmental issues (Lozada and Mintu-Wimstatt, 1995). These two design activities, when combined, shape the scope of the transformation process by determining the types of inputs required and outputs created. Inputs involve substitution of lesser hazardous alternatives for previously hazardous materials. Some outputs are desirable (e.g. cars built) while others, such as pollution, are not.

The NPD process embodies all of the steps necessary to take the product from concept to full production. Recently, this process has undergone extensive revision and rethinking (Hall, 1993; Patterson, 1993) due to increased market pressures to reduce the total cycle lead time (from concept to full production), reduce cost, enhance product flexibility and improve product quality (Cohen and Apte, 1997). These pressures are some of the same forces that impact developments such as TQM, JIT, time-based competition (TBC) (Stalk and Hout, 1990; Carter and Melnyk, 1992) and mass customization (Pine, 1993).

To reduce total cycle lead time, managers have turned to the development of processes characterized by the use of multifunctional teams and close interaction of the team members over the period of the initial design. This multifunctional teaming and interaction is also integrative in terms of the breadth of the manufacturing system. Examples can be seen in the consideration of not only issues of design but also issues pertaining to manufacturing planning and execution. This reorganization of the design and delivery process has been referred to by such names as simultaneous engineering and concurrent engineering.

One can envision the NPD (i.e. product/process design and delivery system) as consisting of seven linked stages (Meyer, 1993, pp. 193-228): advanced research, product concept, product specification, product development, pilot product, production, and finally, reincarnation/disposal. In all stages of the NPD process, environmental factors must be considered in addition to all other objectives and issues (Peattie, 1992). Furthermore, one function or group no longer manages each activity in isolation. Rather, there is integration of multiple groups or stakeholders, both internally, with other functions, and externally with stakeholders, customers and suppliers. In the earlier stages of

NPD, meeting the needs of stakeholders "such as regulators" is important. In the later stages of NPD, working with special interest groups and third-party endorsement of products becomes more important (Polonsky and Ottman, 1998; Polonsky *et al*., 1998).

The end of the NPD process creates several important outcomes, such as the design and introduction of the product, the determination of the types and quantities of materials used and various processing characteristics (i.e. equipment needed). When taken together, the product design process sets in place the material and capacity requirements, establishes the cost and performance traits of the product, and determines the types and timing of waste streams created and when these waste streams will be created.

The design activities are strongly cross-functional in nature. That is, to be successful from both a corporate and marketing perspective, the product design activities must consider the perspectives of multiple parties and stakeholders (Polonsky and Ottman, 1998; McDaniel and Rylander, 1993). Included are areas such as marketing, product engineering, finance, manufacturing, production and inventory control, accounting, manufacturing engineering, quality assurance, top management, stockholders, suppliers, government, competitors, special interest groups and the customer.

Additionally, within the design process, there are transition points. For example, there is a transition point between product concept and product design. The transition point's role is to ensure that all of the major concerns, objectives and issues present in the preceding stage have been addressed before permitting the process to continue to the next stage. At these transition points, different factors affect ERM such as formal information systems, the presence of a green corporate culture; and the use of different tools, metrics, and options. During these transition points we can study how firms generate new opportunities from environmental problems. Our approaches to studying the environmental opportunities a firm can generate are qualitative and based on field studies. The next section details the qualitative methods used to conduct this research.

Methodology

The purpose of this study is to identify and categorize firms which have adopted ERM practices and integrated these practices into the NPD process. Since the focus of this research is exploratory in nature, qualitative data collection methods are used to develop an understanding of important ERM issues and variables. The method followed was similar to the grounded theory development methodology suggested by Glaser and Strauss (1967), Miles and Huberman (1994), and Yin (1994).

In instances where a well developed set of theories regarding a particular branch of knowledge does not exist, Eisenhardt (1989) and McCutcheon and Meridith (1993) suggest that theory building can best be done through case study research. Comparative literature reviews of research on environmental management strategies confirm that ERM is at an early stage of development

(Klassen, 1993; Klassen and Whybark, 1995; Porter and Van der Linde, 1995b; Angell and Klassen, 1999). In this stage of theory building, a key objective is to characterize the different types of environmental practices used in new product design.

There are some pitfalls to case study analysis, including lack of simplicity or narrow and idiosyncratic theories (Eisenhardt, 1989). A primary disadvantage of the case research approach is the difficulty in drawing deterministic inferences, and there are limitations in terms of the external validity of the study. These limitations are often addressed by using large samples, or using "before" and "after" quasi-experimental designs (Cook and Campbell, 1979). However, due to the lack of theory building in the area of ERM, it is important to use the case study approach to identify differences in ERM and new product design processes. While causality can never be shown in case studies, analysis of data collected from multiple sites can help support the development of theory and the generalizability of results.

The researchers participating in this project relied primarily on the methods of qualitative data analysis developed by Miles and Huberman (1994), which consist of anticipatory conceptual model development and simultaneous data collection, reduction, display, and conclusions testing. After the above steps were taken, the authors went back to the literature to look for similar frameworks upon which to build. Multiple research sites were used in order to provide a broader taxonomy of new product design and ERM practices.

The sample

Cook and Campbell (1979) suggest that random samples of the same population be used in theory testing research. However, the sample selected for qualitative research such as in this study should be purposeful and based on theoretical underpinnings (Eisenhardt, 1989; Miles and Huberman, 1994). With this in mind, the researchers initially set out to find a purposeful sample of organizations that were at different stages of integration with regard to ERM and new product design. Firms from different ERM stages, industries, products, processes and sizes were selected based on a literature search and general research knowledge of appropriate case study candidates. Table II describes the number of firms involved in the field research, the industry, and the annual sales.

No. of firms	Industry	Annual sales ($)
3	Tier I automotive suppliers	25M–5B
2	Chemical	>15B
2	Office and furniture	>1B
1	Aviation engine components	>33M
1	Windows and doors	>1B
1	OEM speciality trucks	>25M

Table II.
Firms in the sample

Each of the firms selected was chosen to represent a wide spectrum of ERM status. At one end of the spectrum are firms identified in academic and practitioner literature as environmental leaders. The other firms included in the study were chosen because they were in the same industries as the firms found through the literature search. The objective of this sampling approach was to construct a sample of firms that would be diverse enough to capture the variance of ERM attributes across firms and products that may be overlooked in a single industry or product sample.

Similar to much of the research in operations strategy, several industries were chosen for this study. Single industry studies do not provide a strong basis for achieving generalizability. External validity is more easily achieved in cross-industry studies. However, for the industries selected, the types of environmental issues and range of ERM programs used must offer sufficient variability for study.

Klassen (1995) and Logsdon (1985) determined that industries subjected to environmental regulation for many years, such as the steel, paper, pulp, or petroleum industries tend to have very standardized ERM through contact with industry associations. At the other extreme, if regulation is non-existent for an industry, then little variation in ERM is evident because there is often little perceived environmental impact. ERM is not crucial for all types of industries, and some managers will remain inherently skeptical about it (Shelton, 1995). Thus, ideal industries are those in which significant, new environmental regulations are under development or in the early stages of implementation (Logsden, 1985; Klassen, 1995; Shelton, 1995). This state of uncertainty prompts some firms to try and lead the industry with new approaches, while many other firms adopt a "wait and see" approach; therefore, a high degree of variation in ERM is more likely. Chemical companies, automotive tier-one suppliers, furniture manufacturers, and window and door manufacturers met the criteria for offering a range of ERM processes.

An initial idea of the level of ERM understanding and implementation at each potential firm was obtained through preliminary screening over the telephone. Some of the questions used in making our initial assessment can be found in Appendix I. Twelve firms were initially contacted and screened.

After the initial screening, which also assessed the willingness of the company to participate, ten firms were again contacted and site visits arranged. A total of 16 interviews were performed at ten companies. The interviews were conducted with several managers responsible for portions of the company's overall NPD strategy at each site. Some titles of the people interviewed include "manager of:" corporate quality services, supervisor/planning group, plant planner, global director of development, environmental science and assessment, new product group, and design engineering.

The interview protocol

The interview protocol, included in Appendix II, was developed based on the researchers' general understanding of ERM issues facing industry today. The protocol was pre-tested at two manufacturing facilities and then used for the ten firms included in this study. Minor changes were made to the protocol after the pre-test. Questions focused on previous NPD processes, and the transition of these processes, and the roles of the players involved. Interviews were conducted in the respondents' facilities, and discussions focused on the consideration of ERM as an important part of the NPD process, the factors affecting ERM, tools used, metrics, and perceived ERM opportunities.

To avoid responses exhibiting social desirability, different managers were questioned at the two different sessions. The same structured interview protocol was used at all of the site visits. After each visit the protocol was reviewed, and/or updated to accommodate new lessons learned. This constant updating of the protocol after each visit is the foundation of grounded theory development (Glaser and Strauss, 1967). When the sessions involved multiple respondents, all comments or views of the managers were recorded separately. Subsequent coding of the notes would highlight any differing views of the managers.

Data display, coding, and reduction

Eisenhardt (1989) suggested that data collection and data analysis should be done simultaneously. In other words, the data from one case is collected and then analyzed before the next replication is performed. Important issues that are raised in early cases can be included in the protocol for subsequent replications. This ability to refine and improve upon the protocol between cases is a significant advantage of this type of qualitative research.

The two main components of data analysis included within- and across-case analysis. Within-case analysis focused on DfE in a single context, while the across-case analysis served as a replication where the constructs of interest in one setting were tested in other settings (Yin, 1994). One concern was controlling for the affects of the researchers' *a priori* beliefs as to the reasons why DfE was or was not embraced. This was accomplished in a variety of ways. First, the primary researcher wrote up the field notes prior to coding. The secondary researcher, who also went to the site, reviewed these notes. To ensure objectivity, one or more persons not involved in the data gathering were asked to review the notes. Any discrepancies between the primary researcher and the secondary researchers were clarified through follow-up contact with the respondent.

Miles and Huberman (1994) noted the act of coding could lead to confirmation bias problems in future cases. To mitigate confirmation bias, the amount of within-case analysis performed before the cross-case analysis was limited. Therefore, coding for within-case analysis was limited to categorizing the individual case on previously identified constructs and identifying interesting new issues to pursue at future sites. This allowed the researchers to be more open to alternative explanations raised in future replications by avoiding comparisons and model building early in the research.

Following each interview, the field notes were typed. To facilitate data coding and analysis, a meta-matrix display was constructed. This matrix summarized the major findings at each site (Appendix III)[1]. The next step involved coding the data using Nudist(r) qualitative data analysis software.

On reviewing the first six site visit field notes, a list of 146 primary codes was developed to capture information in 19 different meta-environmental categories. The researchers reviewed the transcribed field notes for all 16 of the site visits at least three times. In doing this, the events and processes observed at each site were classified into an ERM category, and into several other complimentary environmental categories, including product and process hazards, factors effecting ERM, metrics, tools, options, and opportunities[2].

Results and discussion

In the following discussion, information from the firms studied is used to describe the acceptance of DfE concepts, and highlight the interesting characteristics of the firms studied. Interestingly, although some firms are considered environmental leaders in their own industries, they did not all end up in the categories the researchers would have posited. While small- to medium-sized firms may have more flexibility to develop programs and address environmental issues quickly, larger firms seemed to be more developed.

The two innovators identified in this study operate in the chemical industry. They pursue new environmental management techniques aggressively because unique environmental resources are central to their manufacturing process. These firms may have adopted ERM because it was right for them given the regulations and business environment they faced. Environmental innovation is considered part of the formal corporate culture. Innovators promote their green culture, market "green labeled" products, and seek new technology for specialized information, pollution prevention, more effective public relations programs, frequent auditing and reporting, and frequent management reviews and policy improvements. These firms develop an integrated and formal DfE process in order to have a unique resource (e.g. management and decision support systems) and specialized information to aid in decision making. They find that enhanced financial performance and competitive advantage can come from the design process. There are not many innovators, but their success is key because their endorsements reassure the other firms that new environmental initiatives do in fact work.

Two firms in our study were categorized as early adopters and included office and furniture, and window and door manufacturers. The early adopters are much like innovators, having bought into new environmental concepts early in the concept's life cycle but, unlike innovators, their corporate culture does not emphasize environmentalism. Rather, they are firms who find it easy to conceptualize, or understand the first-mover benefits of environmental initiatives, and relate these potential benefits to their objectives. These firms tend to look at environmental initiatives such as DfE from an anticipatory performance measurement and cost savings perspective. Early adopters do not rely on well-established references in making environmental initiative decisions, they instead prefer to rely on intuition and vision. Early adopters become the key to opening up new environmental initiatives in technology or standards. Adoption of DfE or environmental standards such as ISO 14000 is directly aimed at financial enhancement and competitive advantage. The driving forces for environmental improvements are to seek new technology for pollution prevention, more effective public communication programs, some green labeling of products, frequent auditing and reporting, and frequent management reviews and policy improvements.

The two firms classified as early majority share the innovators' and early adopters' ability to relate to new environmental initiatives, but are driven by practicality. In our study, these firms operated in the office furniture and paperboard products industries. They are risk averse, and thereby content to wait and see how others are progressing before they adopt or invest in an initiative. Early majority firms need a compelling, verifiable reason to change. ERM issues are seen as more of an opportunity than an integrated part of business processes. The driving force for environmental improvements is the threat of current and changing future regulation, industry norms, or the appearance of potential risk. The early majority look at environmental initiatives such as DfE opportunistically and informally.

The three firms classified as late majority consider the costs of new environmental too high to handle. As a result, they wait until an initiative has become an established standard before showing support. In our study, late majority firms include tier-one engine suppliers to the automotive industry, and an aviation engine component manufacturer. The driving force for environmental improvements in these firms is favorable public perception of company operations, avoidance of legal liabilities, and protection of the firm's reputation. Environmental initiatives are looked at only periodically and informally.

Our final classification of the firms studied is the laggard. A manufacturer of specialty trucks fit this category, and was the smallest firm in our sample. Firms such this one are last to adopt ERM, and simply don't want anything to do with new environmental initiatives for a variety of reasons. The only time they will buy into environmental initiatives such as DfE is when it is a critical part of their product or when an external group (e.g. customers or regulators) forces it on them. The drivers for environmental improvements are current regulations and norms.

Moore's (1991) technology adoption life cycle identifies gaps between several groups. These gaps are defined as the amount, or the level of resistance that must be overcome before the group will accept the innovation. With slight modification to fit ERM practices, the gaps signify the difficulties firms, or industries, may have with ERM and/or DfE. It is hypothesized that the largest gap, the "chasm", separates the early adopters from the early majority. This chasm is important because the acceptance of environmental initiatives, amount of time, and resources allocated, type of culture necessary, presence of tools or measures available, and environmental options explored are vastly different on either side. The gaps between the other categories of firms are not as clear, and do not impact the acceptance of environmental initiatives as strongly as the chasm. The chasm can also be described in what the early adopter is pursuing. Firms to the left of the chasm can also be described as perceived change agents with a competitive advantage. The chasm is a gap between different levels of ERM and DfE practices.

Firms can, and have, crossed the chasm to improve their environmental business practices. The existence of the chasm does not, in itself, stop the evolution of firms into better environmental business practices. Instead, the chasm represents the greater amount of effort needed by a firm to have a proactive environmental stance on environmental business practices. Being the first to adopt, the innovators and early adopters expect to get a jump on the competition via a specialized asset. This jump on the competition could be a specialized asset, unique resources, reputation and image, legal restrictions to entry and access to new markets, perceived risk reduction by investors, lower product costs, waste reduction, more complete customer service, or some other competitive advantage.

By contrast, the early majority want productivity improvements for existing operations. DfE could be seen as a way to minimize the discontinuity with the old ways of doing business. This minimization could also be called evolution, not revolution. By the time these firms adopt DfE, they expect it to work properly and to integrate with their existing systems and standards. After identifying the types of firms on both sides of the chasm, the question remains – what are the distinguishing environmental characteristics that help to separate these different types of firms? Table III highlights the findings of the field research and identifies the environmental attributes of the firms on either side of the chasm.

Environmental attributes

In the following sections, the distinguishing environmental characteristics each firm possessed were used to categorize the firms. The results reported in this paper help to clarify the role of ERM in the firm, the kinds of product and process hazards the firm is involved in, the factors affecting ERM, to what extent metrics or tools are available or used, and finally the types of perceived environmental options and opportunities available to the firm.

Role of ERM

Innovators and early adopters have formally integrated ERM issues into the new product design process. Examples are found within formal processes that integrate environmental concerns into check sheets in each step of the design process. Databases and information systems are also in place to aid in decision making. This ERM integration may be due to the heightened legal

Table III.
ERM characteristics of firms on either side of the chasm

ERM and DfE factors	Innovators	Early adopters		Early majority	Late majority	Laggards
Role of ERM	Integrated, formal	Integrated, formal and informal		Opportunity, informal	Periodic, informal	Not considered
Product and process hazards	High	Medium	*C*	Ranges from medium to low	Typically low	Low
Factors affecting ERM	Formal responsibility, performance measurement, Env. functional unit, culture	Flexibility, lead time, cost, market driven, performance measurement	*H*	Flexibility, lead time-cost	Flexibility, lead time, cost, budgets	Focus on govt. regualtions, unless there is a problem ERM is not considered
Metrics	Present and extensive	Present, focus more on waste	*A*	Lack of metrics	Lacking, or use EPA guidelines	Lacking
Tools	EMIS, LCA, DfE, Familiarity and availability is better	EMIS, LCA, DfE	*S*	Lack of tools	Lacking, or use some EMIS	No tools available
Options	Focus is on reduction and recycle	Focus is on reduction and recycle	*M*	Recycle, justification	Reduce, reuse, and spread risk	No options considered
Opportunities	Pollution prevention	Pollution prevention		Justification, ROI, and pollution prevention	Pollution prevention	No options considered

requirements placed on these industries and firms over the past 20 years. While legal requirements for a firm are important, the requirements are not the same for all industries or all firms.

The early majority and other firms to the right of the chasm take a more opportunistic, or periodic, and informal approach to ERM. These firms may not even have information systems that help with environmental issues during NPD. Instead, these firms may rely on environmental champions to address environmental problems when they arise. The laggards did not even consider ERM issues.

Product and process hazards

The term product and process hazards refers to the amount of hazardous materials required for a firm's production processes. Innovators and early adopters in our study are involved in products and processes that range from high to medium hazards (such as in the chemical industry). The presence of hazardous materials, and processes to convert them into products, often necessitates the integration of ERM into NPD. The early majority and late majority in our study typically deal with medium to low hazards. Laggards in the make-to-order environment tended to have low amounts of hazardous products or processes.

Factors affecting adoption of ERM

While many factors affect a firm's adoption of ERM practices, the drivers for innovators tend to be the formal cross-functional responsibility found within these firms, environmental corporate culture, the use of environmental performance measures, and the presence of an environmental functional unit. The firms studied in this category tended to be larger and operating in the chemical industry where the adoption of ERM was not initially embraced. These firms have come to embrace the concepts of ERM and DfE over time. Innovators tended to have environmental engineers involved in all of the design processes and they value the inclusion of environmental performance measures in individual and corporate performance assessment. Motivations for implementing ERM activities are impacted by corporate culture. In some situations the CEO of a firm will dictate this "green" culture, while in others, environmental champions within functional areas will lead the way. Early adopters find the factors affecting value (i.e. flexibility, lead time, cost), the market, and performance measurement to be important to the integration of ERM issues into new product design. While the design process itself may be formal, there are components of the process that formally and informally integrate environmental issues. Informal integration is typically the work of an environmental champion, and formal processes involved check sheets, and cross-functional information systems, and a sign-off at each step of the process.

The early majority and late majority focus more on the elements of value, with budgets sometimes constraining their efforts. The late majority tend to consider more carefully the trade-offs concerning the allocation of budget resources to environmental projects. Laggards are reactive, focusing primarily on governmental regulations (specifically Occupational Safety and Health Act (OSHA) and Resource Conservation and Recovery Act (RCRA) regulatory requirements) to drive ERM policy. For laggards, ERM, if it is considered, is the job of the lawyers. The laggard in our study was the smallest firm in our sample. Typically, an environmental problem (spill, accident, or injury) is what will prompt action from a laggard, rather than opportunities for environmental effectiveness and efficiency.

Metrics and tools

If you do not measure environmental business practices, you cannot manage environmental business practices and no one can be held accountable. The idea that metrics and tools are in themselves a solution is a false assumption. Instead, the presence of metrics and tools is an observable attribute that helps to verify the presence of ERM practices and helps a firm to monitor and control its ERM or DfE practices. The presence or lack of ERM metrics can be seen in the chasm between the early adopters and the early majority. The state of ERM metrics appears to be a good indicator of the status of ERM within the firms studied. Innovators have extensive metrics present within their formal system for NPD. The metrics can be firm-wide metrics for waste reduction and economic value added, or they can be individually based measures of design speed, cost and environmental quality. While early adopters also have metrics, these firms tend to focus more on the wastes generated from the manufacturing process as a benchmark. Those firms to the right of the chasm lack environmental measures, and instead rely heavily on regulatory limits of waste generation. These firms tend to think that if they meet the minimum regulatory requirements, everything is fine.

A significant difference exists on either side of the chasm when considering the tools available to manage ERM issues. Innovators and early adopters actively use environmental management information systems (EMIS), life cycle analysis (LCA), and design for environment (DfE) tools. The separation between the innovators and early adopters is found in the amount of familiarity and availability of these tools across functions. Those firms right of the chasm lack decision-making tools for ERM; they may have some sort of EMIS available to aid decision making, but perhaps do not use these systems or reward for this type of job performance.

Options and opportunities

An insightful part of the interview process involved learning what environmental options firms pursued, which depended on the product and process hazards, factors affecting ERM, types of systems in place, tools, and metrics. The options explored by the firms studied are self-reported and observable. The focus on options such as pollution prevention, reduction, reuse, outsourcing, spreading risk, and recycling can be found throughout many of the firms interviewed, especially the innovators and early adopters. Interestingly, we see the need for justification of ERM projects and return on investment (ROI) coming into play on the right side of the chasm for the early majority. Additionally, late majority firms may try to spread environmental risks to supply chain members. This can be done by outsourcing hazardous processes, or by having someone else process and dispose of the waste generated on site. As would be expected by reactive firms such as the laggards, ERM options and opportunities were not even considered.

Conclusions

Limitations of this research include generalizability, causality, and empirical testing. The limited sample size and industries involved constrains the generalizability of the findings. Additionally, the qualitative approach does not support causality and the ability to empirically test propositions and hypotheses surrounding ERM and DfE. Suggestions for future research focus on the evolutionary rather than the revolutionary nature of ERM. There is the need for a quantitative assessment of relationships identified from this research. Researchers should strive to develop environmental performance measures and a more detailed look at the people involved at each phase of NPD process that have the biggest impact on DfE. Additionally, the development of tools to aid in the DfE process is necessary to further advance this approach to product design.

This research identifies some of the strong differences exhibited by firms when integrating DfE considerations during the NPD process. Examples include:

- The differences identified between firms represent "chasms." The biggest chasm is found between the early adopters (to the left of the chasm) and early majority (to the right of the chasm).
- The differences between the late majority and the laggards is also interesting in that some ERM efforts are voluntarily undertaken by the late majority, whereas they are typically forced by external factions before implemented by the laggards. The mentality of waiting for external factions to force an issue can be considered an obstacle to implementation of ERM and DfE.
- The role of ERM is more formal and integrated in the innovators and early adopters.
- When looking at the factors affecting ERM we find a greater influence from a "green" corporate culture in the innovators and early adopters. For the early majority, late majority, and laggards we find performance factors such as costs, quality, flexibility, and lead-time having a stronger influence on firms.
- Few ERM and DfE metrics and tools are employed by the early majority, late majority, and laggards.
- Environmental options (i.e. reduction, recycling) and opportunities such as pollution prevention are very much the same, with the exception that firms in the categories of early majority, late majority, and laggards may need more justification for their actions.
- The innovators and early adopters tend to have integration of environmental specialists in all design stages.
- Innovators and early adopters have more formal, cross-functional involvement in the transition points between NPD stages. Specifically, environmental specialists, systems such as EMIS, and tools such as LCA are available to the innovators and early adopters during the early stages of NPD.

The implications for those making decisions about ERM and DfE focus on the differences between the early adopter and the early majority. Early adopters will have more formal processes in place for ERM and DfE. Formal processes help everyone in understanding how decisions are made, and who the participants in the decision-making process will be. Additionally, early adopters have a better understanding of the total cost of a product due to the presence of environmental management systems, ERM performance measurement, and metrics that the early majority may not have. The presence of systems, metrics and performance measures can better facilitate waste reduction and bottom-line improvement. These benefits do not come without a price. Early adopters will take on more risk initially when selling environmental programs to others within their firm. Without performance programs linked to "environmental" performance, the initiatives of some environmental champions may go unrecognized, or projects may fail. The amount of time and resources will need to be carefully planned in advance of environmental projects to ensure the cost/benefit analysis is accurate in its assessment. Additionally, the proper tools and systems need to be in place to support environmental projects.

After examining the role played by environmental issues during the NPD process we find a new way of looking at firms involved in ERM. The firms studied can be categorized into one of five major groups: innovators, early adopters, early majority, late majority and laggards (Moore, 1991). Of interest is the gap that exists between the early adopters and early majority firms. This gap forms a "chasm." Firms wanting to cross this environmental chasm and integrate DfE need compelling evidence before any initiatives will be started to facilitate the journey. Environmental evolutions have taken place in the firms studied (i.e. chemical, automotive suppliers, office furniture, and window and door manufacturing). While these evolutions may have caused some of the firms' characteristics to be different, the purpose of this study is to identify and categorize firms which have adopted ERM practices and integrated these practices into the NPD process. The findings presented in this paper contribute to the advancement of the theory of ERM and DfE. Specific propositions to guide future research include:

(1) DfE has the greatest impact early in the new product design process.

(2) Integrated environmental management systems will impact the breadth of environmental options a firm considers and firm performance.

(3) Indicators of advanced ERM and DfE practices include the presence of personal and departmental environmental performance metrics, green corporate culture, and integrated, formal processes.

(4) Motivations for adopting ERM and DfE practices are externally driven for firms considered laggards and internally driven for all other categories of firms.

Those factors accounting for acceptance of ERM and DfE in the innovators and early adopters on one side of the chasm are significantly different from those factors observed in the early majority, late majority, and laggards on the other side of the chasm. Strong differences between the environmental attributes found on either side of this chasm include the importance of the role of ERM in the firm, product and process hazards, factors affecting ERM, metrics and tools used, waste reduction options available, and the environmental opportunities considered by the firms. While the focus of this paper is on the chasm between the early adopters and early majority, the effort needed for firms to move from no action (laggards) to some action (late majority and the rest) is also of interest. Crossing this second chasm may lead to the greatest aggregate environmental improvement and should be explored in the future. It is unclear if ERM and DfE will propagate through all industries. While, these practices may not be implemented by all industries, those industries that choose to explore these environmental practices will find many opportunities and obstacles.

Notes

1. The meta-matrix is available from the authors upon request.
2. To check the reliability of the coding, an approach suggested by Miles and Huberman (1994) was applied:

$$\text{Reliability} = \frac{\text{Number of agreements}}{\text{Total of items}}$$

Miles and Huberman (1994) suggest 70 percent intercoder reliability is appropriate when using multiple raters to code field notes. An agreement was achieved when at least two of the three researchers agreed on the coding used. The total number of agreements minus the number of disagreements comprised the actual number of agreements used in the reliability formula. The coding of each interview had reliabilities ranging from 0.90 to 1.00, with an average intercoder reliability of 0.95.

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Appendix I. Initial assessment questions

1. Could you tell us about the NPD processes for an obsolete product and its successor?
2. What stakeholders are included in the NPD process?
3. Do you incorporate environmental issues into NPD?
4. Is NPD a top management priority?
5. Do you have an environmental division or functional unit?
6. Do you have formal or informal NPD processes (i.e. documented, systems support...)?

Appendix II. Interview protocol

Protocol for new product development interview

Date:
Name of respondent(s):
Name of interviewer(s):
Company:
Primary product(s):
Primary customer(s):
Your job title:
How long have you been involved (directly or indirectly) with new product development?
What is the length of time in your current position?
What are your current job responsibilities?
What were your previous job responsibilities?
What is the nature of your formal education?

Protocol for ERM interview current product

1.0 Want to hear the story of how your firm developed the product:

2.0 Specifically, how was this product:

2.1 Designed:

2.2 Supplied:

2.3 Prototyped:

2.4 Tested:

2.5 Manufactured:

2.6 Internally approved:

2.7 Quality controlled:

2.8 Evolved once in production:

3.0 Looking specifically at environmental issues for this product line what were your firm's:

3.1 General:

For each item, who was responsible? (Title)

What could have been done better?

What remains to be done?

What are the sticking points with respect to environmental programs?

What remedies might work?

3.2 Goals:

3.2 Strategy:

3.3 Structure:

3.4 Information technologies (tools, methods, and SOPs):

3.5 Performance issues (linked to goals):

3.6 Supplier issues:

Appendix III. Meta-matrix for Company A

Summary

Company A is an innovator regarding ERM issues. This firm is typically proactive and understands the financial benefits of ERM if done correctly. The environmental functional unit is responsible for ERM issues and regulations at the plant level making sure the necessary tools are available. The goal is sustainable development through maximizing environmental operations and minimizing waste. ERM issues are a formal and integrated part of the NPD process. ERM issues are also viewed as opportunistic and should help reduce risks, differentiate products, and be cost effective.

The factors affecting ERM are many. A strong corporate culture and government regulation has a strong impact on ERM. Many ERM metrics help firm A conduct audits, evaluate product and personnel performance and track waste. EMIS, LCA and DfE are the primary ERM tools used. Some of firm A's facilities are already ISO 14000 certified and there is a large effort under way to conform to standard environmental management systems across plants. The largest opportunity for ERM is in pollution prevention. With the vast amount of products firm A is involved in, suppliers play a wide range of roles in NPD, and manufacturing.

Context of the firm

1. Large:
2. Public:
3. Manufacturing includes: MTO, MTS, ATO, ETO
4. Importance of international trade-high: an example of this importance can be seen in the positioning of a new product in a particular country because of the manufacturing advantages this country offered.

Respondent (Primary (/P), Secondary (/S)

1. ERM:
2. Engineering:
3. Quality:
4. NPD:

Product type

1. Chemical

Product hazard

1. High: this seems to be the default hazard for the chemical industry.

Process hazard

1. High: again perceived as high due to the many chemically intensive processes.
2. Recognized environmental hazard (uncertain): the uncertainty is due to the wide range of products this firm makes. Products can range from very high to very low environmental hazards.

Design process

1. Internal:
2. Formal:
3. Market driven:

ERM status

1. Innovator: while realizing the financial benefits to ERM, firm A is proactive in such things as ISO 14000 certification, environmental information systems, life cycle analysis of products, and Goal 2000 (beyond pollution compliance goals).

ERM stage

1. Growth. Eric discussed plant level scheduling and the environmental operations group. This group is responsible for environmental issues and regulations at the plant level and making sure the necessary tools and equipment are available. "Goal 2000" is a program in place that has a beyond compliance emphasis. The goal is sustainable development through maximizing environmental operations and minimizing waste. This should all lead to getting out from under regulations (beyond compliance) and future liabilities.

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