5

Constructing a Product Design for the Environment Process

Daniel P. Fitzgerald[1], Jeffrey W. Herrmann[1], Peter A. Sandborn[1], Linda C. Schmidt[1] and Thornton H. Gogoll[2]

[1]University of Maryland in College Park, Maryland, USA
[2]Black & Decker in Towson, Maryland, USA

Abstract: The greatest opportunity to reduce the environmental impact of a new product occurs during the design phase of its life cycle. Design for environment (DfE) tools, when implemented, become part of the product development process. Often, however, the DfE tools are isolated from the other activities that comprise the product development process. To avoid this problem, tools must be situated in a DfE process that describes how the DfE tools will be used and links DfE activities with the rest of the product development process. This paper presents an innovative DfE process that is being incorporated into an existing product development process at a leading power tool manufacturing company, The Black & Decker Corporation. The DfE process includes DfE tools and activities that are specifically designed to help Black & Decker achieve their environmental objectives.

5.1 Introduction

Environmentally responsible product development (ERPD), also known as environmentally benign manufacturing, considers both environmental impacts and economic objectives during the numerous and diverse activities of product development and manufacturing. ERPD seeks to develop energy-efficient and environmentally benign products. Products generate environmental impacts throughout all stages (*i.e.* raw material extraction, manufacturing, assembly, distribution, and end of life) of their life cycle. There are many ways to minimize these environmental impacts. Studies demonstrate the greatest opportunity for ERPD occurs during the product design phases [1]. The decisions that are made during these phases determine most of the product's environmental impact. Although ERPD requires extra effort, it not only protects the environment but also provides a channel for the application of environmental policies determined at the corporate level.

Consequently, manufacturing companies have spent a great deal of effort developing tools to help designers create environmentally benign products. The two major classes of tools are life cycle assessment (LCA) [2] and design for environment (DfE) tools [3]. LCA provides a fundamental methodology that evaluates the environmental impact associated with a product during its complete life cycle. DfE tools are design decision support tools that help a designer reduce these impacts by improving the product design. DfE incorporates the consideration of national regulations, human health and safety, hazardous material minimization, disassembly, recovery, recycling, and disposal into the design process.

Many obstacles to the effective use of LCA and DfE tools have been noted [1]. Two of the most significant obstacles are the difficulties acquiring the needed data and the challenges developing realistic, appropriate metrics of environmental impact. Consequently, LCA and DfE tools are, generally, not integrated with the other activities and tools used in the product development process. That is, the information flow and decision-making required for existing LCA and DfE tools to be effective is inconsistent with the information flow and decision-making present in product development organizations. The result is often a post-design, standalone, environmental review of a product.

However, manufacturing firms need a tool to consider environmental objectives during the design of new products. Especially urgent is the need to comply with an ever-increasing number of environmental regulations and customer demands. To overcome the limitations of standalone DfE tools, manufacturing firms need to consider important environmental objectives in a systematic way during the design process. This chapter describes such a DfE process for a leading worldwide power tool manufacturer, The Black & Decker Corporation. In close collaboration with Black & Decker, the authors have developed this DfE process. Black & Decker is now working to implement this process.

The development of this DfE process was advanced by considering the product development process as a decision-making system. The next section of this chapter elaborates on this perspective and desscribes a methodology for improving product development, which can be used to enhance any type of performability engineering. Section 5.3 presents an overview of Black & Decker's environmental objectives. Section 5.4 presents the specific product-level metrics that product development teams can evaluate and describes how they are relevant to Black & Decker's environmental objectives. Section 5.5 makes recommendations about the product development milestones when these metrics should be complete. Section 5.6 describes compares this innovative DfE process to traditional DfE and LCA tools. Section 5.7 concludes the chapter.

5.2 A Decision-making View of Product Development Processes

Product development is a complex and lengthy process of identifying a need, designing, manufacturing and delivering a solution, often in the form of a physical object, to the end-user. Product development is a difficult task made more difficult by the challenges inherent in complex, open-ended, and ill-defined tasks. A successful product development process incorporates information inputs from seemingly unrelated and remote areas of an organization into the decision-making process [4].

Due to their complexity, it is not surprising that a variety of perspectives is needed to understand product development processes. The task-based perspective view product development as a project of related tasks and emphasizes project management guidelines. Smith and Reinertsen [5] present an economic view of product development and stress the relationships between development time, development cost, unit cost, and product performance and the product's overall profitability.

5.2.1 Decision Production Systems

Building on both the decision-based perspective of engineering design and the decision-making paradigm of organizational design, Herrmann and Schmidt [6] argued that product development organizations are decision production systems and describe product development as an information flow governed by decision-makers who operate under time and budget constraints to produce new information. The term is relevant because a product development organization creates new product designs and other information that are the accumulated results of complex sequences of decisions. Herrmann and Schmidt [7] present a methodology for improving a product development organization. Herrmann [8] further explores the concepts on which this view depends and considers their implications for designing product development processes.

The decision production system (DPS) perspective looks at the organization in which the product development process exists and considers the decision-makers and their information processing tools (like databases) as units of a manufacturing system that can be viewed separately from the organization structure. By viewing organizations in this manner, one can understand how information flows and who is making the key decisions. As a result the hierarchical view and decision production system view of a product development organization are quite different. Similarly, Simon [4] noted that an organization's "anatomy" for information processing and decision-making is naturally different than the departmentalization displayed in an organization chart. The greater the interdependence between decision-makers, the less the DPS will resemble an organization chart.

The DPS perspective is an overarching framework to map product development activities (with an emphasis on decisions) within an organization in such a way as to illustrate current decision-making practices. The DPS representation of a product development organization provides a meta-level view of the actual decision-making processes taking place in an organization, which are not necessarily the processes that management may have prescribed. The DPS perspective enables problem identification in decision-making practices that will lead to a more effective deployment of resources including decision support tools.

The DPS perspective enables a deeper understanding of the organization than typical hierarchical organization charts of a firm or Gantt charts of product development projects. Understanding the real process (as opposed to the corporate guide for the design process) is a key step in improving product development. Furthermore, recognizing design as a "knowledge agent" and the designing activity as a crucial organizational knowledge process can improve an organization's ability to innovate within their competitive environment [9]. The need for research on new work practices [10] and the need for developing new representation schemes for product development [11] are additional motivations for considering the DPS perspective.

5.2.2 Improving Product Development Processes

Simon [4] argues that systematic analysis of the decision-making in a product development process would be useful for implementing changes to the product development organization in a timely and profitable manner, and he proposes the following technique for designing an organization:

- Examine the decisions that are actually made, including the goals, knowledge, skills, and information needed to make those decisions.
- Create an organization pattern for the tasks that provide information for these decisions.
- Establish (or change) the pattern of who talks to whom, how often, and about what.

Of course, this must be repeated for the more specific decisions that form the more general decisions.

Viewing a product development organization as a decision-making system leads to a systems-level approach to improving product development. In particular, this perspective is not concerned primarily with formulating and solving a design optimization problem. Moreover, the problem is not viewed only as helping a single design engineer make better decisions (though this remains important). Instead, the problem is one of organizing the entire system of decision-making and information flow to improve the performability of the new products that are being developed.

As with other efforts to improve manufacturing operations or business processes, improving product development benefits from a systematic improvement methodology. The methodology presented here includes the following steps in a cycle of continuous improvement, which is based in part on ideas from Checkland [12].

1. Study the product development decision-making system.
2. Build, validate, and analyze one or more models of this decision-making system.
3. Identify feasible, desirable changes.
4. Implement the changes, evaluate them, and return to Step 1.

The important features of the decision-making system are the persons who participate in it, the decisions that are actually made, including the goals, knowledge, skills, and information needed to make those decisions. Also relevant are the processes used to gather and disseminate information. It will also be useful to study other processes that interact with product development, including marketing, regulatory compliance, manufacturing planning, and customer service.

An especially important part of studying product development is determining the sources that provide information to those making decisions. If they are not documented, changes to the system may eliminate access to these sources, which leads to worse decision-making. In addition, like any group of tools accumulated over time, it is critical to review how and when each decision support tool is applied to the product development process. This requires a meta-level understanding of decision-making during all phases of product development.

Modeling is a key feature of this methodology. Creating a model of the as-is product development organization has many benefits. Though it may be based on pre-existing descriptions of the formal product development process, it is not limited to describing the "should be" activities. The process of creating the model begins a conversation among those responsible for improving the organization. Each person involved has an incomplete view of the system, uses a different terminology, and brings different assumptions to the table. Through the modeling process, these persons develop a common language and a complete picture. Validation activities give other stakeholders an opportunity to give input and also to begin learning more about the system. Even those that are directly involved in product development benefit from the "you are here" information that a model provides. For more details about possible models, see Herrmann and Schmidt [7].

5.3 Environmental Objectives

Based on discussions with Black & Decker staff, such as the Director of Engineering Standards and the Senior Manager of Environmental Affairs, and documents provided by Black & Decker, we identified six primary environmental objectives based on the corporation's environmental policy:

1. Practice environmental stewardship.
2. Comply with environmental regulations.
3. Address customer concerns.
4. Mitigate environmental risks.
5. Limit financial liability.
6. Report environmental performance.

This section describes these in more detail.

5.3.1 Practice Environmental Stewardship

Black & Decker seeks to demonstrate environmental awareness through creating an environmental policy and publishing it on their website, including information about recycled content on packaging, and its Design for Environment program. In addition, Black & Decker belongs to environmental organizations such as the World Environmental Center, which contributes to sustainable development worldwide by strengthening industrial and urban environment, health, and safety policy and practices. It is also member of the Rechargeable Battery Recycling Corporation (RBRC) and RECHARGE which promote the recycling of rechargeable batteries.

5.3.2 Comply with Environmental Regulations

As a global corporation that manufactures, purchases, and sells goods, Black & Decker must comply with all applicable regulations of countries where its products are manufactured or sold. Currently, the European Union exerts significant influence on addressing environmental issues through regulations and directives. Listed below are examples of important US and European environmental regulations.

There are many regulations that apply to US and European workers and these are set by both federal and state agencies. The Occupational Safety & Health Administration (OSHA) limits the concentration of certain chemicals to which workers may be exposed. The Environmental Protection Agency (EPA) regulates management of waste and emissions to the environment. Black & Decker provides employees with training on handling hazardous wastes, which is required by the Resource Conservation and Recovery Act and the Hazardous Materials Transportation Act [13]. California's Proposition 65 requires a warning before potentially exposing a consumer to chemicals known to the State of California to cause cancer or reproductive toxicity. The legislation explicitly lists chemicals known to cause cancer and reproductive toxicity.

The EU Battery Directive (91/157/EEC) places restrictions on the use of certain batteries. The EU Packaging Directive [14] seeks to prevent packaging waste by requiring packaging re-use and recycling. In the future, countries in the European Union will require Black & Decker to adhere to certain laws so that the state achieves the goals of the EU Packaging Directive. Thus, Black & Decker will be interested in increasing the recyclability of its packaging.

Black & Decker has also implemented procedures to comply with the Waste Electrical and Electronic Equipment Directive (WEEE). The following excerpt describing this directive is from the UK's Environmental Agency [15]: "The Directive is one of a series of 'producer responsibility' directives that makes producers of new equipment responsible for paying for the treatment and recycling of products at the end of their life. It affects any business that manufactures, brands or imports [electrical and electronic equipment (EEE)] as well as businesses that sell EEE or store, treat or dismantle WEEE within the EU. It will affect businesses that have WEEE to dispose of and the public who will have more opportunities to reuse, recycle and recover these products."

This regulation requires appropriate marking on EEE, sets targets for household WEEE collection, requires EU member states to register EEE producers, requires procedures to enable take-back and treatment, and sets targets for recycling and recovery.

5.3.3 Address Customer Concerns

Black & Decker's retail customers are concerned about the environmental impacts of the products they sell. Examples of customer concerns are: ensuring timber comes from appropriate forests, increasing the recyclability and recycled content in packaging, using cadmium in batteries, and using lead in printed wiring boards and electrical cords. More specifically, some retailers require that Black & Decker's products be free of lead-based surface coatings.

5.3.4 Mitigate Environmental Risks

An activity's environmental risk is the potential that the activity will adversely affect living organisms through its effluents, emissions, wastes, accidental chemical releases, energy use, and resource consumption [16]. Black & Decker seeks to mitigate environmental risks through monitoring chemical emissions from manufacturing plants, reducing waste produced by its operations, ensuring safe use of chemicals in the workplace, and ensuring proper off-site waste management.

5.3.5 Reduce Financial Liability

There are different types of environmental liabilities [17]:

- Compliance obligations are the costs of coming into compliance with laws and regulations.
- Remediation obligations are the costs of cleaning up pollution posing a risk to human health and the environment.
- Fines and penalties are the costs of being non-compliant.
- Compensation obligations are the costs of compensating "damages" suffered by individuals, their property, and businesses due to use or release of toxic substances or other pollutants.

- Punitive damages are the costs of environmental negligence.
- Natural resource damages are the costs of compensating damages to federal, state, local, foreign, or tribal land.

Some of these may be a concern to Black & Decker.

5.3.6 Reporting Environmental Performance

Black & Decker reports environmental performance to many different organizations with local, national or global influence and authority. An example of an organization is the Investor Responsibility Research Center (IRRC).

Consistent with its policy, Black & Decker's environmental objectives will evolve. New regulations will be promulgated in the years to come. Stakeholders will ask for additional environmental information. Black & Decker must be flexible enough to comply. The need for a DfE process that is robust and can adapt to the constantly changing nature of environmental regulations and requirements is great.

5.4 Product-level Environmental Metrics

Incorporating a DfE process that fits into the existing product development process has significant potential to help manufacturing firms achieve their environmental objectives. This section briefly describes eight product-level environmental metrics developed by the authors and Black & Decker staff that product development teams can evaluate during the product development process. These metrics were chosen because they relate directly to a particular product (they are not plant or corporate metrics). In addition, the measures concern attributes that are relevant to Black & Decker's primary environmental objectives, as described below.

5.4.1 Description of the Metrics

There are eight product-level environmental metrics, which the following paragraphs describe:

1. Flagged material use in product
2. Total product mass
3. Flagged material generated in the manufacturing process
4. Recyclability/disassembly rating
5. Disassembly time
6. Energy use
7. Innovation statement
8. Application of the DfE approach

Flagged Material Use in Product

This measures the mass of each flagged material contained in the product. A material is considered flagged if it is banned, restricted or being watched with respect to regulations or customers. A consulting firm has provided Black & Decker with a list of materials that are banned, restricted and being watched. This metric addresses the following corporate environmental objectives:

- Comply with environmental regulations.
- Address customer concerns.
- Limit financial liability.
- Report environmental performance.

Total Product/Packaging Mass

This measures the mass of the product and packaging separately. This metric addresses the following corporate environmental objectives:

- Comply with environmental regulations.
- Address customer concerns.
- Report environmental performance.

Flagged Material Generated in the Manufacturing Process

This is a list of each flagged material generated during the manufacturing process. A material is considered flagged if it is banned, restricted or being watched with respect to regulations or customers. This metric addresses the following corporate environmental objectives:

- Comply with environmental regulations.
- Address customer concerns.
- Mitigate environmental risks.
- Limit financial liability.
- Report environmental performance.

Recyclability/Disassembly Rating

This metric is the degree to which each component and subassembly in the product is recyclable. Recyclability and separability ratings can be calculated for each component based on qualitative rankings. Design engineers are provided with a list of statements that describe the degree to which a component is recyclable or separable and a value from 1 to 6 is associated with each statement. Low ratings for both recyclability and separability facilitate disassembly and recycling. The design engineer rates the recyclability and separability of each component, subassembly, and final assembly. If both ratings for an item are less than "3", than the item is recyclable [18].

This metric addresses the following corporate environmental objectives:

- Practice environmental stewardship.
- Comply with environmental regulations.
- Address customer concerns.
- Mitigate environmental risks.
- Report environmental performance.

Disassembly Time

A measure of the time it will take to disassemble the product. Research has been conducted on how long it typically takes to perform certain actions. Charts with estimates for typical disassembly actions are provided to the design engineers who can then estimate how long it would take to disassemble a product [18].

This metric addresses the following corporate environmental objectives:

- Practice environmental stewardship,
- Mitigate environmental risks.

Energy Consumption

The total expected energy usage of a product during its lifetime. This metric can be calculated by multiplying the total expected lifetime hours by the energy use per hour the product consumes. This metric need to be calculated only for large energy consumers such as compressors, generators, and battery chargers.

This metric addresses the following corporate environmental objectives:

- Practice environmental stewardship.
- Comply with environmental regulations.
- Address customer concerns.
- Mitigate environmental risks.
- Limit financial liability.

Innovation Statement

A brief paragraph describing the ways a product development team reduced the negative environmental impact of their product. The product development team should write this after the product is launched. All environmental aspects considered should be included as well.

This metric addresses the following corporate environmental objectives:

- Practice environmental stewardship.
- Report environmental performance.

Application of DfE approach

This binary measure (yes or no) is the answer to the following question: Did the product development team follow the DfE approach during the product development process? Following the DfE approach requires the team to review the DfE guidelines and evaluate the product-level environmental metrics.

This metric addresses the following corporate environmental objectives:

- Practice environmental stewardship.
- Report environmental performance.

While this list of metrics cannot completely measure every environmental impact, the metrics provide designers with a simple way to compare different designs on an environmental level. Black & Decker plans to track the trends of these metrics as the products advance through future redesigns. Furthermore, each product will have environmental targets set at the beginning of the project, and the metrics provide a way to track how well the product development team performed with respect to attaining the targets. The Corporate Environmental Affairs group will also use the metrics to respond to retailers requests for environmental information.

5.4.2 Scorecard Model

A scorecard was created in Microsoft Excel in order to ensure that the metrics above could be used more effectively during the product development process. There is a single worksheet with inputs and outputs specifically related to most of the aforementioned metrics. Calculations for each metric are carried out on a hidden calculations worksheet. Separate worksheets contain the most important outputs from each metric and appropriate graphs. The following paragraphs list the specific inputs and outputs for each metric.

Flagged Material Use in Product:

Inputs: The components containing flagged material, mass of each component, flagged material contained within each component, percent of each component that is hazardous.
Outputs: The mass of each flagged material in each component, and the total mass of each flagged material within each product.

Total Product and Packaging Mass:

Inputs: Product weight and packaging weight.
Outputs: Product mass and packaging mass.

Flagged Material Generated in Manufacturing Process:

Inputs: Flagged material generated, manufacturing process, component being made.
Outputs: List of flagged materials generated for product.

Recyclability/Disassembly Rating:

Inputs: Assembly name, component name, quantity, material the component is made of, total mass, recyclability rating, separability rating.
Outputs: Total mass of product for each recyclability rating, total mass of product for each disassembly rating, pie charts for both sets of outputs, percent of the product that is recyclable, whether a particular component is recyclable.

Disassembly Time:

Inputs: Disassembly step, fastener used, removal method, time per fastener, number of jobs.
Outputs: Total time for each step, total time for disassembly.

Energy Consumption:

Inputs: Expected lifetime of the product, total power rating.
Outputs: Total energy used by product over lifetime.
The innovation statement and application of DfE approach metrics are not included in the spreadsheet because they do not involve numbers or calculations. The final output page highlights key environmental metrics and is calculated with the spreadsheet based on the designer inputs listed above. The key environmental metrics are: Amount of flagged material in product (g), total product mass and (g), number of manufacturing processes that generate flagged materials, percent product recyclable, total disassembly time (s), and total energy consumed (kJ).

5.4.3 Guidelines and Checklist Document

To ensure that design teams at Black & Decker address appropriate environmental concerns during the product development process, a guidelines and checklist document has been created. The checklist portion of the document lists items that must be addressed before the product is released to the market. The document contains references which are links to additional information about the requirements and guidelines. The guidelines section of the document lists issues that engineers should try to address to make the product more environmentally friendly. Not addressing an item in the guideline section would not prevent a product from going to the market however.

The Checklist of Regulatory and Policy Requirements contains the following requirements:

- No material restricted by Black & Decker is used in the product or manufacturing process.
- All materials restricted in the RoHS directive are under the respective threshold limit within the product.

- All special lead applications are under the respective threshold limit within the product.
- Product manual contains appropriate Proposition 65 warning if necessary.
- Packaging of product adheres to the European Packaging Directive.
- Batteries contain no materials banned in the European Union's battery directive.
- Product and manual contain appropriate markings for products with batteries.
- Product and manual contain appropriate markings for products with respect to the WEEE directive.
- Prohibited manufactured processes are not used.

The following are the Design for Environment Guidelines:

- Reduce the amount of flagged materials in the product by using materials not included on Black & Decker's should not use list.
- Reduce raw material used in product by eliminating or reducing components.
- Reduce the amount of flagged material released in manufacturing by choosing materials and processes that are less harmful.
- Increase the recyclability and separability of the product's components.
- Reduce the product's disassembly time.
- Reduce the amount of energy the product uses.

Samples of these documents can be found in Fitzgerald *et al*. [19].

5.5 The New DfE Process

Ideally, every product and process design decision should consider environmental concerns. However, this is not feasible because some designers are unfamiliar with DfE principles. Therefore, we defined a DfE process that naturally integrates environmental issues into the existing product development process with little extra effort or time. Black & Decker uses a stage-gate product development process that has eight stages. Every stage requires certain tasks to be completed before management signs off giving permission to proceed to the next stage. This signoff procedure is known as the gate.

Currently, Black & Decker has safety reviews during stages 2, 3, 4, and 6. Safety reviews are meetings intended for reviewers to evaluate the assessment, actions, and process of the design team in addressing product safety. The DfE process adds an environmental review to the agenda of the safety reviews held during Stages 2, 4, and 6. A separate environmental review will be held during Stage 3, an important design stage, in order to focus specifically on the environmental issues for the particular product. The environmental reviews will require design teams to review the checklist of key requirements and to consider guidelines for reducing environmental impact. When the DfE process is first implemented, design teams will have to fill out the Environmental Scorecard only during Stage 6 after the product design is complete. Doing this begins the process of recording environmental data and allows design teams to adapt gradually to the new process. When design teams become more familiar with the process, the scorecard will be completed two or more times during the stage-gate process in order to track design changes that effect environmental metrics during the development process.

In addition to the environmental reviews, environmental targets will be set during Stage 1 as goals for the new product. The design team will write a lessons learned summary during Stage 8 to highlight innovative environmental design changes. The lessons learned summary will provide the innovation statement metric. Figure 5.1 shows the Safety Review Process and Environmental Review Process running in parallel. The sections below discuss the aforementioned environmental activities in more detail. Note that, throughout this process, many other product development activities occur, causing changes to the product design.

5.5.1 Product Initiation Document

The Product Initiation document is a document that Black & Decker uses to benchmark competitors, define performance targets, and predict

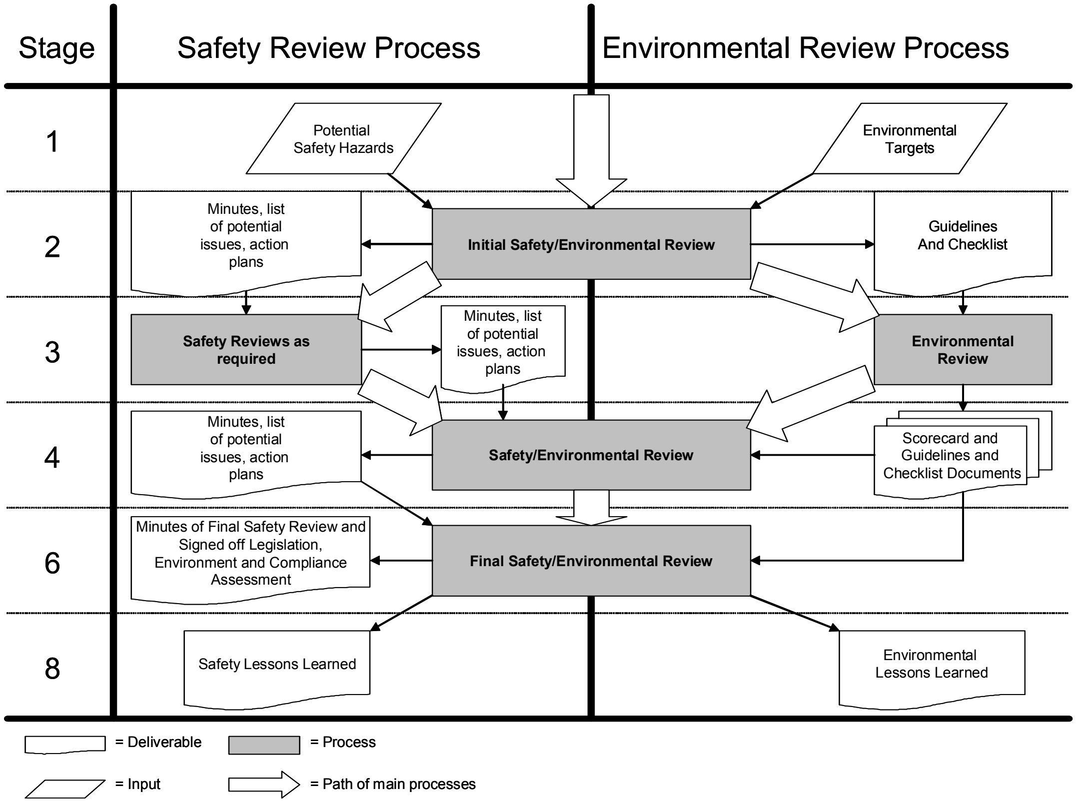

Figure 5.1. Combined safety and environmental review process [19]

profitability and market share. In addition to these issues, the product initiation document will also address environmental regulations and trends and opportunities to create environmental advantage. Targets for environmental improvement will also be included.

5.5.2 Conceptual Design Environmental Review

The second environmental review is held separately from the safety hazard review. During this meeting, the project team will check compliance regulations, fill in the guidelines and checklist document, discuss the metrics in the guidelines and checklist document and write the minutes.

The lead engineer will update the scorecard and review opportunities and additional environmental issues for the next meeting.

The result of this meeting is an updated guidelines and checklist document and meeting minutes. The reliability representative will update.

5.5.3 Detailed Design Environmental Review

The third environmental review is coupled with a safety review. During this meeting, the project team should ensure that all environmental compliance issues are resolved. There should be no further changes to the design due to environmental reasons after this meeting. The result of the meeting is an updated guidelines and checklist document and meeting minutes. The reliability representative will update the guidelines and checklist document and write the minutes. The lead engineer will update the scorecard for the next meeting.

5.5.4 Final Environmental Review

The fourth and final environmental review is coupled with a safety review. During this meeting, all environmental compliance issues must be resolved. Optimally, no design changes due to environmental reasons would have been made between the last meeting and this meeting. The result of the meeting is a final guidelines and checklist document and meeting minutes. The reliability representative will finalize the guidelines and checklist document and write the minutes. The lead engineer will finalize the scorecard and create a material declaration statement (MDS) packet for the product.

5.5.5 Post-launch Review

Black & Decker includes a lessons learned summary in their product development process. This document discusses what went well with the project, what did not go well with the project, and reasons why the product did not meet targets set in the trigger document. The lessons learned summary will include environmental design innovations realized during the product development process for publicity and customer questionnaires. An example of an item to be included in the lessons learned summary is a materials selection decision. Details should include what materials were considered and the rationale of the decision. The lessons learned summary is a very important part of the DfE process because it provides future design teams with the environmental knowledge gained by the previous designers.

5.5.6 Feedback Loop

The completed checklist and guidelines documents and lessons learned summaries create a feedback loop for the DfE process. Design engineers working on similar products can use this information to make better decisions immediately and the information is also valuable when the next generation of the product is designed years down the road. Design engineers will record what environmental decisions were made and why they were made. The decision information, scorecards and comments on the guideline document will be archived permanently. The goal is to save the right things so the information is there in the future when more feedback activities, such as a product tear-down to verify scorecard metrics, can be introduced.

5.6 Analysis of the DfE Process

Black & Decker's new DfE process described above is innovative and has many advantages compared to traditional DfE tools. There are many standalone DfE tools available to designers. Otto and Wood [18] provide an overview of some of the DfE tools currently used. Two examples cited are general guideline/checklist documents and life cycle assessments (LCAs).

A general guideline/checklist document is a simple DfE tool that forces designers to consider environmental issues when designing products. Integrating a guideline/checklist within a new DfE process is simple and effective way to highlight environmental concerns. However, it should be noted that the guideline/checklist document needs to be company specific and integrated systematically into the product development process. Using an existing generic, standalone guideline/checklist document will most likely be ineffective. First, the point of a guideline/checklist document is to ensure that designers are taking the proper steps towards achieving environmental objectives. Another organization's guidelines /checklist document was designed to obtain their own objectives which may not coincide with another company's objectives. Second, obtaining a guideline/checklist document and simply handing it to designers will lead to confusion as to when and how to use the list. Specific procedures need to be implemented to ensure the designers are exposed to the guideline/checklist document early in the product development process to promote environmental design decisions.

LCAs are time-consuming projects that research a product's environmental impacts and conducts tests to produce environmental impact quantities. The problem with LCAs is that they take a long time, are very expensive, and provide information only after the design is complete. LCAs do not help designers improve a current product's environmental impact. Our DfE process, however, provides guidelines that help achieve Black & Decker's environmental objectives, and it contains a lessons learned summaries that provide a design engineer with helpful information about previously used decisions and techniques.

Klein and Sorra [20] argue that successfully implementing an innovation depends upon "the extent to which targeted users perceive that use of the innovation will foster the fulfilment of their values." The DfE process contains values that coincide with the organization's values. Within the Corporation's Code of Ethics and Standards of Conduct [21], there is a section titled Environmental Matters which "places responsibility on every business unit for compliance with applicable laws of the country in which it is located, and…expects all of its employees to abide by established environmental policies and procedures." Black & Decker's environmental objectives were taken into account and consequently the DfE process requires designers to track related metrics. The process leverages existing processes hence minimizing time-to-market and requiring little extra effort from the designers. Black & Decker's product development process was studied to ensure information availability. A DfE process that is customized for Black & Decker is much more likely to be implemented than standalone tools. By researching any organization's product development process and understanding the decision-making processes, information flow, and organizational and group values, it is possible to construct a DfE process that is customized and easy to implement.

5.7 Conclusions

This chapter describes an innovative DfE process in which a design team repeatedly considers key product-level environmental metrics. These metrics are directly related to the corporation's environmental objectives. These metrics do not require excessive time or effort. The iterative nature of the DfE process means that design teams consider different aspects of DfE at the most appropriate time, when information is available and key decisions must be made.

The DfE process was created specifically for Black & Decker through studying their product development process and incorporating DfE activities with similar existing activities. Environmental regulations are treated in a systematic and formal way so that the design teams can document the new product's compliance. Finally, this report includes guidelines and an environmental scorecard that the product development teams can use to improve the product's environmental performance.

The research team is now assisting with the implementation and planning assessment activities such as material declaration forms and upgrading service bill of material lists to include material identification for recycling. The assessment of this approach remains for future work. Such an assessment would need to involve performance metrics such as: the time required for DfE reviews, the number of additional tasks required, the improvement in product environmental metrics, and the percentage of questions that can be accurately answered in customer questionnaires. Further research using this methodology will establish its usefulness for improving product development.

Acknowledgements

The authors greatly appreciate the help provided by Black & Decker employees, especially Mike Justice. This material is based upon work supported by the National Science Foundation under grant DMI-0225863. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

[1] Handfield Robert B, Melnyk Steven A, Calantone Roger J, Curkovic Sime. Integrating environmental concerns into the design process: the gap between theory and practice. IEEE Transactions on Engineering Management 2001; 48, (2): 189–208.

[2] Menke Dean M, Davis Gary A, Vigon Bruce W. Evaluation of life-cycle assessment tools. Environment Canada. 30 August 1996. http://eerc.ra.utk.edu/ccpct/pdfs/LCAToolsEval.pdf

[3] Poyner JR, Simon M. Integration of DfE tools with product development. Clean Electronics Products and Technology, (CONCEPT), International Conference on 1995; 9-11 Oct: 54–59.

[4] Simon Herbert A. Administrative behavior (4th edition). The Free Press, New York, 1997.

[5] Smith Preston G, Reinersten Donald G. Developing products in half the time. Van Nostrand Reinhold, New York, 1991.

[6] Herrmann Jeffrey W, Schmidt Linda C. Viewing product development as a decision production system. DETC2002/DTM-34030, Proceedings of the 14th International Conference on Design Theory and Methodology Conference, ASME, Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Montreal, Canada 2002; September 29–October 2.

[7] Herrmann Jeffrey W, Schmidt Linda C. Product development and decision production systems. In: Chen W, Lewis K, Schmidt LC, editors. Decision making in engineering design. ASME Press, New York, 2006.

[8] Herrmann Jeffrey W. Decision-based design of product development processes. Working paper 2007.

[9] Bertola P, Teixeira JC, Design as a knowledge agent: how design as a knowledge process is embedded into organizations to foster innovation. Design Studies 2003; 24:181–194.

[10] Brown John Seely. Research that reinvents the corporation. In: *Harvard Business Review on Knowledge Management*, Harvard Business School Press, Boston, 1998.

[11] Krishnan V, Ulrich Karl T. Product development decisions: a review of the literature. Management Science 2001; 47(1):1–21.

[12] Checkland Peter. Systems thinking, systems practice. Wiley, West Sussex, 1999.

[13] Knudsen Sanne, Keoleian Gregory A. Environmental law: exploring the influence on engineering design. Center for Sustainable Systems, University of Michigan, April 5, 2001; Report No. CSS01-09, Available online at http://css.snre.umich.edu/css_doc/CSS01-09.pdf, accessed July 1, 2003.

[14] Directive 2004/12/EC of the European Parliament and of the Council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste. Official Journal of the European Union. Accessible online at http://www.europa.eu.int/eur-lex/pri/en/oj/dat/2004/l_047/l_04720040218en00260031.pdf

[15] Waste Electrical and Electronic Equipment (WEEE) Directive. UK's Environmental Agency. Accessible electronically through the Environmental Agency's Website http://www.environment-agency.gov.uk/business/444217/444663/1106248/?version=1&lang=_e

[16] Terms of environment. Environmental Protection Agency. Document number EPA175B97001. Accessibly electronically through The Environmental Protection Agency's Website. http://www.epa.gov/OCEPAterms/eterms.html

[17] EPA. Valuing potential environmental liabilities for managerial decision-making. EPA742-R-96-003. Dec. 1996. http://www.epa.gov/opptintr/acctg/pubs/liabilities.pdf3

[18] Otto Kevin N, Wood Kristin L. Product design: techniques in reverse engineering and new product development. Prentice Hal, Upper Saddle River, NJ. 2001.

[19] Fitzgerald DP, Herrmann JW, Sandborn Peter A, Schmidt Linda C, Gogoll Ted. Beyond tools: a design for environment process. International Journal of Performability Engineering 2005; 1(2):105–120.

[20] Klein Katherine J, Sorra Joann Speer, The challenge of innovation implementation. Academy of Management Review 1996; 21(4):1055–1080.

[21] The Black & Decker Corporation Code of Ethics and Standards of Conduct. 13 February 2003. http://www.bdk.com/governance/bdk_governance_appendix_1.pdf