AN ENVIRONMENTAL INDEX FOR HOUSEHOLD, DURABLE, CONSUMER GOODS

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I

INTRODUCTION

Statement of the Problem

This research introduces the concept of, and defines in qualitative terms, an overall environmental index (EI) to be assigned to household, durable, consumer goods (see page 5.). The EI will provide a manufacturer an indication of a household consumer good's relative impact on the environment via risk assessment and pollutant ranking during the creation and disposal phases of the product's life cycle. While the use portion of the product's life cycle can contribute much impact to the environment, that portion of the life cycle was not examined in this research.

As such, the index would provide a tool for management decision making and for engineers during the design stage of the goods. What-if scenarios, sensitivity analysis, and decision theory could then examine the environmental harm and liability associated with certain materials and processes directly. The index could also be used by consumers to evaluate the relative environmental impact of goods they are considering purchasing and to estimate the environmental impact of foreign products.

Initial EI Formulation

The initial environmental index (EI) that formed the basis for this research was composed of elements laid out in a decision tree configuration (see Figure 1. on the next page).

Level 0, or the top-most level, was the final environmental index (EI). The EI could focus either on the total durable good, or any single component, or group of components, that make up the durable good. Level 1 contained the two major subindices of the EI: a manufacturing process index (MPI) and a disposability index (DI).

Level 2 of the EI decision tree contained the next major subparts of the (MPI), the process descriptors. The MPI process descriptors at Level 2 were to be calculated by ranking the various waste streams of these processes at Level 3. Each process description would have been given a scoring weight by that process's effect on land (RCRA)[1], air (CAA)[2], water (CWA)[3], and indoor air quality (IAQ)[4]. The scoring weight was to have come from some type of overall EPA relative ranking system for all pollutants. Each durable good's (or component's) process description was to have been also weighted according to what percentage (of mass) the component(s) occupied compared to the mass of the entire durable good. If the entire durable good is examined, this percentage would go to 100%.

1. Resource Conservation and Recovery Act (EPA)
2. Clean Air Act (EPA)
3. Clean Water Act (EPA)
4. Indoor Air Quality (EPA, OSHA)

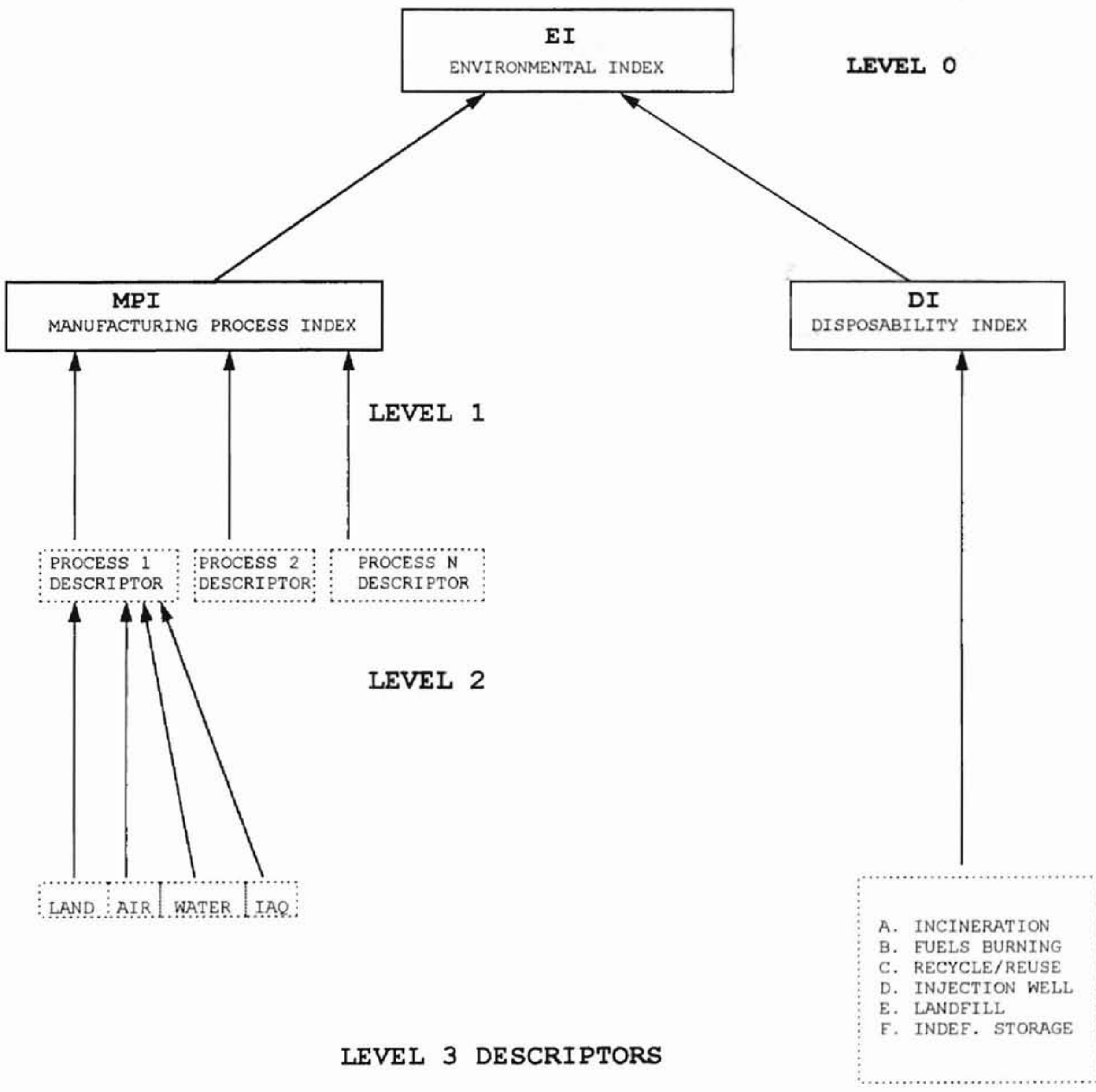

FIGURE 1. Environmental Decision Tree Model

Level 1 contained the other immediate subpart of the environmental index, the disposability index (DI). The disposability index would have had ranking factors at Level 3(disposal options) that affected a percentage mass figure for the amount of material from the product that must be ultimately disposed. These ranking factors tended from less environmental harm to greater environmental harm (e.g. incineration to hazardous waste land fill). The disposability index would have been weighted by the relative amount of mass of the durable good, or component associated with disposal. The DI would be scaled from 17 to 100 (6 possibilities giving scores of 1/6*100 to 6/6*100 - low environmental impact to high environmental impact) depending on the percentage weighing and the ranking factors. The relationships between product component, manufacturing process, and the waste streams associated with these processes were to have come from a list of general manufacturing processes used in industry, and the typical waste streams associated with these processes (see Chapter Two and Chapter Three, Methodology, for further explanation). The manufacturing index was also to have been scaled from 0 to 100 (low environmental impact to high environmental impact). The environmental index that resulted (level 0), would be a two part, alpha-numeric code such as [M12D60]. The (M)anufacturing (12) would show the total durable good's environmental impact due to the manufacturing process needed to construct the durable good, or its component parts. The (D)isposability (60) would refer to the relative ease or difficulty of disposing of the product's waste material. The EI would have been a relative measure of environmental impact or harm.

Before proceeding, it should be pointed out that the EI need not be limited to the area of household consumer goods. In fact, the greatest application of the EI may be realized in such diverse applications as building construction, structures such as bridges and roads, electronics, and vehicle construction (anything from automobiles to aircraft carriers). Almost anything that can be manufactured can find applications with the EI. The EI can also be attached to disposable items such as boxes of soap, food stuffs in containers, and other rapidly exhausted supplies. For this study household consumer goods were selected in order to provide simple, understandable examples.

The intended audience for the EI need not necessarily be just manufacturing. From a marketing perspective, the EI can be used as tool. This study does not address product marketing but firms are always searching for the competitive edge over other's products. A lower (more environmentally friendly) EI would probably find greater public acceptance over a competitor with a higher (less friendly) EI. This brings up the point that identical products made in different ways by different manufacturers may not have identical sales to the public. When facing similar products, consumers may go the next level and try to determine which product is more environmentally friendly (even though the price may be incrementally higher). In this scenario the EI is a good method of product comparison.

Economics will play a big role if the EI is used as a marketing tool. It is probable that the better EI will cost more to produce. This would have to be weighed against the possible increase in market share.

It should also be mentioned that the EI should be site specific for the particular manufacturing situation (this is addressed in later chapters).

Research Objectives

1) Complete the formulation of an environmental index (EI) decision tree model, its components, and subparts, and their respective scales.
2) Describe, on a conceptual level, the EI decision tree model.
3) Apply the EI to a simple household consumer durable good product and evaluate the validity of the approach used in 1 above.
4) Suggest areas for future research.

Definitions

Household consumer durable good - A mechanical, powered or unpowered, product used in the typical household to perform tasks ranging from cooking to cleaning to clerical that is not rapidly exhausted during its use. The household consumer good is not considered a "disposable" product in that it has not been made with rapid disposal as one of its design criteria. Examples of household consumer durable goods are:

* Oven/stoves, including microwave ovens
* Refrigerators
* Vacuum cleaners
* Computers, typewriters

The following products do not meet the definition of household consumer durable goods:

* Food, perishable items
* Paper plates, napkins, disposable items
* Vacuum cleaner bags
* Cleaning supplies (solvents, soaps, etc.)

Environmental Impact or Harm - Adverse effects (present and future) to human health and the environment (impacts may not necessarily be negative and future EI's may reflect this).

Environmental Risk - The probability (perceived or calculated) that an action will lead to environmental impact or harm.

Pollutant - A waste or contaminant that is introduced into the environment.

Limitations

This research will not assess or evaluate:

1) The EI's effects on life cycle costs.
2) Products that do not satisfy the definition of household consumer durable goods used in this study.
3) Product packaging.
4) An EI calculated for actual product application.

Assumptions

The following is a set of assumptions used in this study:

* For this study, product use does not play an important role in deciding the environmental performance of a household consumer durable good.

* Manufacturing Process Index (MPI) and Disposability Index (DI) are independent.

* The Environmental Index (EI) is a linear function of the MPI and DI which are, in turn, linear functions of their respective components.

Importance of the Study

A legitimate need exists for the ability, at the concept stage, to design and make comparative judgments regarding the environmental impact of manufactured goods. Currently there is no single process, or indicator, capable of tracking the various impacts that manufactured, or durable goods, bring upon the environment. Within certain industries there has been some movement towards identifying what material is used in a product (plastics industry), or the ability to recycle certain parts of a product (Levy, 1993).

The trends in environmental action in the industrial sector have gone the following route:

* Waste treatment
* Pollution prevention in the manufacturing facility
* Changing packaging and materials used in the manufacturing process

Note, this is not a strict chronological representation; these trends tend to appear and reappear at different times. The Environmental Index attempts to go farther upstream to the design phase of the product. Using the EI, a design engineer could track environmental impact of a product as different materials or processes are investigated. Upper management could use the EI to determine possible future liability problems associated with disposal of a product with a certain (risky?) calculated EI. While the above management concerns could be considered cost arguments Management's aversion to liability issues (variety of negative consequences) can influence whether a product is produced or not. The possible economic calculations and considerations involving the EI are examined in Chapter 6. The EI could also be used as a marketing tool to appeal to consumers, or as a means to reverse engineer a competitor's product and build a new model with a lower EI.

II

LITERATURE REVIEW

Historical Overview

Assigning an index or some quantitative measure to durable goods in regard to their impact on the environment is a relatively new endeavor. As of this point, no body of research has been found that examines work done toward developing an overall environmental index which would reflect both the disposal and manufacturing phase of a product's life cycle. To that end, the EI is being proposed.

The trends in the environmental arena concerning pollution prevention or waste minimization overlap considerably. A rough chronology tends to begin with treatment or containment of wastes. This widespread method of pollution control is very much after-the-fact. Unfortunately, the ability of the environment to absorb the great amounts of waste generated in industrial societies has been strained. Landfills in the USA began to close in the sixties and regulations arose regarding what types of waste could be put into the remaining landfills. In wealthy, land-constrained societies such as Japan, this landfill space shortage has become an important issue. Japan has focused on recycling and incineration and sends only 10% to 20% of the country's unprocessed municipal solid waste to landfills (Hershkowitz and Salerni, 1987).

Another step in the environmentally clean arena of manufacturing is pollution prevention at the manufacturing plant. In its most basic form, this can be accomplished by minimizing the use of materials that end up as waste.

Methods of production can also be altered to minimize pollutant release. An example of this methodology can be seen in the use of vapor degreasers. Many degreasers use (soon to be phased out) Chloroflourocarbon (CFC) based cleaning fluid/vapor. The release of CFC vapors into the atmosphere is believed to be one of the major contributors to stratospheric ozone depletion. Several containment methods can be employed to minimize the unintentional release of CFC vapors from these degreasers. Again, this is a noble effort but it is attacking a problem (symptom) that has already developed.

The next area of pollution prevention has been attempted at various periods during the environmental movement. Manufacturers have realized for some time that fixing environmental problems is best accomplished by first eliminating or reducing the source of the problem. By changing the product's materials, packaging, or both, waste streams or disposal problems can be reduced. For example, some manufacturers have gone to CFC-free foams used in the their products. Other manufacturers have reduced or eliminated certain materials used in their products. Examples include: asbestos used in hair dryers, PCBs used as transformer dielectric material, lead used in paint or painted products, reduced packaging bulk in soap products, silicon used in breast implants, and formaldehyde used in many wood and insulation products. In almost all of the above cases, the reduction or elimination of the pollutant or hazard came after the pollutant present in a product was determined to be dangerous.

Life Cycle View

A much better method to deal with the pollution dilemma is to have an understanding of the potential environmental impacts or hazards of a product during the product's life cycle (before the product is introduced to the public). This life cycle analysis, or viewpoint, has been researched by various parties (Levy, 1993). Life cycle analysis examines the costs - or some other parameter such as energy - needed to produce the product, use the product for its entire useful life, and ultimately dispose of the product. Life cycle analysis gives a more accurate picture of the overall costs, or other parameters, involved in the product's entire life.

Various approaches (research) have been taken to identify and study the environmental impact of products during some of the stages of a product's life such as: disposal, re-refining, re-alloying, remanufacturing, extraction and reuse of used components, and initial manufacture (Jackson, 1993). What follows is a review of this body of literature.

Attempts at Quantifying the Environmental Impacts of Manufactured Goods

While there may not currently be a standardized method of evaluating the total environmental impact of manufactured products (e.g. household or other products), quite a bit of activity has concentrated on quantifying portions of the product's life cycle impact on the environment. What follows is a review of some of the research and activities in the fields relevant to this study.

It is difficult to decide on a starting point to examine - such as design or materials. The following areas of activity are so completely interrelated that it is challenging to single out a topic and begin.

Recycling is so dependent on the following subjects that it is best to not examine it separately. An example is that Design for Recycling comes from the work done on Design for Disassembly, and the work done on Material Selection.

Design

Increasing environmental legislation in various countries is forcing the issue of product design to be closely examined. Many European countries including Germany, the Netherlands, and Switzerland have passed laws that hold the manufacturers responsible for the ultimate disposal of the manufactured goods (Committee on Small Business, 1992). At least 14 countries either already have such legislation in place, or are in the proposed rule making stage.

By being held responsible for the take back phase of the product's life, manufacturers realize that the costs for recycling and/or disposal will be on their shoulders. Therefore the costs, or externalities (see chapter 6), will have to be internalized and passed on as new product cost to the customer. An obvious method of lowering these eventual costs is to design the product initially, for ease of reclamation, or disposal, later. This "green" design philosophy is not currently widespread because presently many of these externalities are simply passed on to everyone (environment and humans), with the costs showing up as possible increased morbidity and mortality rates (Cohrssen and Covello, 1989) and destruction of the nonhuman environment (see chapter 6 on economic analysis).

Design for the environment should take on the Industrial Engineering Concurrent Design philosophy in that all aspects of design should be examined by a range of people. All parties that have an awareness of potential environmental impacts of the final product must have input during the product design stage.

Innovations in computer design software such as the CYCLOPS (Criteria Yielding, Consistent Labeling, Optimization and Precedents-based System) (Navinchandra, 1991) computer program, have been developed which will allow product designers to include various parameters for design. Several of these design parameters could be manufacturing effects on the environment, recyclability, and disposability. For that matter, a defined

Environmental Index such as proposed by this paper could be one of the design software's search criteria.

Design for Dis(assembly)

Probably the best known work in the area of design for assembly and disassembly is that produced by Boothroyed and Dewerst (1983). In their disassembly model, the main metric is cost due to labor time. The labor time will vary depending on the type of task that must be accomplished in order to separate the component parts into their most elemental pieces. Component fastening methods are a major variable in this model.

Chen, NavinChandra, and Pritz (1994) suggested the following rules for design engineers to use in design for disassembly:

* Choose joints that are easy to disassemble.
* Simplify and standardize component fits and interfaces.
* Identify separation points.
* Use water soluble adhesive whenever possible.
* Label materials to ease identification and separation.
* Layout plastic parts close to the top of the level of the disassembly path.
* Design for ease of handling and cleaning of components.
* Choose easy separating joints for parts which have reuse value.
* Provide "easy to see" access for disassembly.
* Use rust proof joints if parts are exposed to harsh environments.

* Use the same size of joints (same system) for adjacent parts.
* Provide access for hand tool and power tool operation.

The Chen, NavinChandra, and Pritz model also uses cost (dollars) as the metric.

Volkswagen of Germany has begun to code all of the plastic parts in their new car models. This will allow auto dismantlers to identify and sort the different types of plastics. Volkswagen has also considered the idea of using quick release fasteners for the disassembly of cars (The Economist, 1990).

General Motor's Saturn line of cars is designed with plastic body panels that can be remolded. Presently these panels are used because factory defects can easily be fixed but these designs could be used in the disassembly/recycling stage of a product's life.

Materials

Material selection is a key issue in whether a product's parts may be easy to manufacture and recycle. Product materials usually fall into one of three categories: plastics, glass, and metals. A separate examination of each of these material categories follows.

Plastics. Products contain more plastic now than any time in history. Plastic parts are fairly easy to form and do not require the large amounts of energy (thermal) that glass or metal require in the forming process. Because of this, one would expect plastics to be perfect candidates for recycling. But plastics bring a unique set of problems to the reclamation equation.

Plastics vary considerably between types. Many plastics are incompatible with each other. When these different types of plastics are mixed together, they tend to form brittle, low quality material (Hegberg, Brenniman, and Hallenbeck, 1992). This implies that plastic parts would have to be carefully separated and grouped according to type. This could cause a recycling program to fail when dealing with large amounts of mixed waste, as the German government discovered after the passage of the Toepfer Decree (Fishbein, 1994). Collecting the waste plastic was no problem; the manual separation of different types of plastic proved to be economically infeasable (virgin material was still less expensive) (Fishbein, 1994). (The labeling of different plastics will be covered in another section.)

Research is ongoing regarding turning waste plastics into liquid products (Manufacturing Chemists Association, 1974). Firing plastics at 1,000 degrees Fahrenheit in the absence of oxygen (pyrolysis) produces liquid petroleum products, carbon, and gas products. Plastics can also simply be burned for their Btu content.

Glass. Like plastics, glass has to be sorted if it is to be recycled. Glass is usually sorted according to color. The color categories are:

* Clear or Flint glass
* Brown or Amber glass
* Green glass

Glass can become easily contaminated with metal, ceramic, and other mineral products. Because of this, the glass must also be sorted for the amount of contamination present.

The major benefit of recycling glass is in the energy savings to produce the finished product. It is much easier to produce glass products from recycled "cullet" than having to start with raw materials. The energy savings can run from 50 to 90 percent. This is accompanied by a corresponding drop in air pollution emissions due to the lower energy requirements.

Metals. Metals probably have the oldest history of recycling. Metal properties make these materials almost perfect candidates for reuse. Pure metals can be melted and reused almost indefinitely. Care must be taken to ensure that certain metals do not get mixed together before melting. Small amounts of copper can contaminate steel and produce an end product that is very low quality steel.

In 1993 the United States used 46.3 million metric tons of ferrous scrap at a delivered value of 5 billion dollars (U.S. Bureau of Mines, 1993).

Aluminum is a good example of a metal reclamation effort that is economically sound. The driving force in aluminum recycling is the savings in energy costs to produce the aluminum product from existing metal versus raw material (bauxite ore).

Producing aluminum out of bauxite ore requires 9 times the amount of energy to process recycled aluminum (Sullivan, 1992).

Labeling

The plastics industry has already experimented with labeling products for possible future recyclability. The familiar recycling symbol made of three arrows forming a triangle with a number from 1 to 7 inside with the plastic material's acronym underneath the triangle can be found on many plastic products today (Levy, 1993). The symbol can be used to facilitate the eventual sorting of the different kinds of plastics. Unfortunately, as of this writing, raw virgin material is less expensive than sorted, recycled material (Economist, 1993).

The attorneys general of several states have formed an ad hoc committee to study the problem of companies using false advertising claims and labels on products. The committee generated the Green Report II in May of 1991 (Sullivan, 1992). This report recommended that environmental claims and labels be as specific as possible about the environmental benefits derived from the product. The committee also recommended that all claims be scientifically verifiable.

The Northeast Recycling Council (NERC) has suggested that product labels be specific as to reusability, recycled content, and recyclability. Labels would also include information on the material composition (percentages and volumes) of the product in question.

Packaging

Packaging makes up a substantial volume of post consumer waste. In 1984 packaging comprised about 42.2 percent of all post consumer wastes (Curlee, 1986). For this reason, many countries are concentrating on product packaging (source reduction) as a means to reduce landfill and incineration material.

The German Toepfer Degree advocated that manufacturers use recyclable packaging for their products. This produced some opportunities for waste management companies, but for the most part, added to the complexity of the now faltering decree.

In addition to requiring that packaging be recyclable, the Toepfer Decree required that German manufacturers implement a "take-back" policy on all companies that use packaging on their products. The packaging was put into three categories: transport packaging, sales packaging, and secondary packaging. This forced the manufacturers to consider packaging in the life cycle costing of products. This in turn raised the initial prices on some products.

Disposability

The Agency for Toxic Substances and Disease Registry (ATSDR) has produced a list of the "Top 20 Substances". This is a ranked list showing what ATSDR considers the most harmful (for humans) substances that people might be exposed to from waste sites. In a way this is also a ranking of the relative (non)desirability of disposing of these substances in certain manners (e.g. landfills)(Moses 1988).

Literature Review
Summary and Conclusion

Currently, there is no quantitative method of comparing the overall environmental impact of one product versus another. Industrial upper management has been forced to make educated guesses regarding possible environmental (liability) problems associated with a new product line (source). With the certain increase in environmental penalties and costs levied against polluters, it seems logical that at some point, the producers of products could be liable for the pollution created during the disposal phases of the product's life-cycle. A manufacturer listed as a potentially responsible party (PRP) under EPA's superfund (CERCLA) could pay future penalties for having its products disposed of in an improper manner.

III

METHODOLOGY

Research Methodology

The major sections of this chapter include: Type of Research Study; Overview of Approach; Data Collection; Validation of the Environmental Index. Subsections are included within several major sections.

Type of Research Study

This chapter outlines an exploratory study into the validation of a methodology for defining and constructing a two part environmental index (EI) which would accurately describe the environmental impact, or risk of impact, by the manufacturing and disposal phases of a household durable good's life cycle. The research was applied in that the constructed environmental index could be used by engineers and environmental professionals to evaluate actual products. The research attempted to validate this environmental index model by surveying industry environmental "experts" as to their opinion of the ability of the model to perform its intended task of identifying environmental impacts of products. The research was qualitative in that the two subindicies that make up the environmental index (MPI, and DI) are based on expert judgments, which are later manipulated into indices. Finally, the research was exploratory in that the EI has not been previously defined. This research was an attempt at providing a methodology towards the definition of the environmental index with the full knowledge that further research is needed and may support or rework the environmental index.

Data Collection

The type of data used in this research falls under the category of descriptive survey data. Questionnaires are given to the overall environmental experts for suggestions and comments. Examples of the questionnaires are given on the next page.

Overall EI Validation Questionnaire

The overall environmental experts were given a full copy of the preceding three chapters of this paper. This provided the experts with an understanding of the workings and methodology of the environmental index (EI). A full write up of the analysis of the blender components with corresponding EI code was given to the experts. An example of the blender component analysis and EI coding is provided at the end of this chapter. An example of the main expert questionnaire is also provided in Figure 3.2.

Overview of the Research

What follows is a description of how the research was accomplished. A process-type flow diagram (Figure 2.) was provided to assist in the understanding of the research method description.

Review Body of Knowledge

This research begins with a review of the current body of knowledge in the area of quantifying environmental harm/benefit or risk of manufacturing processes, recycling schemes, and disposal methods. This review has been addressed in Chapter 2 of this paper. Material that has been selected from other research has been referenced in Chapter 2.

Formulate Environmental Decision Tree Model

The second step in the research method was to define and construct the environmental index (EI) decision tree model. A description of the model is given in Chapter 2. A tree diagram representing the EI model (Figure 1) is shown on page 3.

Select Durable Good's Components or Parts

The third step in the research method was to select a "typical" household durable good. For the purposes of this

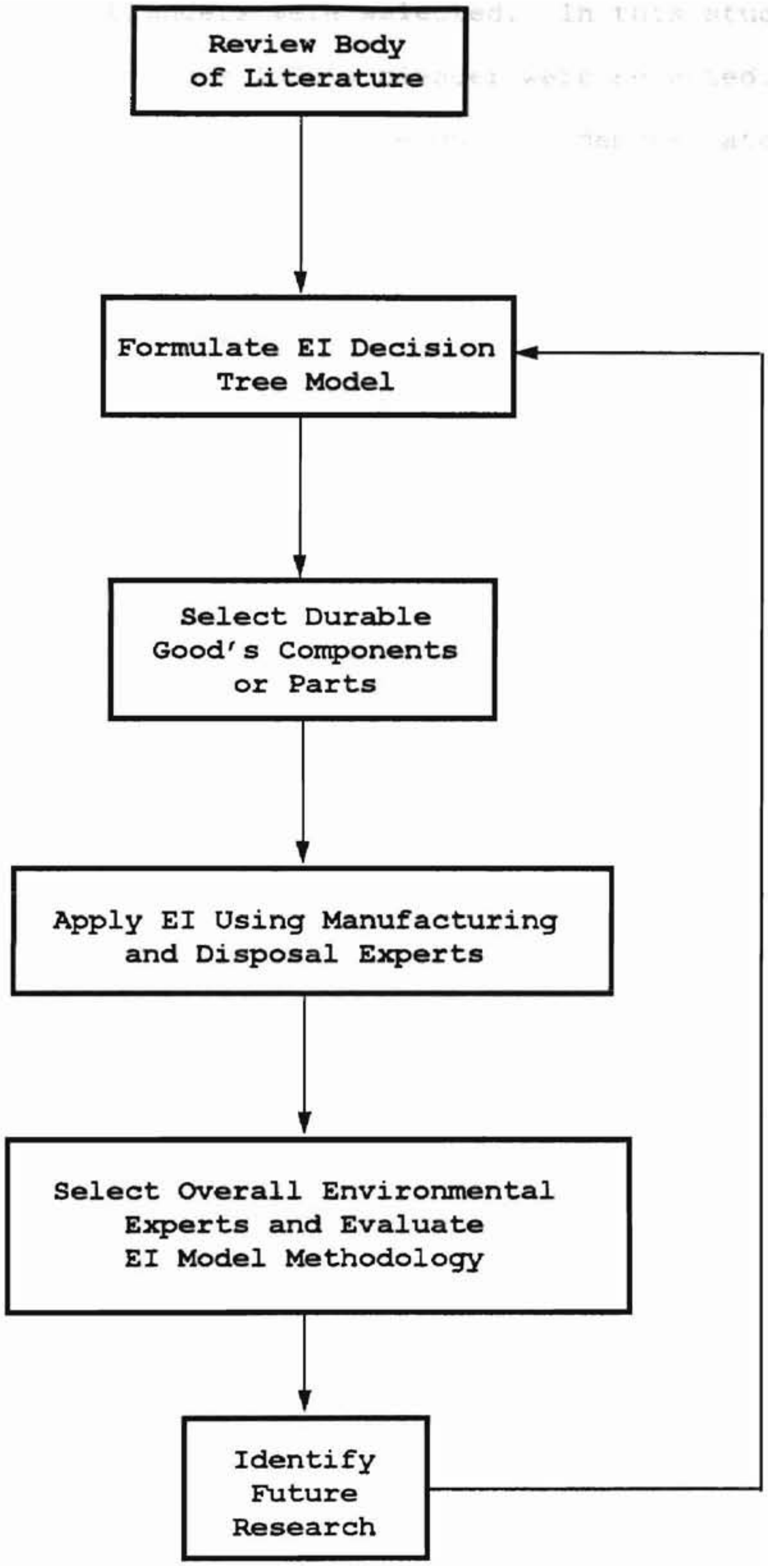

Figure 2. Overview of Research Method

study, two table-top blenders were selected. In this study, a 1960's vintage blender and a 1990's blender were selected. From each blender, three components will be used to demonstrate the EI: the food container, the metal blending blades, and the base of the unit (shell). The materials used in the two blenders (old and new) would probably be different, and this should be reflected in the two EI's generated by the blenders' components.

Apply EI Using Manufacturing Experts

The fourth research step was to choose the manufacturing experts for the determination of the MPI and apply the manufacturing process index and disposability index to the blender components. In the case of the MPI, three manufacturing experts provided manufacturing processes for the blender parts used and identified the waste streams associated with these processes. These waste streams were then categorized using the code of federal regulations regarding types of waste (40CFR 260 - 268). The waste streams were then ranked using a scale that represents the relative environmental danger posed by the particular categorized waste streams.

The disposability index (DI) uses the work done by Scott Moses (1988). In this index, possible disposal options (see Figure 1.) were be ranked by a scale developed by Moses which depicts perceived environmental risk for different disposal options.

At the end of this step, a two part alpha-numeric EI was assigned to the blender parts.

Select Overall Environmental Experts and Evaluate EI Model Methodology

Once the EI model has produced an alpha-numeric code for the durable good (or components), in the fifth step, the overall environmental experts were selected (2 to 8 experts). The selection criteria for the overall environmental experts were the following criteria:

* Possess a broad view of the environmental arena.
* Have no specific interest in a particular environmental field (e.g. water, air, solid waste, etc.).
* Have practical (industrial) experience with environmental issues.

These experts were shown the EI model methodology and the particular application to the selected product. The methodology and coding process were explained in detail to the environmental experts and they were then asked the questions shown in Figure 3 (questionnaire) regarding the EI and its methodology. The experts were then asked to critique the EI methodology.

Identify Future Research

On the questionnaire shown in Figure 3., the experts were asked to give suggestions regarding problems with the methodology and/or changes they thought needed to be made. This information is to be used in future research and will reenter the research method at the second stage (formulate EI decision tree model). The suggestions could be used to improve or reconstruct the EI model.

Also, this section will describe future research and uses for the EI. For this paper, this is the final step of the research method.

ENVIRONMENTAL INDEX QUESTIONNAIRE

Given the product example provided:

1) Please describe areas where you felt that the Environmental Index did a good job (all areas from process description to ranking of disposal options to overall methodology).

2) Please describe areas where you felt that the Environmental Index could be improved or changed (all areas from process description to ranking of disposal options to overall methodology).

3) Please suggest how the areas identified in 2) could be improved or changed.

4) Please include any comments you have regarding the overall research.

Figure 3. Overall Environmental Expert Questionnaire

IV

FINDINGS

Reevaluation of the Original EI Formulation

During the literature review and case study phases of this paper, it became apparent that parts of the original decision tree model (see Chapter 1) would have to be changed. What follows are the changes, with explanations, to the original model.

The manufacturing process Index (MPI) was to use a scoring system based on ranking the process wastes according to some accepted overall list (EPA, International etc.) ranking wastes from little harm, or risk, to greater harm, or risk. Such an overall list does not exist. There are types of waste rankings within parts of regulations but these rankings are usually specific in regard to some effect on human health and the environment. For example, there is a ranking system (EPA) for carcinogens (A,B1,B2,C,D) where A is "humans carcinogen, with sufficient evidence from epidemiological studies" to D which is "evidence of noncarcinogenicity for humans". For pollutants that are not carcinogenic, but toxic, there is a type of ranking in that the pollutant materials are assigned doses at which they are lethal to humans. These two ranking systems are separate and can not be directly compared.

Sometimes a pollutant can show up in several different ranking systems. Benzene is a good example. Benzene is a listed carcinogen. Benzene is acutely lethal at certain doses. Benzene is also flammable and is classified as a physical hazard.

What makes one waste worse than another varies according to quantity of material, type of discharge, environment in which it is located, storage versus release, and a myriad of other concerns. An index that could capture all of these descriptions would be several pages long.

The revised MPI does not take quantity of waste generated into account but simply looks at which medium the pollutant is released into (air, water, hazardous waste (land), and other). In this way the MPI gives the manufacturer a dynamic (accumulating) indicator of what types of disposal methods or regulations will have to be dealt with by manufacturing a product with certain materials and certain processes.

It must be pointed out that future research into the EI must capture the quantity of waste generated and must somehow quantify the nature of the waste (i.e. a manufacturer would probably be more interested in a kilogram of dioxin than a kilogram of lead dust).

Another issue is that a particular waste may show up in more than one medium. Volatile solvents may produce hazardous waste sludge and at the same time give off air borne vapors (air pollutant). In these cases the EI will examine the implicit threshold quantities of the pollutants produced in order to determine if one waste can show up in the EI as affecting more than one medium.

Present EI Formulation

The EI, as presently conceived, is composed of elements laid out in a two branch decision tree configuration (see Figure 4.). The first, or top-most level, is the final environmental index (EI). The second level contains the two major subindices of the EI: a manufacturing process (MPI) and a disposability index (DI).

Levels below the MPI and DI contain the factors and data by which the MPI and DI are derived. In the case of the MPI, the process, or processes, for a particular single part or component are identified. The waste streams created during the process(es) are also identified. The mediums that these waste streams effect (e.g. (A)ir, (W)ater, (H)azardous waste, (O)ther media) are identified (S for solid waste in future research). By keeping records, an eventual library of processes and associated waste streams could be created. All of the mediums effected by the waste streams involved with the particular component or subassembly are summed together and displayed as the MPI. The MPI is an alpha numeric code.

The second level of the decision tree model contains the other immediate subpart of the environmental index, the disposability index (DI).

ENVIRONMENTAL INDEX DECISION TREE MODEL

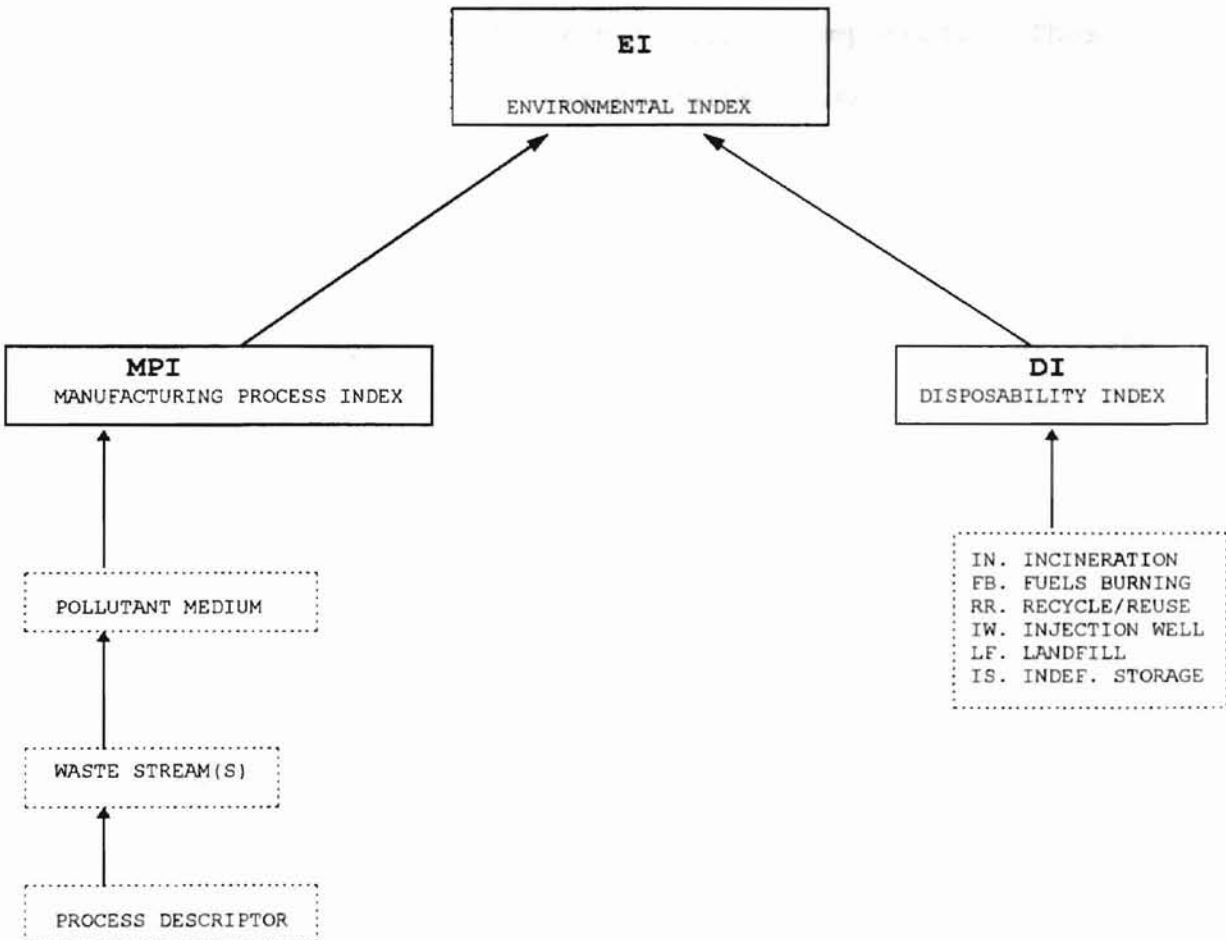

Figure 4. Reevaluated EI Model

The disposability index has ranking factors (disposal options) that reflect the best (in regard to perceived future liability), current disposal method for a particular component. These ranking factors tend from less perceived risk of future liability (environmental harm) for a disposal option, to greater perceived risk (e.g. incineration to indefinite storage) for a particular mass of material. These rankings come from a survey of industrial environmental professionals done by Moses (1988). The rankings are displayed as a two part alpha code (IN through IS) with IN being the

least perceived risk, to IS, the most perceived risk. For a multicomponent product, several disposal methods might appear.

The Environmental Index that results (top level) is a two part, alpha-numeric code such as [A12W6H1/1IS1LF]. The (M)anufacturing "A12W6H1" demonstrates the total durable good's (or particular component) number of waste streams and their effected mediums (environmental impact) due to the manufacturing process involved. In this case there are twelve air pollutants, six water pollutants, and one hazardous waste.

The Disposability "IS,LF" refers to the projected best type of disposal method(s) needed, and the perceived risk by industrial environmental professionals of future liability involved with this particular disposal method. In this case there are two disposal methods (IS-indefinite storage and LF-landfill) indicated for at least two of the product's components. The EI is a relative measure of environmental impact or risk. The EI scale does not give absolute measures to be compared to a master listing that could be referenced.

Case Study Application

Manufacturing Processes and Associated Wastestream Identification

What follows is a case study where the EI is applied to three components from an old, and new, food blender. The blender parts included: the beater blades, the food containment vessel, and the base (not including motor and hardware).

The old and new blender parts were shipped to the Materials Sciences Division of the Department of the Army in Corpus Christi, Texas. The parts were examined by two manufacturing engineers and an industrial chemist. These people have 37 years of combined experience in the manufacturing and materials field. As such, they are familiar with the manufacturing processes and wastestreams involved with the blender parts.

Old Blender: Process and Waste Identification

Beater Blades:

The metal beater blades were a type of stainless steel (304 C.R.E.S.). The processes involved in forming the final blades would be as follows:

1) Sheet stock sheared into strips.

2) Strips placed into a fixture to punch the center hole.

3) Strips placed into a fixture and formed.

4) Edges deburred and ground.

5) Final part cleaned in vapor degreaser.

By-Products:

1) 1-1-1 Trichloroethylene (degreaser)

2) Spray Lube

3) Spray Lube Propellant (Chlorofluorocarbons)

4) Metal Trimmings

5) Grinding Dust (10% Nickel, 19% Chromium, 71% Steel)

6) Grinding Wheel Dust (Silicon Carbide)

Blender Base:

The old blender had a cast metal base. The processes involved in forming the metal blender base would be as follows:

1) Zinc metal (probably AG-41A) heated to molten state, probably gas fired.

2) Metal injected into mold.

3) Part pushed out by ejector die (no release agent needed).

4) 8 holes drilled and tapped.

5) Top of base sanded to remove flash metal.

6) Copper plate activated in acid.

7) Base rinsed in water.

8) Base plated with nickel.

9) Base rinsed in water.

10) Base plated with chrome.

By-Products:

1) Lead (dust)

2) Nickel (dust)

3) Cadmium (dust)

4) Hexavalent Chromium (sludge)

4) Perchloroethylene (degreaser)

5) Cyanide

Glass Canister (Food Container):

The old blender had a glass food container. The processes involved in forming the glass container would be as follows:

1) Sodium and potassium added to refined sand.

2) Compound heated to molten state.

3) Molten glass injected into mold (no release agent required).

By-Products:

1) Sodium and potassium fumes

2) Scrap glass

New Blender: Process and Waste Identification

Beater Blades:

Like the old blender blade, the new metal beater blades were also stainless steel (304 C.R.E.S.). The processes involved in forming the final blades would be as follows:

1) Sheet stock sheared, punched, and formed in one operation.

2) Edges deburred and ground.

3) Final part cleaned in vapor degreaser.

By-Products:

1) Terpene Solvent (degreaser)

2) Spray Lube

3) Metal Trimmings

4) Grinding Dust (10% Nickel, 19% Chromium, 71% Steel)

5) Grinding Wheel Dust (Silicon Carbide)

Blender Base:

The new blender had a plastic base. The processes involved in forming the plastic blender base would be as follows:

1) Polypropylene (PP) powder or pellets placed in injection molding machine.

2) Polypropylene heated to molten state.

3) Molten plastic injected into mold.

4) Plastic (PP) cured in mold.

5) Dies opened and blender base ejected (no release agents needed).

By-Products:

1) Propylene gas and other volatile organic compounds (VOC)

2) Titanium Dioxide (pigment)

3) Plastic scraps

Clear Plastic Canister (Food Container):

The new blender had a clear plastic food container. The processes involved in forming the plastic container would be as follows:

1) Polymethyl methacrylate slurry delivered to end user. Note: If end user manufactures slurry, there are several more waste streams (end user usually does not manufacture slurry).
2) Thermoplastic slurry injected into mold.
3) Plastic is cured in mold.
4) Die opened and container ejected (no release agents needed).

By-Products:

1) Some volatile organic compounds (VOC's) are released as fumes
2) Plastic scraps

Application of the EI to Old and New Blender Parts

The parts of the blenders examined were: the food container, or vessel, the metal blades used to chop and blend whatever is in the food container, and the base of the unit where the motor is located (the motor was not examined in this study). What follows is a list of the process wastes and disposal methods best suited for the component in question that would enter into the EI calculation. Finally, the two EI's for the old and new blender parts are calculated and examined.

Old Blender Parts

Blades:

1-1-1 Trichloroethylene (degreaser) = Hazardous Waste (H)

Spray Lube Propellant (CFC) = Air pollutant (A)

Chromium (grinding Dust) = Hazardous Waste (H)

Disposal Method Needed (Blades) = Recycle Scrap (RR)

Plated Blender Base:

Lead (fumes and dust) = Hazardous Waste (H)

Cadmium (fumes and dust) = Hazardous Waste (H)

Hex. Chromium (mist) = Hazardous Waste (H)

Perchloroethylene (degreaser) = Hazardous Waste (H)

Cyanide (used in plating) = Hazardous Waste (H)

Disposal Method Needed = Landfill (LF)

Glass Food Container:

Sodium and Potassium (fumes) = Air Pollutant (A)

Disposal Method Needed = Recycle (RR)

New Blender Parts

Blades:

Chromium (grinding dust) = Hazardous Waste (H)

Disposal Method Needed = Recycle (RR)

Plastic Blender Base:

Volatile Organic Compounds (gas) = Air Pollutant (A)

Disposal Method Needed = Recycle (RR)

Clear Plastic Food Container:

Volatile Organic Compounds (gas) = Air Pollutant (A)

Disposal Method Needed = Recycle (RR)

Environmental Index for Old Blender Components is **H7A2/2RR1LF.** The Environmental Index for New Blender Components is **H1A2/3RR.**

Examination of the two EI's show that the older components generated considerably more hazardous waste. The older components also had at least one part, or component, that needed to be landfilled.

V

OUTSIDE EVALUATION OF ENVIRONMENTAL INDEX

Survey Method for the Environmental Expert Questionnaire

The environmental experts were chosen from a list of recent participants in the Oklahoma State University Engineering Extension certified hazardous materials seminar program. The reason for this selection pool is that these people are familiar with both waste stream generation and disposal options for various materials. Many of the participants work for manufacturing firms, and as such could comment on the EI's value, or lack of, in pollution prevention.

TABLE I

DEMOGRAPHICS

ENVIRONMENTAL EXPERTS (RESPONDENTS)	TYPE OF WORK FACILITY	NUMBER OF YEARS WORKING IN ENVIRONMENTAL FIELD	NUMBER OF EMPLOYEES
1	MANUFACTURING	5	189
2	TRANSPORTATION (OIL LINES)	8	128
3	MANUFACTURING	5	500
4	ENVIRONMENTAL CONSULTING	4.5	7
5	TRANSPORTATION (AIRLINE)	7	2,800
6	MANUFACTURING	12	156
7	MANUFACTURING	4	89
8	ENVIRONMENTAL CONSULTING	6	10

The participants come from many different locations in the nation, and this lends possible different views based on individual states' legislation. Some of the expert's demographics are shown in Table I. The experts were contacted by telephone to determine if they would be interested in participating in this survey (questionnaire). If the expert wished to participate, a brief explanation of the EI research was given and then the survey packet (see appendix A) was either sent by facsimile or by mail to the participant. In order to ensure a high response rate, a date and time were scheduled during the initial telephone contact when the expert could be called back and interviewed over the telephone regarding the four questions in the survey packet questionnaire.

At the agreed date and time the expert was contacted by telephone and asked if he or she wanted to participate in the survey and questionnaire. Some of the participants needed to reschedule the survey to a later date. In these cases a new date and time was agreed on and the contact by telephone for the questionnaire proceeded the same as in the first contact. No experts had to reschedule more than once in this study. If prepared to answer the questionnaire, the experts were asked to respond to the four questions starting with question number one. All comments regarding the particular question (1-4) were recorded. After the comments regarding question number four were recorded, the expert was asked if there were any additional comments about the research not asked by the questionnaire that they would like to make. After all comments were recorded, the experts were asked if they would like to receive a final copy of the paper at a later date. (All responded, "yes.)" The actual responses to the survey are in Appendix B. It should be pointed out that the conclusions and opinions expressed in this paper are those of the author and do not necessarily reflect the position of individual respondents or their places of employment.

Implications of Survey Results on the Environmental Index

Several observations can be made from the responses to the questionnaire. There are two large trends apparent in the responses. The first is that all of the environmental experts thought the idea (EI) had merit. Some of the respondents were enthusiastic about the concept (see responses to question 1. in Appendix B). This shows that the concept has validity with outside experts.

The other trend that shows up in the survey results is the need to get the Environmental Index (and subindicies) into a more numerical form (see responses to question 3. in Appendix B). In numerical form, the EI is more adaptable to various forms of analysis, such as decision theory or economic analysis. This fact was apparent early in the study, long before the surveys. At the time it proved such a barrier to continuation of the study that a more qualitative approach was taken. Even so, this has not prevented the current EI from being used in a decision matrix in which it (the EI) seems to function well. The issues of the EI's use with decision theory and economic analysis are examined in Chapter 6.

Two singular responses to the survey should be considered for incorporation directly into the next generation EI. Solid waste should be added to the mediums under the Manufacturing Index (see responses to question 3. in Appendix B). It would probably show up as an "S". The respondent correctly pointed out that solid waste sites often become future clean-up locations. When this occurs, many of the site's users can become entangled in the legal and financial trouble that ensues. Therefore these types of wastes that occur in a manufacturing process would need to be included in the EI.

Another interesting response was that of having the EI be site specific (see responses to question 4. in Appendix B). In other words, within each facility, or even within a group of manufacturing cells, people (or computers) would be comparing EI's for processes and materials. This would tend to eliminate some of the dilution that the "global" EI experiences when trying to describe the maximum number of possible scenarios.

VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

While the Environmental Index (EI) is an interesting idea, to be of any real use, applications of the EI need to be demonstrated. In its present form, the EI can be used in elementary decision theory and economic analysis (for proposed or existing projects, or products).

Decision Theory

Decision theory is a field of study that attempts to analyze the consequences of various actions (Gardenfors and Sahlin, 1988). A typical use of decision theory is to find the most rational solution to a complex problem. Often these problems involve risk, money, or limited resources. The current EI operates in the realm of money and risk.

Classical decision theory can include linear programming, probability theory, and utility theory (Lindgren, 1971). A tool that is often used in this field is known as a decision matrix. This analysis tool can take on various forms. A typical decision matrix might compare a set of parameters such as failure rates of certain components in a product to different locations of product manufacture (see Figure 5.).

LOCATION OF MANUFACTURER / FAILURE RATES OF COMPONENTS (%)	MD	OK	AR	VA	TX	AZ	MI
COMPONENT A	0.0023	0.0035	0.0018	0.0028	0.0058	0.0026	0.004
COMPONENT B	0.0042	0.0041	0.005	0.0056	0.0042	0.0046	0.0039
COMPONENT C	0.0078	0.0068	0.0059	0.0079	0.0072	0.0062	0.0048
COMPONENT D	0.0012	0.0018	0.001	0.00078	0.002	0.0018	0.0013

Figure 5. Classical Decision Matrix

The cells in a matrix such as this contain numerical values. Classical decision theory always works in the numerical realm. Several of the EI survey respondents noted that the EI would be more useful if its component parts could brought into numerical form. The survey respondents may have envisioned the EI working in this type of numerical decision matrix (one respondent mentioned the term "decision matrix"). As mentioned previously, at this point the EI could not be reduced to a further quantitative (numerical) state.

There is a type of decision matrix that can work with the EI. This type of matrix is often called an evaluation matrix (Pugh, 1991). An evaluation matrix compares "criteria" (rows) to different "methods" in the columns (see Figure 6.). The methods for the EI are the different manufacturing and material methods used in a particular process. For example, method 1 might be a metal baseplate that is plated. Method 2 might be a metal baseplate that is painted. Method 3 might be a plastic baseplate (and so on).

CRITERIA	METHOD								
WASTES	AIR POLLUTANT (A)								
	SOLID WASTE (S)								
	HAZ WASTE (H)								
	WATER POLLUTANT (W)								
	OTHER (O)								
DISPOSAL METHOD	INCINERATION (IN)								
	FUELS BURNING (FB)								
	RECYCLE/REUSE (RR)								
	INJECTION WELL (IW)								
	LANDFILL (LF)								
	INDEF. STORAGE (IS)								
COMPARISON	SUM(+)								
	SUM(-)								
	SUM(S)								

Figure 6. Evaluation Matrix

Usually, one of the methods is referenced as the datum. The datum is usually the closest to optimal solution (method) imagined. The datum might be the part that costs nothing to make, never breaks, uses no resources, or it can be more realistic. The datum is almost never fully attainable because in reality all of the criteria cannot be met. The various different methods (1, 2, 3, ...) are compared to the datum's criteria. There are three possible cell outcomes: better than the datum (+), worse than the datum (-), or same as the datum (S). The bottom row of the matrix displays the summation of all of the (+),(-), and (S) scores for the particular methods. The method that contains the most (+)'s and (S)'s (better than and same as datum) is the optimal method investigated.

An evaluation matrix using the EI would be set up such that the criteria would be the various subparts of the EI (see Figure 7.), such as Air Pollutants (A), Hazardous Waste (H), Water (W), Solid (S), Other (O), and the disposal options (IN-IS). The "methods" would be different manufacturing methods and materials. The industry using the matrix would decide on a datum (method). As different methods are added to the matrix, optimal combinations of manufacturing methods and materials would begin to emerge.

CRITERIA \ METHOD		1	2	3	4	5	6	7	8
WASTES	AIR POLLUTANT (A)	D	(S)	(-)	(+)	(+)	(S)	(-)	(+)
	SOLID WASTE (S)	A	(S)	(-)	(S)	(-)	(+)	(-)	(S)
	HAZ WASTE (H)	T	(+)	(S)	(-)	(-)	(+)	(S)	(S)
	WATER POLLUTANT (W)	U	(+)	(+)	(S)	(S)	(-)	(S)	(-)
	OTHER (O)	M	(-)	(S)	(S)	(-)	(S)	(S)	(S)
DISPOSAL METHODS	INCINERATION (IN)		(S)	(-)	(+)	(S)	(+)	(+)	(-)
	FUELS BURNING (FB)		(-)	(+)	(+)	(-)	(S)	(-)	(+)
	RECYCLE/REUSE (RR)		(-)	(S)	(-)	(+)	(-)	(-)	(-)
	INJECTION WELL (IW)		(+)	(-)	(S)	(-)	(-)	(+)	(-)
	LANDFILL (LF)		(S)	(+)	(S)	(S)	(S)	(S)	(S)
	INDEF. STORAGE (IS)		(+)	(+)	(S)	(-)	(+)	(-)	(+)
COMPARISON	SUM(+)		4	4	3	2	**4**	2	3
	SUM(-)		3	4	2	6	**3**	5	4
	SUM(S)		3	3	6	3	**4**	4	4

Figure 7. Evaluation Matrix with EI

Different industries, or locations, would have different datum's (if the datums reflect reality). For example, one manufacturer might have air pollution control technologies in place in the plant. This manufacturer may not be too concerned about a high air pollution number in the EIs. Therefore the datum for this particular matrix user might have a high "A" value for comparison purposes.

Over time, a comprehensive library of manufacturing methods and materials, and their associated waste streams, and disposal options for a particular type of component may be formed. At this point the evaluation matrix using EIs could even be automated (see section Future Research).

Economic Analysis

There is a reason why industry currently does not do more with issues such as pollution prevention and recycling. Environmental legislation does not cover all aspects of manufacturing. (This is not a judgment as to whether this is good or bad). The idea of social choice in the area of economics has been examined for some time (Arrow, 1951). Currently, most industry has not been burdened with all of the indirect costs placed on society due to the manufacturing and disposing of that particular industry's products. These "passed-on" costs are called externalities (Bromley, 1991).

Externalities are simply unwanted costs that are passed on to others (usually a third party). While the basic concept of the theory of externalities is easy to understand, actually allocating costs to these externalities is very complicated. The area of interest in externality theory for the EI involves marginal expenditure in production and consumption decisions (Bromley, 1991).

An example will be helpful in illustrating this concept. In the past, a manufacturer of kitchen appliances, such as refrigerators and stoves, might simply dispose of wastes (including hazardous wastes) in landfills or waterways, or release pollutants to the atmosphere. The landfills might begin to leach the hazardous wastes into the ground water; the river would then becomes polluted, and air pollution might affect people's health. The manufacturer would be oblivious to this chain of events, and would price its products based on the simple profit method (selling price - expenses = profit, where "expenses" do not include the costs of the externalities).

At some point, the ground water, the river, and the air would have to be cleaned up due to social pressure. These after-the-fact clean ups can be very expensive. Much of the costs would become a burden to the tax payer in the form of remediation, increased burden on the health care system, reduced property values, and others. The appliance manufacturer would have created these externalities, but is not being held accountable for them.

Now, some time later, legislation would have been passed that requires that wastes be disposed of with very specific (expensive) methods. Water and air pollutant releases would be limited and monitored. This is the typical way that externalities are handled in society. Expensive permits would be required in order to manufacture goods under this scenario. Personnel would have to be hired in order to monitor the situation. The manufacturer would now be well aware the costs to the organization. The price of a produced appliance in this situation would be incrementally higher than the product in the unregulated scenario (see Figure 8.). The increase in the manufactured goods' price would cover the expense of pollution prevention and control. The legislation that would impose these expenses is a method of assigning costs to the externalities.

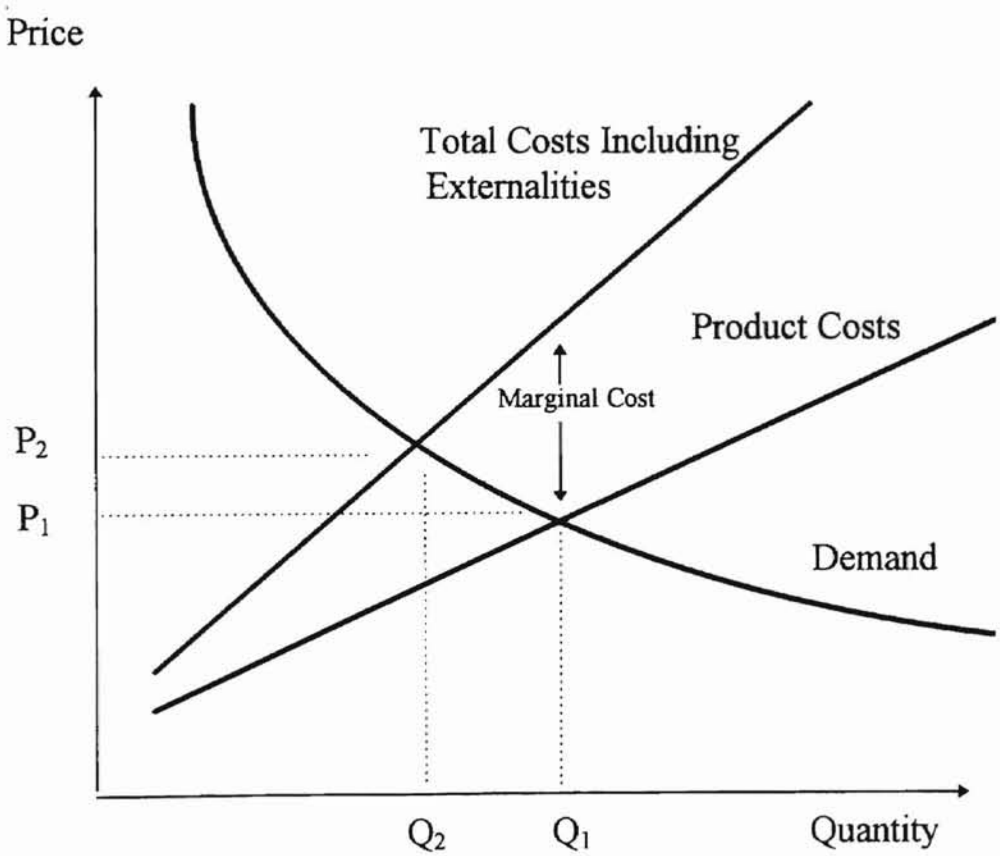

Figure 8. Marginal Costs Due to Externalities

The decision as to whether or not to manufacture a good that produces a certain amount of waste and pollution is called the marginal decision (Aldrich, 1996). For the appliance manufacturer, a marginal decision would be whether or not to manufacture an appliance in such a way that these marginal costs make the product's price too expensive and therefore uncompetitive.

The EI is a tool that can be used to aid the manufacturer considering these marginal decisions. By alerting the manufacturer to higher risk processes and materials in the design stage of a product, or good, the EI would be useful in helping to lower the marginal costs and make the manufacturer's product more competitive. This points to a simple concept. A manufacturer may not need to raise the price of a product to get a higher profit. By reducing the marginal costs due to externalities, the overall cost of producing the product may go down. This combining of decision theory and economic analysis is known as economic decision analysis (Fabrycky and Thuesen, 1980).

Once the externalities are addressed with the marginal costs, they are not really externalities anymore. The environmental index addresses what is arguably another type of externality that occurs during the disposal phase of the durable good. It is unclear who is placing the externalities associated with disposing of durable goods onto society (filling expensive landfills, air pollution from incineration, etc.). Some recent legislation in Europe indicates that governments are quite willing place to this burden on the original manufacturer, not the final user of the good, or product.

The EI (disposability index portion) is useful in that it gives the manufacturer a chance to consider what might show up as a future marginal cost. The future of disposal regulations is unknown, but it would be prudent to assume that they might become more strict for the manufacturer.

Recommended Areas for Future Research

An obvious area for improvement to the current EI design is to further distinguish the wastestreams of the manufacturing process index. Presently, the MPI simply counts the various wastes generated (actually, the mediums, such as water or air, affected). As previously mentioned, some wastes are worse than others. This could be indicated by some ranking system. But how does one rank different wastes (see Chapter 4)?

One of the suggestions from the survey was to make the EI site specific. In other words, the ranking of the wastes would depend on what the manufacturer has to deal with at a specific site. A manufacturer may have very good pollution control technology for some mediums such as water, but may lack control technology for air pollutants. This manufacturer probably will be able to rank some air pollutants as worse than others because all releases will be fugitive emissions which are severely regulated in some areas (Flagan and Seinfeld, 1988). On the other hand, someone may be able to come up with an overall waste ranking, or ranking of perceived risk due to all the various wastes.

Another very important area in this life-cycle type of analysis is the energy used to manufacture the good, and the energy used by the good during its useful life. These embedded aspects of the durable good are very real. This raises an interesting question. What about the pollution created when this energy is used? In the manufacturing portion of the good's life cycle, this externality may be addressed by the manufacturer in the form of pollution controls at the plant (this applies mostly to fossil fuels), or higher cost of electricity so that the electric generating station can implement pollution control technology.

Another area not addressed by the current EI is the possible energy used by the durable good (if the good actually does use energy) during its useful lifetime. In life cycle cost analysis this is a very important issue.

Finally, the most useful incarnation of the environmental index may be in the form of software and computer code. If the EI could be made into a more numerical form, it would be fundamentally simple for a machine to analyze great numbers of manufacturing methods and materials. Such a computer program could be given the desired qualities of the finished product and left alone to run through thousands of different methods until achieving optimality. This form of exhaustive iteration is well known in the mathematical community as a way of finding ranking, or ranking of perceived risk due to all the various wastes.

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Such a computer program could also be made somewhat intelligent. Every time the computer would find an optimal manufacturing method and material (with an associated EI), the program could "remember" the solution compared to the initial desired qualities of the durable good. In this way, the next time a similar request is made of the software, the program could go to a file and pick better "seed" methods to start the iterative search. It is interesting to note that this method of evaluation could be used outside of the environmental field in areas such as optimal product design.

For the software to be useful, it would need to be connected to an updated ranking system for the wastes and disposal methods. This updated database would come from the latest federal and state regulations regarding the wastes and disposal methods.

Concluding Comment

The responses to the questionnaire indicate that, from the small sample of surveyed professionals, the model has validity, and could be currently used in some form in the marketplace or industry. The survey responses also indicate that there appears to be two distinct ways of using the EI. The EI can be used as a demonstration tool to show people (not necessarily technical professionals) the possible ramifications of certain processes

SELECTED BIBLIOGRAPHY

Aldrich, J. R. (1996). Microeconomics. Pollution Prevention Economics: Financial Impacts on Business and Industry. (pp. 1-38). New York: McGraw-Hill.

Arrow, K. J. (1951). Notes on the theory of social choice. Social Choice and Individual Values. (pp. 102-105). Cowles Foundation for Research in Economics at Yale University.

Baum, B., & Parker, C. H. (1974). Plastics Waste Management. Prepared for Manufacturing Chemists Association by DeBell & Richardson, Inc. (pp. 26-36). Washington D.C.

Bromley, D. W. (1991). Property rights and externalities. Environment and Economy. (pp. 59-78). Cambridge: Basil Blackwell, Inc.

Chen, R. W., Navinchandra, D., & Prinz, F. B. (1994). A cost-benefit analysis of product design for recyclability and its application. IEEE Transactions, 17, 502-506.

Cohrsson, J. J., & Covello, V. T. (1988). Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks. U.S. Department of Commerce. (NTIS No. PB89-137772).

Committee on Small Business. (1992). House of Representatives, one hundred second congress, second session, hearing before the subcommittee on environment and employment. (Serial No. 102-63). (pp. 61-63). Washington D.C.: U.S. Government Printing Office.

Cummings, R. G., Brookshire, D. S., & Schulze, W. D. (1986). Historical perspective for the CVM assessment. Valuing Environmental Goods. (pp. 10-21). New Jersey: Rowman & Allanheld.

Curlee, T. R. (1986). Economics. The Economic Feasibility of Recycling: A Case Study of Plastic Wastes. (pp. 82-83). New York: Praeger Publishers.

Fabrycky, W. J., & Thuesen, G. J. (1980). Linear programming models. Economic Decision Analysis. (pp. 355-357). New Jersey: Prentice-Hall, Inc.

Fishbein, Bette, K. (1994). Germany, Garbage and the Green Dot. Washington D.C.: U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory.

Flagan, R. C., & Seinfeld, J. H. (1988). Introduction. Air Pollution Engineering. (pp. 14-15). New Jersey: Prentice-Hall, Inc.

Gardenfors, P., & Sahlin, N. (1988). Introduction: Bayesian decision theory - foundations and problems. Decision, Probability, and Utility. (pp. 1-5). Cambridge Press: Cambridge.

Hegberg, B. A., Brenniman, G. R., & Hallenbeck, W. H. (1992). Mixed Plastics Recycling Technology. New Jersey: Noyes Data Corporation.

Henstock, M. E. (1988). Design for Recyclability. Vermont: The Institute of Metals.

Hershikowitz, A., & Salerni, E. (1987). Landfills. Garbage Management in Japan: Leading the Way. (pp. 103-110). New York: INFORM, Inc.

Houck, G. H. (1994). Recycling Iron and Steel Scrap (1993 Annual Report). Washington D.C.: U.S. Bureau of Mines.

Jackson, T. (1993). Clean Production Strategies: Developing Preventive Environmental Management in the Industrial Economy. London: Lewis Publishers.

Levy, G. M. (Ed.). (1993). Packaging in the Environment. Chapman and Hall: London.

Lindgren, B. W. (1971). Preliminaries. Elements of Decision Theory. (pp. 1-3, 31-33). New York: The Macmillan Company.

Moses, S. A. (1988). Liability Exposure of a Hazardous Waste Generator: A Preliminary Assessment of Certain factors. Oklahoma State University, Stillwater.

Navinchandra, D. (1991). Putting it all together: A detailed architecture of CYCLOPS. Exploration and Enovation in Design. (pp. 111-114). New York: Springer-Verlag.

Pugh, S. (1991). Design core: conceptual design. Integrated Methods for Successful Product Engineering.(pp. 74-86). Cornwall: Addison Wesley.

Recycling cars: Mass destruction. (1990, November 10). The Economist, 317, 82-83.

Second Time Around: Recycling to extremes. (1993, May 29). The Economist, 327, 8-12.

Sullivan, T. F. P. (Ed.) (1992). The Greening of American Business: Making bottom line sense of environmental responsibility. Rockville, Maryland: Government Institutes, Inc.

APPENDICES

APPENDIX A

SURVEY PACKET FOR ENVIRONMENTAL EXPERTS

MEMO

FROM: Scott Frazier

TO: ______________

RE: THESIS SURVEY

Thank you very much for taking the time to review the attached survey. Basically it is an abbreviated version of the next to last chapter of my thesis paper. The last chapter will include the comments from industry professionals such as yourself.

I have worked for Dr. Turner in the HAZMAT and energy management areas while attending the Industrial Engineering and Management College at Oklahoma State University. I received my BSIE at OSU in 1993 and am currently pursuing an MSIE. If you have any questions that Dr. Turner could answer regarding this research, he can be reached at 405-744-6055.

If you would like a copy of the complete paper when it is finished, please let me know when I call to get your observations of the survey. My call to you for your responses is scheduled for ____ _M (your Time) on ___________. If you have any questions, or need to reschedule I can be reached at E-mail: fraziers@smeco.com, or fax 301-274-4455, or call phone number 301-274-9299 ext. 4020. I will reimburse the cost of the call.

Again, thank you for your time and interest in this endeavor.

Thank you for your time and assistance with this research survey. My thesis consists of a proposed Environmental Index (EI), an example application of the index on actual manufactured components, and a survey of professionals working in the manufacturing and environmental areas.

The EI is to be used as a concurrent engineering tool. The EI would allow manufacturers to examine the possible risks of using different materials and manufacturing methods on a particular product. The EI could eventually be used in a decision matrix application.

If possible I would like you to examine the packet literature and example. The last page of the packet is an example questionnaire. Please look the questions over and I will contact you by phone on the agreed date to get your observations.

This packet consists of:

1) This cover page.

2) A short description of the Environmental Index formulation.

3) Results of the application of the EI to actual product components.

4) A short questionnaire to examine.

Again, thank you for your time and assistance with this. I know that you are busy. If you would like a copy of the completed thesis at a later date please let me know when I call for the survey observations and I will be happy to send you the entire paper.

Scott Frazier, BSIE

The EI, as presently conceived, is composed of elements laid out in a two branch decision tree configuration (see Figure 1. on the next page). The first, or top-most level, is the final environmental index (EI). The second level contains the two major subindices of the EI: a manufacturing process index (MPI) and a disposability index (DI).

Levels below the MPI and DI contain the factors and data by which the MPI and DI are derived. In the case of the Manufacturing Process Index, the process, or processes, for a particular single part or component are identified. The waste streams created during the process(es) are also identified. The mediums that these waste streams effect (e.g. (A)ir, (W)ater, (H)azardous waste - land disposal, (O)ther media) are identified. By keeping records, an eventual library of processes and associated waste streams will be created. All of the mediums effected by the waste streams involved with the particular component or subassembly are summed together and displayed as the MPI. The MPI is an alpha numeric code.

The second level of the decision tree model contains the other immediate subpart of the environmental index, the disposability index (DI). The disposability index has ranking factors (disposal options) that reflect the best (in regard to perceived future liability) current disposal method for a particular component. These ranking factors tend from less perceived risk of future liability (environmental harm) for a disposal option, to greater perceived risk (e.g. incineration to indefinite storage) for a particular component. These rankings come from a survey of industrial environmental professionals done by Scott Moses in 1987. The rankings are displayed as an alpha letter, IN through IS, (see Figure 1. below) with IN being the

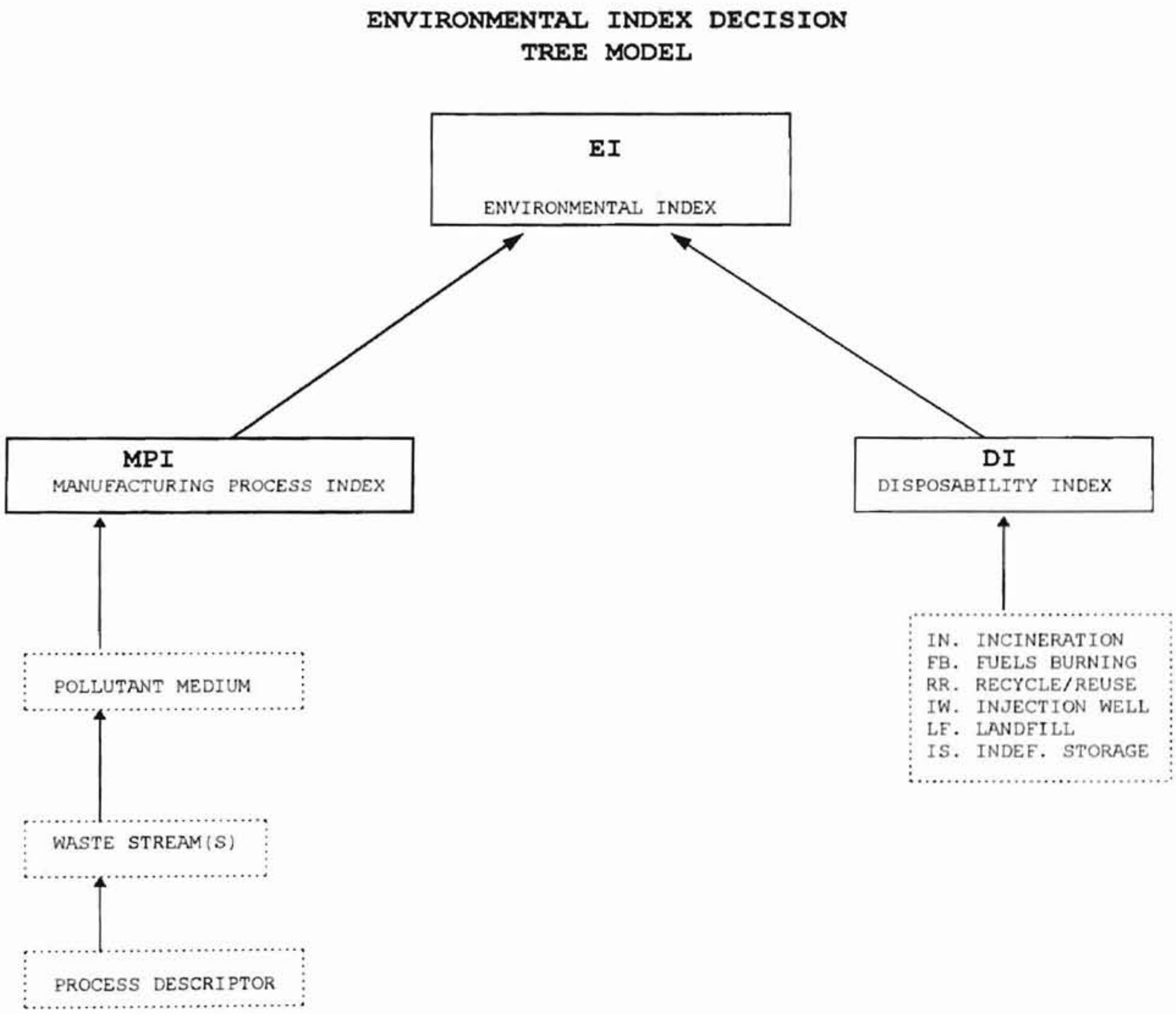

Figure 1. Environmental Index Decision Tree Model

least perceived risk to IS, the most perceived risk. For a multicomponent product several disposal methods might appear.

The Environmental Index that results (top level), is a two part, alpha-numeric code such as [A12W6H1/1IS1LF]. The "A12W6H1" demonstrates the total durable good's (or particular component) number of waste streams and their effected mediums (environmental impact) due to the manufacturing process involved. In this case there are twelve air pollutants, six water pollutants, and one hazardous waste.

The Disposability index "1IS1LF" refers to the projected best type of disposal method(s) needed, and the perceived risk by industrial environmental professionals of future liability involved with this particular disposal method. In this case there are two disposal methods (IS-indefinite storage and LF-landfill) indicated for at least two of the product's components.

The EI is a relative measure of environmental impact or risk. The EI scale does not give absolute measures to be compared to a master listing that could be referenced.

Application of the Environmental Index to a Consumer Product

A typical consumer product was selected to apply the Environmental Index (EI). An example of a food blender made in the 1950's, and a modern food blender were selected. Because the materials and manufacturing methods are (were) different for the same type of product, we should see a difference in the respective Environmental Indexes. The parts of the blenders examined were: the food container, or vessel, the metal blades used to chop and blend whatever is in the food container, and the base of the unit where the motor is located (the motor was not examined in this study). What follows is a list of the process wastes and disposal methods best suited for the component in question that would enter into the EI calculation.

Old Blender Parts

Blades:

1-1-1 Trichloroethylene (degreaser) = Hazardous Waste (H)

Spray Lube Propellant (CFC) = Air pollutant (A)

Chromium (grinding Dust) = Hazardous Waste (H)

Disposal Method Needed (Blades) = Recycle Scrap (RR)

Plated Blender Base:

Lead (dust) = Hazardous Waste (H)

Cadmium (dust) = Hazardous Waste (H)

Hex. Chromium (sludge) = Hazardous Waste (H)

Perchloroethylene (degreaser) = Hazardous Waste (H)

Cyanide (used in plating) = Hazardous Waste (H)

Disposal Method Needed = Landfill (LF)

Glass Food Container:

Sodium and Potassium (fumes) = Air Pollutant (A)

Disposal Method Needed = Recycle (RR)

New Blender Parts

Blades:

Chromium (grinding dust) = Hazardous Waste (H)

Disposal Method Needed = Recycle (RR)

Plastic Blender Base:

Volatile Organic Compounds (gas) = Air Pollutant (A)

Disposal Method Needed = Recycle (RR)

Clear Plastic Food Container:

Volatile Organic Compounds (gas) = Air Pollutant (A)

Disposal Method Needed = Recycle (RR)

Environmental Index for Old Blender Components: **H7A2/2RR1LF**

Environmental Index for New Blender Components: **H1A2/3RR**

This indicates that the old materials and manufacturing methods generated more waste streams and higher risk disposal methods.

ENVIRONMENTAL INDEX QUESTIONNAIRE

Given the product example provided:

1) Please describe areas where you felt that the Environmental Index did a good job (all areas from process description to ranking of disposal options to overall methodology).

2) Please describe areas where you felt that the Environmental Index could be improved or changed (all areas from process description to ranking of disposal options to overall methodology).

3) Please suggest how the areas identified in 2) could be improved or changed.

4) Please include any comments you have regarding the overall research.

APPENDIX B

RESULTS OF ENVIRONMENTAL EXPERT QUESTIONNAIRE SURVEY

The results of the survey are all qualitative responses and are used to check the validity, or possible usefulness, of the EI, and possible areas where the EI could be improved. What follows are the responses to the individual questions (1-4). These responses are not taken in any particular order from the list of environmental experts.

Question 1) Please describe areas where you felt that the Environmental Index did a good job (all areas from process description to ranking of disposal options to overall methodology)

- "This could really be used on consumer goods for comparing two similar items."
- "The ranking of the disposal options was correct."
- "This methodology would be great for single site situations (manufacturing plant). It has interesting properties in that it could be used in a management of change program. It is often difficult to perswade upper management or stock holders that a certain process will have long term disadvantages (liability, cost, etc.). If they can see a measure of this that is easy to grasp, sometimes the change can be made."
- "Easy to demonstrate effects to different people, readily shows differences between processes and materials."
- "A good tool for risk assessment."

- "I think we can use a version of this now."
- "Good to show waste reduction after a process change."
- "Could be used to market a product or level international playing field."
- "Easy, makes sense, liked indexing."
- "Would make my life easier."
- "Pretty good overall, neat."
- "Pretty cool, good."
- "I can see using this my business."

Question 2) Please describe areas where you felt that the Environmental Index could be improved or changed (all areas from process description to ranking of disposal options to overall methodology)

- " We felt that the disposal options ranking was incorrect."
- "Some of the hazardous waste streams are worse than others, consumer might miss out on this."
- "Define more things (such as pollutants)."
- "It doesn't seem to apply to us."
- "It doesn't show the energy consumption in the process and the accompanying waste and pollution associated with this energy use."
- "Some stuff (waste) is worse than others. How can we capture this?"

- "How can this be used to show that a process has changed for the better?"

Question 3) Please suggest how the areas identified in 2) could be improved or changed

- "The ranking for the top three disposal options should be recycle/reuse, fuel burn, and then incineration."
- "A numerical score for this index, or parts of it, are eventually needed."
- "Use regulatory pollutants for water and air."
- "Should include solid waste in Manufacturing Process Index mediums. Solid waste is a CERCLA nightmare."
- "Should consider that particular states will be more strict on certain wastes such as toxins than the government."
- "Give numerical ranking to Disposability Index for a matrix."
- "Need to show economic implications of different EI's."

Question 4) Please include any comments you have regarding the overall research

- "Possibly could use a percentage of weight of waste per particular product or component."
- "Might include a recycle content number for a new product such as, 50% virgin material and 50% recycled material is

used to make X. If this were a ratio like percent recycled material divided by percent virgin material normalized for the part in question, then a manufacturer could receive credits as this ratio approaches one."

- "The EI should use facility specific codes versus product codes. In other words, the facility achieves a ranking, not the products."
- "In regard to the mediums in the Manufacturing Process Index, consider air. Where does the release occur? Is it really an air pollutant if it is released inside the plant but captured by control technology before reaching the outside environment? Fugitive emissions are a problem. Point source emissions can be controlled. Are they both air pollutants"? "Index (EI) could be a good or a bad thing for manufacturers. It might just turn out to be another hurdle that a struggling business has to deal with when a competitor can churn out plenty of product with better indexes."
- "What about wastes transferred upstream or downstream? What if the process change produces a change from an air pollutant to a water pollutant, is there a way to show this has happened? Possibly this could be indicated by a star next to the MPI. For example, an electric car is great for the folks in L.A., but not great for the guy living next to the electric generating station up north."
- "This could be used in other areas such as quality control. Is it better to use infrared scanners, which are expensive, for detecting cracks metal parts, or is it better to use

cheaper materials such as powder coatings and penetrant dyes which leave hazardous wastes?"

- "Combine questions 2) and 3) on the questionnaire."

IRB EXEMPTION FORM

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: 10-22-96 **IRB#: EG-97-000**

Proposal Title: AN ENVIRONMENTAL INDEX FOR HOUSEHOLD, DURABLE, CONSUMER GOODS

Principal Investigator(s): Wayne Turner, Robert Scott Frazier

Reviewed and Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING, AS WELL AS ARE SUBJECT TO MONITORING AT ANY TIME DURING THE APPROVAL PERIOD.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Signature: John H. Wyckoff Date: October 24, 1996
Chair of Institutional Review Board
cc: Robert Scott Frazier

VITA

Robert Scott Frazier

Candidate for the Degree of

Master of Science

Thesis: AN ENVIRONMENTAL INDEX FOR HOUSEHOLD, DURABLE, CONSUMER GOODS

Major Field: Industrial Engineering and Management

Biographical:

Education: Graduated from Thomas Jefferson High School, Alexandria, Virginia in May 1976; received Associate in Science in Mathematics from Rose State College, Midwest City, Oklahoma in December 1990; received Bachelor of Science degree in Industrial Engineering and Management from Oklahoma State University in May 1993. Completed the requirements for the Master of Science degree with a major in Industrial Engineering and Management at Oklahoma State University December 1996.

Experience: Spent part of childhood living in South America; employed by Oklahoma State University School of Industrial Engineering and Management as a graduate research assistant and the Energy Analysis and Diagnostic Center, 1993 to 1994.

Professional Memberships: National Society of Professional Engineers (Southern Maryland Chapter), Institute of Industrial Engineers, Association of Energy Engineers.