IDENTIFYING ACTIVITIES AND DETERMINING COSTS AND RISKS ASSOCIATED WITH THE PRESENCE OF HAZARDOUS MATERIALS AND GENERATION OF WASTES

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PREFACE

Current organization's decision analysis techniques are not designed to handle major environmental costs. As environmental regulations increase, the costs become a larger portion of overall operational expenses. The environmental costs are generally unknown and accounted for in overhead. Organizations are in a reactive mode to new health, safety, and environmental (HSE) laws and regulations. This research's purpose is to help organizations be proactive in considering new process methods. It allows the HSE concerns to be quantified and compared with the directly affected elements.

I wish to thank the chairman of this thesis, Dr. Wayne C. Turner, for the guidance, advice, support, and availability during the course of this research. I would also like to thank Dr. David Pratt and Dr. Ken Case for their assistance and insight on this thesis. Most of all, my thanks go to my wife and my parents for their encouragement and support.

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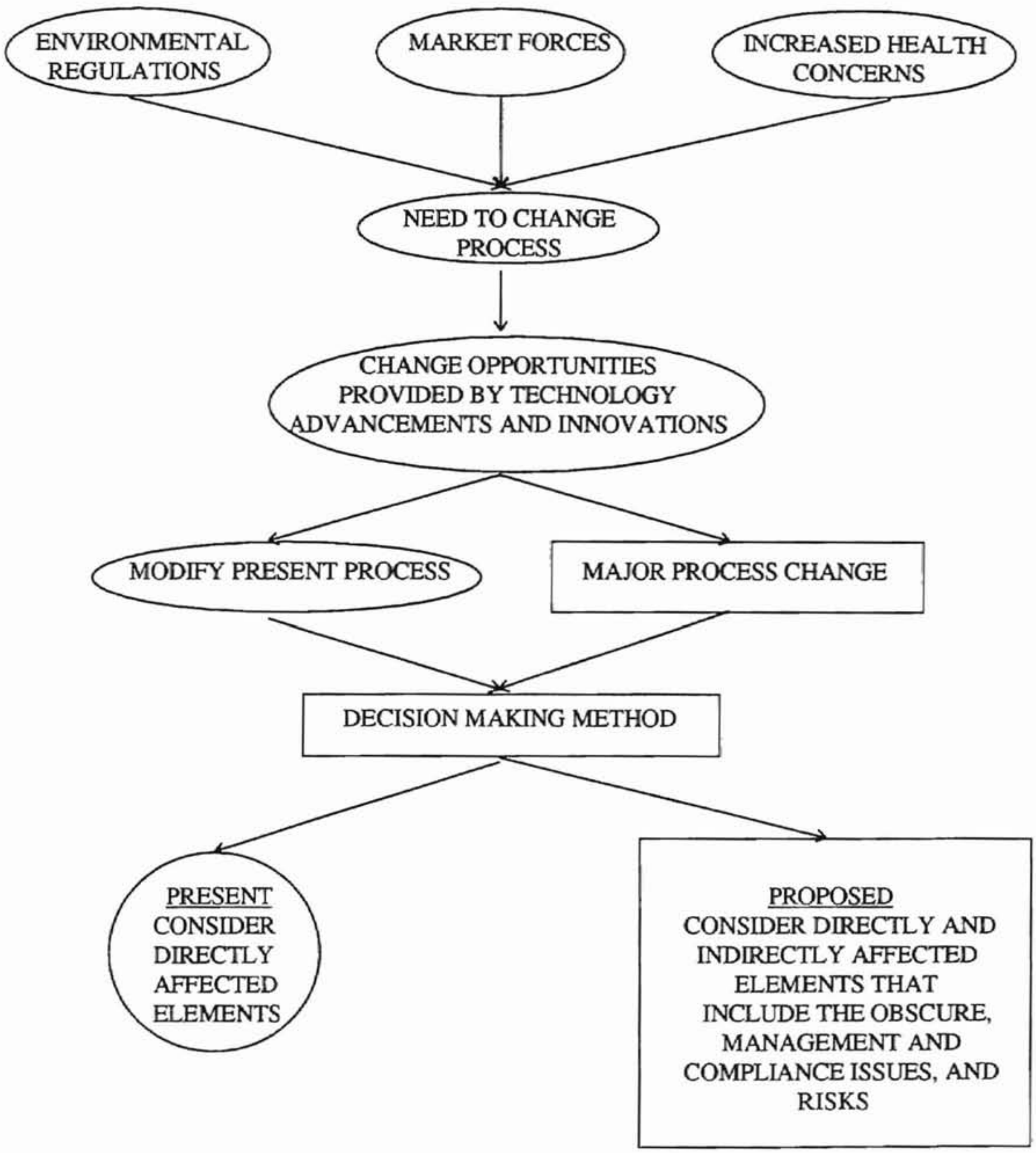
1.1 Introduction

Organizational operations are changing rapidly. Industries are realizing conventional direct economic analysis misses many important factors such as environmental issues. For each process alternative, only the directly affected elements are considered and quantified. Engineering economics is used to determine which alternative is best. There are additional elements (other than direct) that make a large impact on operational costs and decision analysis. These additional elements have developed because of the added forces that govern production processes. These new forces are primarily environmental and health concerns that develop into governmental compliance regulations, workman's compensation claims, and/or torts. These forces added to market forces, technology advancements, and innovations have complicated decision analysis. A graphical presentation of this problem is located in Figure 1. The main focus area of this study is a proposed decision making method to analyze the affect of major process changes. In Figure 1, the report's main focus areas are outlined in boxes. This thesis will develop decision making tools (analysis procedure) that take into consideration these other factors. The following sections will describe the forces that are requiring organizations to make more complete decision analyses.

Figure 1

Problem overview



1.2 Market Forces

There are several major market forces that are catalysts for change. In recent years, sales markets have widened, and the number of competitors has increased. Markets and competitors are changing rapidly due to the removal of foreign trade barriers. Market forces can have multiple effects on an organization. Frequently, they create the need to improve quality, and/or increase or reduce price, production rates, or costs. These needs often force an organization to make process changes to increase production rates or reduce costs. Process changes may require small changes, such as increasing the hours of operation, or major modifications, like changing the entire production method. When major changes are required, companies need to be careful to examine all the implications of their new process decisions. Process changes create trade-offs that an analyst must consider before action is taken. To respond to competitors and new market forces successfully, companies must be prepared to act quickly and to fully understand both the short and long term consequences of their actions or their decision not to take action.

1.3 Environmental Regulations

In the last decade, environmental regulations governing the purchase, usage, storage, and disposal of products and materials have increased dramatically. Since 1974, the Environmental Protection Agency's (EPA) Title 40 Code of Federal Regulations (CFR) has increased from 450 pages to approximately 12,000. Companies have no choice but to try to handle the new regulations in such a way as to minimize negative effects since regulations have resulted in increased management and compliance costs. Organizations must also avoid using chemicals that are in the process of being banned (CFC's, PCB's, Dioxins, etc.) or that require extensive handling and disposal costs. These additional compliance issues are difficult to account for, because their present costs and the future regulation changes are unknown. When changes are made, there is very little historical information upon which to base estimates of the new costs of operations. Thus, the new regulations create decision opportunities that make it very difficult to understand what will be affected and how much the changes will cost.

1.4 Increased Health Concerns

People are now more educated about what can cause them harm. Workers desire to minimize the risk of accidents and eliminate the need to work with recognized hazards. When research determines certain substances are dangerous, companies that use them are forced to take precautionary action. They need to explore the possibilities of using alternate and less harmful chemicals or implementing an increased safety policy. A safety policy's purpose is to reduce the risks associated with having to use hazardous materials by requiring safe working practices. New information on hazards is being compiled quickly. Companies must research old and new operation alternatives and be prepared to make necessary changes immediately. The alternatives' effect's on operating costs must be weighed against the cost of present operations. Awareness of the dangers associated with using certain substances and processes has in turn raised the insurance rates of companies that use them. The knowledge that substances are hazardous increases a company's liability to keep their workers, society, and the environment safe. New health concerns present a need to evaluate current practices, to explore new or different alternatives, and to determine organizational costs for both. Companies must be prepared to act quickly and to take the most appropriate action. Many times, health concerns lead to dramatic changes in safety regulations (by the Occupational Safety Health Administration (OSHA)). In the last 5 years, there has been a major increase in safety and health regulations from OSHA. The procedure must be able to recognize potential health effects and their costs.

1.5 Technology Advancements and Innovations

Technological advancements and innovations make improvements of current operations possible through new methods for processing and producing materials. These often require major changes in operations and raw materials. It is very difficult to measure all the resulting effects that changes to current processes will have. An organization must be able to identify elements and their costs related to present operations. Technological advancements effects are especially difficult to fully understand and almost impossible to quantify. This is because there is generally very little historical information, such as case studies, that completely details their effects. Unless the impact of operational alternatives can be quantified, it is difficult to determine the best action to take.

1.6 Summary

Due to the factors above, decision making should no longer concentrate only on directly quantifiable elements. Instead, managers should recognize the impact decisions can have on other elements (compliance costs, health and safety costs, etc.). These elements are much more difficult to define and quantify; thus, there is a need for a methodology to systematically define and determine these costs. The methodology should be sensitive to the effects that may result from process changes. It is preferable for one to be able to compare the total costs of process alternatives before any decisions are made, because at this point all alternatives are viable and no investment has been made. This will allow decisions to be chosen from all possible alternatives instead of making changes to the current operations to reduce the processes negative effects.

The methodology should be flexible for identifying elements and their costs for a wide range of changes. This process must also be fast so companies can make quick decisions that will help them keep pace with or beat their competitors.

1.7 Objective

THE OBJECTIVE OF THIS RESEARCH IS TO DEVELOP A METHODOLOGY FOR IDENTIFYING DECISION AFFECTING ELEMENTS NOT NORMALLY QUANTIFIED AND DETERMINING THEIR IMPACT.

The advancement in this research focuses on the process elements that result from hazardous material usage and waste generation, including waste management and compliance issues and the associated process risks. The methodology can be divided into three deliverables.

1. Identifies the elements affected by current and alternate processes. This includes a system for categorizing the different types of elements.

2. Defines the waste and management cost elements of current processes and can be used to estimate the costs of proposed process elements.

3. Determines the risk rating for each alternative due to the presence of hazardous material and generation of hazardous wastes.

Chapter 2 is a summary of the relevant literature in this field. The methodology portion of this text is presented in Chapter 3, and it is divided into six main sections. The first three sections define an environmental impact decision, identify and categorize the types of process elements, and determine the present costs. The last three sections present the influence that a new process alternative can have on costs, determine cause and affect relationships of the elements, and study the future elements costs and risks. Chapter 4 contains three case study examples in which the methodology is used. The last chapter includes a conclusion and recommendations for further research.

2 Review of Literature

In preparing for this research, an extensive search for relevant literature was undertaken. There was a great deal of information in certain related areas, but no literature was found on the exact topic. The research focuses on helping industries to more extensively evaluate process decision making. It concentrates on the routine elements included in economic decision analysis and goes further in developing the environmental compliance cost elements. It crosses a number of different areas that are well researched, but no literature discusses these areas collectively. The research that does combine these elements includes waste reduction and pollution prevention case studies, environmental policies, and environmental costing and decision making. In the following paragraphs, a synopsis detailing the information found in each of the three areas will be presented.

The sources reviewed include various economic case studies. These case studies are titled either waste reduction or pollution prevention. The studies present proven ideas for environmental coordinators or manufacturing managers to control wastes. The purpose of the studies is to present waste-reducing or waste-eliminating ideas. In Proven Profits from Pollution Prevention: Case Studies in Resource Conservation and Waste Reduction (Husingh, Donald, Larry Martin, Helene Hilger, and Neil Seldom, 1986, pages 27-242), various waste reducing ideas are described and their effects are detailed. A large portion of the analysis is concentrated on ideas that directly affect production processes. Usually, the factors considered are easily quantifiable, while other elements are examined qualitatively. After analyzing the case studies, it is very evident that the general factors are answered in many different ways. The general factors are typically answered quantitatively with a number, a dollar amount, or qualitatively by describing the number. This research attempts to quantify more of the elements including the ones that are currently being answered qualitatively. A survey on the type of answers found in ten case studies is presented in Table 1. These ten case studies were chosen because the changes evaluated impacted operational processes. Table 1 contains thirteen general factors to which each company was asked to respond. There are four types of answers; quantity (amount) of the factor, the dollar cost of the factor, a qualified response, and a no affect response. Each case study's response for these general factors is included in one of the four types of answers. Thus there are ten responses for each factor. An example of the four types of responses for wastes generated are as follows: decreased 1000 pounds, disposal costs reduced by $10,000, eliminated some waste, or had no affect on wastes. Table 1 displays how the thirteen general factors were answered in the ten case studies.

Table 1

The response of ten pollution prevention and process changing case studies to thirteen general factors

General Factor	Quantified (Amounts)	Total Dollar	Qualified	No affect
Wastes Generated	8	0	2	0
Productivity	0	0	6	4
Product Quality	0	0	3	7
Down Time	0	0	1	9
Facilities	1	2	1	6
Equipment	0	7	2	1
Raw Material	0	8	1	1
Water	1	0	1	8
Energy	3	3	0	0
Waste Disposal	0	6	3	1
Pollution Control	1	2	2	5
Personnel/maintenance	0	1	4	5
Net Benefits	0	0	10	0

It is very evident from the chart that many of the factors are not affected by waste reduction or pollution prevention ideas. Generally, the equipment, raw materials, and waste disposal are the only factors that are consistently quantified in dollars. Waste generated is one factor that is being quantified, but no dollar amounts were stated. The large number of factors that are either qualified or quantified are not being factored into the dollar savings or costs of the projects. They may be used as deciding factors, but until they can be stated as dollars, the total true costs remain unknown. It is also important to realize that general factors are not always affected by a new process alternative. Thus, each new process alternative will uniquely affect the general factors.

In other literature covering waste reduction (Springer, Johnny, Jr., April 1992 and Turner, Wayne C., Richard E. Webb, and James M. Shirley), different types of ideas and areas of application are developed. But as with the survey of the case studies, there is no method developed to determine costs for factors other than equipment, raw materials, water, and waste disposal.

Serious Reduction of Hazardous Waste (Office of Technology Assessment, September 1986, page 31), identifies and describes many of the more obscure factors that are affected by process changes. It also states that when these factors are not considered, the economic decision is biased against waste reducing ideas (Office of Technology Assessment, September 1986, page 31). For example, when waste management costs are not charged to specific generating activities, the decision analysis is biased against the waste reduction idea. It also states the problems and uncertainties in determining the costs of factors such as avoided waste management, liabilities, raw material consumption, and other indirect economic benefits (Office of Technology Assessment, September 1986, page 31). In summary, the literature on waste reduction and pollution prevention has clearly identified problems involved with waste reduction. It has also demonstrated that industries are having difficulty identifying the change in costs associated with waste reduction and that the analysis seldom includes the obscure factors that this research examines.

There is a great deal of literature covering environmental policies. The purpose in reviewing this literature is to identify the ways companies are being charged for environmental pollution and to find methods to measure environmental effects. This literature describes the effects of environmental pollution and determines the best possible actions for minimizing or eliminating the effects. The types of regulations have to be researched and their effects compared with the effects of not adding regulations. Evaluation of policies measure the environmental benefit and costs, ease of implementation, and adverse impact on industry. Regulatory agencies must choose from options of taking no action, improving existing programs, or developing and implementing new ideas. Once these policies are put into action, organizations must determine the effect they will have on production costs. The regulatory costs appear in industry as emission charges, product charges, user charges, deposit-refund systems, or permits (Organization for Economic Co-operation and Development, 1991). Organizations should be very aware of these costs and the possibility of their increasing. Generally the policies are developed as a result of benefit-cost analysis. Benefit-cost analysis is an effective method to determine what environmental pollution is costing society and what is appropriate to spend on preventing it (Organization for Economic Co-operation and Development, 1992). This method allows society to put a value on aspects of the environment based on what is worth to them. The driving force behind benefit-cost analysis is to maximize the overall benefits to society. The driving force for an organization is to minimize their present and future costs. Benefit-cost analysis could be used by individual organizations, but their focus would be on the benefits and costs directly affecting their company.

Environmental costing was an area where very little literature was found. Environmental costing is the ability to translate hazardous materials, wastes, and the management and compliance activities that are required into costs. These costs are important because they can be eliminated if hazardous materials are not used and hazardous waste are not generated. Many process changes greatly affect and sometimes eliminate the hazardous material and wastes involved in the process. Other costs incurred while operating a process are likely to fluctuate but still be present when process changes are made. In the true cost model (Turner, Wayne C., Richard E. Webb, and James M. Shirley, 1987) a large number of hazardous material and waste factors are identified and their costs inserted into a cost model. In this model, discount factors is dropped from the true cost model equations because the life of these cost factors is generally between 3-5 years. Thus, only a small difference would enable a much simpler equation to be used. The fact that technology changes so rapidly also encourages the elimination of the discount factors.

The total cost method includes the following cost factors: purchase, disposal, shipping, testing, and OSHA and RCRA requirements (Turner, Wayne C., Richard E. Webb, and James M. Shirley, 1987). The purchase, disposal, and shipping costs are taken especially for the hazardous material and waste involved with the process. The other cost factors are for all company activities; they are multiplied by the percentage of hazardous waste contribution and divided by the annual volume of all hazardous materials used. In this analysis, the percent volume of each hazardous material is equal to the percentage of costs occurred from that material. This is a good estimate, but there are many times when an extremely hazardous material will result in more costs than the same amount of a slightly hazardous material. The methodology is accommodating to users in that the fixed costs for things such as storage space, training, emergency equipment, and record keeping was totaled for all hazardous materials and wastes. This is helpful because it is very time consuming and nearly impossible to track the exact cost for each hazardous material and waste.

The methodology also presents a summary of likely events if all hazardous materials and wastes are eliminated, if one is eliminated, if reuse or recycling is done, and finally, if the volume is minimized. These are some of the instances that are to be looked at more closely in this report. It would make sense that the elimination of all hazardous materials and wastes would eliminate all of the materials management costs. But some initial costs will continue even if the hazardous materials and wastes are eliminated. Some costs may not even be affected at all when a single hazardous material or waste is eliminated because, as in the case of emergency equipment, it is generally still needed for the other hazards. In summary, the true cost model is excellent for obtaining current costs for hazardous materials and wastes, but it lacks the flexibility to be used to accurately to determine the changes in costs when operational modifications are implemented.

Environmental costing research has attempted to quantify many factors, but environmental, health, and safety (EHS) concerns have been ignored. Generally, the EHS elements are uncertain. The risk associated with these EHS elements are a factor of hazard and exposure (Rosenblum, G. R., W. S. Effron, J. L. Siva, G. R. Mancini, and R. N. Roth, page 69). No research found attempted to put a dollar value on these EHS concerns. However, the Integrated Risk Index System, a scoring system to rank materials, has been developed. The scoring system is a function of potential exposure, physical hazard, health hazard, and environmental hazard. Potential exposure factor incorporates annual production and potentially exposed populations. Physical hazard factor is based on flammability and reactivity. Acute and subchronic toxicity, carcinogencity, mutagenicity, teratogenicity, and reproductive effects are health hazard factors. The potential for ecological damage under hypothetical spill conditions is incorporated in the environmental hazard factor. This index system is comprehensive and could be very effective if used properly. Its major downfall is that it does not take into consideration knowledge of process, except in the exposure factor. Knowledge of process should be incorporated to weight to the factors that are most important in a specific work environment. It does not attempt to quantify the dollar costs associated with using hazardous materials. The information for this index is quite extensive. It may be time consuming to implement. Other literature was researched for liability information (Moses, Scott A., 1989). Research was accomplished to identify and rate what activities were most important to the liability exposure of a hazardous waste generator (Moses, Scott A., 1989). This approach is effective in identifying which areas a company should focus on to reduce risks. Whether a company reduces its risk by changing materials or improving its compliance activities, the change in costs have not been determined.

Literature on environmental decision making is also reviewed. Almost all of this literature is from the point of view of policy implementation. There are very few instances where the literature shows how individual industries deal with environmental decisions. According to the Environmental Protection Agency (EPA), US companies spent $115 billion complying with environmental regulation in 1992 (Makower, Joel, 1993). It is unknown how much EHS efforts are costing. EHS includes emissions, waste, MSDS, hazardous material, incidents, and monitoring. There are few companies that are allocating EHS costs to their products. Without this data, it is difficult to make correct decisions. One study (Seldner, Betty J. and Joseph P. Cothrel, 1994) found four questions that are very important for financial executives to consider for entering or retaining businesses: 1) What are the environmental issues affecting price and liabilities of the availability of materials? 2) What are the environmental issues governing price and liabilities of transportation of materials to our plant? 3) What are the potential material and waste handling costs, risks, and liabilities with regard to the work force and the environment? 4) What are the regulatory requirements of operation, and what are their associated costs? These questions clearly present the need to consider environmental factors before decisions are made, but a methodology for accomplishing this was not given. The evaluation of the cost of environmental programs only includes information on the environmental pollution or cleanup. Other environmental decision making factors are considered briefly. These include the subjects of prevention and risk-weighted liability-limiting investments (Seldner, Betty J. and Joseph P. Cothrel, 1994, page 219-220). These investments present what and how cost factors could be affected. The prevention investments include expenditures for technology evaluation, operating system development, capital system development, product component alternatives, and development of long-term regulatory compliance. The risk-weighted liability-limiting investments include insurance premiums for accidents, retainers, contractual relationships with legal advice, and the business operating structure to limit the liability of investors and principal owners. The accounting information for these investments involves defining only a few terms. For a company to fully account for the environmental costs of its operation, it requires that each product or service be analyzed for its inputs and outputs. This should include the resources going into the product or service and the waste or by-products that result from the product's manufacture, use, and disposal. Makower presents this as cradle to grave or life-cycle assessment (Makower, Joel, 1993). Life-cycle assessment is ideal, but it is really beyond the scope of this research. Defining the costs associated with waste and by-product's resulting from the product's manufacturing is the biggest step for industry to take. In many cases, the use and disposal wastes are issues that environmental policy are already affecting. Examples of where governmental policies have come into effect is with the use of PCBs, CFCs, asbestos, leaded gasoline, and SO_2 emissions. For most of industry, it is easier to let the government deal with these issues. However, it is necessary for those in industry to watch carefully so that they can make adjustments before changes come into effect. Often, it is beyond the industry's ability to measure the outside costs of waste and by-products during the products use and disposal.

There is a vast amount of literature seeking to determine the cost of pollution. The questions that are most important to this research are 1) what is the cost of controlling operations and 2) how to include that cost in decision analysis.

3 Methodology

3.1 Introduction

The methodology in this study has been developed to systematically identify and determine costs for production processes that recognize more than conventional factors. The factors considered include environmental compliance costs and risks. A methodology is presented to define process elements and categorize them. Cost equations are developed for these elements. The influence that process alternatives have on elements' costs is then analyzed. The influence that the influential elements have on other elements is described. Finally, the processes' future costs and risks are analyzed.

3.2 Defining an Environmental Impact Decision

Environmental impact decisions include factors that are outside the present scope of general engineering economy. They involve some materials that are considered toxic or dangerous or processes that have by-products that are pollutants. The by-products can be in any form: liquid, gas, or solid. This type of process and its by-products require additional management to control because of regulations and/or heightened tort concerns. The process involves changing initial materials into a final, salable product or service. The process can be broken down into several steps, such as cleaning a part, making a part, or assembling a product. These processes will generally have several direct outputs which include scrap material, solid and liquid wastes, and emissions. These processes provide an opportunity to reduce, recycle, or eliminate material or unwanted by-products by making changes to the process. The methodology in this report allows decisions with an environmental impact to be analyzed more thoroughly.

Emphasis in this study was placed on the processes that have associated health concerns and are governed by environmental regulations. The methods were developed to cover the needs associated with decision making when environmental regulations and health concerns are present. These methods are based on the fact that there is a desire to accomplish a specific task. The task is such that there are multiple alternate processes that can be used to accomplish the task. Each possible process has its own unique inputs and outputs. These specific inputs and outputs are the driving force for the presence of regulations and health concerns. Regulations and concerns force organizations to take action that is not related to the actual completion of the task. These actions are becoming a larger portion of the total effort required to complete the task. Thus, it is most important to recognize and account for all the activities that are required due to environmental regulations and health concerns.

To make decisions regarding process alternatives, some criteria must be established. The methodology is based on the assumption that a task needs to be accomplished within preset guidelines at a minimum present and future cost to the company. To achieve this, efforts must be focused on the cost of the elements that each alternative process will affect. Thus, the process and all the process effects are the focal point of this study.

3.3 Identifying and Categorizing the Types of Elements

There are three categories which describe the types of elements. The categories are "defined, ill-defined, and non-defined." "Defined" are elements that the analyst can easily identify and determine associated costs. These elements are either tangible or visible; this makes them identifiable. "Ill-defined" elements are identifiable, but they are not obvious. They are intangible activities that do not have high visibility. The costs of ill-defined elements are not easy to capture or define. "Non-defined" elements are basically undefinable and uncertain; thus, it is extremely difficult to determine their correct costs. Broad categories are the only method to cover the wide variety of undefinable and uncertain events.

The three categories that include defined, ill-defined, and non-defined elements are made up of present and future direct and indirect inputs and outputs. A summary of the traits of the defined, ill-defined, and non-defined elements can be found in Table 2.

Table 2

Description of the "Defined," "Non-defined," and "Ill-defined" elements

	Present	Future
Direct inputs and outputs Example of	Defined Raw materials	Non-defined Future product revenue
Indirect inputs and outputs Example of	Ill-defined Spill prevention plan	Non-defined Future employee accidents

When identifying elements in a process, the analyst should start with the defined. These elements can be divided into direct process inputs and outputs. Direct inputs include raw materials, energy, labor, capital investments, etc. Direct outputs are products, process wastes, scrap materials, etc. These input and output elements should also include the factors that directly affect them, such as material handling and maintenance. The process should be examined and each input and output should be noted. Next, the ill-defined elements can be identified. Ill-defined elements are the present indirect inputs and outputs. The inputs are usually controlled by laws and regulations which require management and compliance actions. Employee safety programs, OSHA, RCRA training, RCRA contingency plans, and emergency equipment are among the indirect inputs. The laws and regulations are meant to control and prevent the ill-defined inputs and outputs from having harmful effects. Careful analysis of the activities involved with management and compliance issues will reveal these elements. The outputs can be called "risks." They include spills, leaks, fines, environmental effects, and employee and society health. So all the possible implications that may result from a process should be identified. The future elements are more difficult to identify and calculate. The direct inputs and outputs generally do not change, but their costs will vary with market changes. Regulations, however may force organizations to make adjustments to the processes, therefore creating change in the direct inputs and outputs. Because the future elements are difficult to determine and the costs of inputs and outputs are virtually impossible to define, these elements are called non-defined elements. Generally, the future cost of many elements are the same as the present. But, future cost factors change in a number of ways. For example, the cost of raw materials may increase, or present materials being used could be found hazardous, which would increase disposal, testing, and handling costs. The indirect inputs and outputs can be defined for the present, but for the future they are unknown and therefore non-defined. An existing material that is found to be hazardous will also increase the management and compliance costs (indirect inputs). For this situation, it is not possible to determine what the new regulations will require, so even attempting to estimate additional costs is futile. However, an astute analyst can often predict effectively that material A has a higher chance of being regulated than material B. The ill-defined and non-defined elements are developed from a environmental standpoint. These elements can be modified to fit an organization with different concerns or needs.

Liability costs can change significantly over time. As waste-handling equipment and storage containers become older and less reliable these costs may increase. The liability costs also may decrease as workers become more experienced and less likely to have accidents. Indirect factors will continue to be a concern in the future, but not knowing how these factors will be affected makes it impossible to determine costs. It is important that circumstances are analyzed to identify the possible changes in liability factors. accomplish Analyzing the circumstances that will affect non-defined elements can lead a company to make decisions that will minimize these elements' costs.

The relationship of the defined, ill-defined, and non-defined elements to a process can be found in Figures 2 and 3. In both figures, the inputs are in the left column and the outputs are in the right. Figure 2 contains the elements that presently effect the process, while future elements are in Figure 3. In Figure 2, the present defined and the ill-defined elements are shown. The defined elements are the direct inputs and outputs, which are depicted on the top of the figure. The bottom half of the figure presents the ill-defined elements. These lists of elements are comprehensive but not complete. Additional elements will be needed for special cases. Also, the items on the list will change from one process to another. Figure 3 contains the future elements that are non-defined.

Figure 2

Present elements affected by process changes

Present

DIRECT INPUTS

<u>DEFINED</u>

- Raw material
- Water
- Capital investment
- Installation labor
- Energy
- Investment maintenance
- Process labor
- Material handling
- Process training
- Research & development
- Testing

------>

MANAGEMENT COMPLIANCE

<u>ILL-DEFINED</u>

- Employee safety program
- Management
- OSHA, RCRA training
- 1st RCRA contigency
- Annual RCRA contingency
- 1st emergency equipment
- Annual emergency equip.
- 1st storage area
- Annual storage area
- Record keeping
- Special handling
- Annual manifesting
- Permits
- Legal consultation
- Insurance

------>

P R O C E S S

------>

DIRECT OUTPUTS

<u>DEFINED</u>

- Haz solid waste disposal
- Haz solid waste transport
- Haz solid waste storage
- Haz solid waste testing
- Recycle
- Waste storage
- Water disposal
- Water testing
- Water treatment
- Water storage
- Emissions
- Scrap material
- Product revenue
- Product quality
- Material handling

------>

RISKS

<u>ILL-DEFINED</u>

- Noncompliance
- Waste water leak
- Transportation spill
- Employee health
- Employee perception
- Fines
- Environmental pollution
- Societal perception
- Employee accidents

Figure 3

Future elements affected by process changes

Future

DIRECT INPUTS ------> PROCESS

NON-DEFINED
- Raw material
- Water
- Energy
- Investment maintenance
- Process labor
- Material handling
- Process training

MANAGEMENT COMPLIANCE ------> PROCESS

NON-DEFINED
- Employee safety program
- Management
- OSHA, RCRA training
- 1st RCRA contigency
- Annual RCRA contingency
- 1st emergency equipment
- Annual emergency equip.
- 1st storage area
- Annual storage area
- Record keeping
- Special handling
- Annual manifesting
- Permits
- Legal consultation
- Insurance

P R O C E S S

PROCESS ------> INDIRECT OUTPUTS

NON-DEFINED
- Haz solid waste disposal
- Haz solid waste transport
- Haz solid waste storage
- Haz solid waste testing
- Recycle
- Waste storage
- Water disposal
- Water testing
- Water treatment
- Water storage
- Emissions
- Scrap material
- Product revenue
- Product quality
- Material handling

PROCESS ------> RISKS

NON-DEFINED
- Noncompliance
- Waste water leak
- Transportation spill
- Employee health
- Employee perception
- Fines
- Environmental pollution
- Societal perception
- Employee accidents

The defined elements are those that can be seen as direct inputs or outputs of the process under evaluation, and they can be identified and calculated easily. The following elements are defined, and examples of how process changes can affect them are stated.

DEFINED INPUTS

Raw material - The type, amount, and/or number of input materials used in the process. These factors often change, and the result is increased or decreased cost.

Water - The amount of water used directly in the process.

Capital investment - Each process alternative has equipment that is required. If equipment is already purchased and paid for, this may not be a factor.

Installation labor - Often, the installation of the process equipment is extra. The extra cost can be either in-house or out-of-house.

Energy - The energy cost for process equipment can be different due to changes in efficiency, energy source, hours of operation, or energy consumption.

Investment maintenance - Routine maintenance and repairs required for the process equipment.

Process labor - The cost of labor can vary due to changed number of hours or skill level of worker required.

Material handling - The cost of moving the associated raw material through the plant. This can include the need for or use of employees, special equipment, or plant layout changes.

Process training - Costs associated with the annual training of employees.

Research and development - The costs involved with researching technological advancements and present and future hazards, and developing a plan to possibly change the present production process. The cost is mostly due to the time spent in this process and the engineering design work done.

Testing - Costs associated with testing present operations and new alternative production methods or ideas.

DEFINED OUTPUTS

Hazardous solid waste disposal - Cost of special disposal of any process hazardous and/or solid waste.

Hazardous solid waste transport - Cost to transport the material to the disposal site.

Hazardous solid waste storage - Cost of the storage area, plant modifications, and containers meeting all regulations.

Hazardous solid waste testing - Cost of testing the waste to determine its characteristics and the appropriate type of disposal required.

Recycling - Cost of the resources required to recycle the material.

Waste storage - The storage cost of waste including containers and storage area.

Water disposal - Cost of special disposal of any process waste water.

Water testing - Cost of testing the waste water streams to determine their characteristics and the appropriate type of disposal required.

Water treatment - Cost of treating the water to make it safe for disposal.

Water storage - Cost of the storage area, plant modifications, and containers to meet regulations.

Emissions - Cost of containing and/or filtering emissions.

Scrap material - The cost of left-over materials that cannot be used in the finished part or product.

Product revenue - The revenue obtained through the sale of the product. This can increase as a result of improved productivity and additional sales.

Product quality - The increase or decrease in costs associated with changes in the product's quality. Changing the percentage of faulty products will result in an increase or decrease in material, energy, production labor, inspection labor, and machine time required for production. Also, a product's changed quality will affect customer satisfaction and thus affect product sales and the market value.

Material handling - The cost of moving the wastes in the plant. This can include the need or use of employees, special equipment, and/or plant layout changes.

Examples of ill-defined inputs and outputs are given below. These elements are driven by environmental and health regulations.

ILL-DEFINED INPUTS

Employee safety program - Elements included are a corporate safety policy, an organizational plan, inspections, safety committees, management, and supervision. Safety programs should also include risk assessments. Risk assessment involves identifying hazards and the exposure of people, or equipment to the hazards and developing the proper barriers and controls.

Management - Judicious and effective management of people, equipment, and materials to minimize cost or maximize profits.

OSHA, RCRA training - First time and annual training employees to know and adhere to governmental regulations pertaining to the process.

1st RCRA contingency - Planning to develop a contingency plan and first time training to implement the procedure in the case of an accident.

Annual RCRA contingency - The yearly costs of updating and retraining employees on the contingency plan.

1st emergency equipment - All equipment needed in the event of an accident or a spill.

Annual emergency equipment - Annual emergency equipment testing and replacement when needed.

1st storage area - The cost to prepare an area to accumulate hazardous materials and meeting the necessary regulations.

Annual storage area - The yearly upkeep expenses for the storage area following all regulations.

Record keeping - The cost of recording all hazardous waste information and management activities, documentation of all problems, corrective action taken, training records, environmental audits, and material safety data sheet correspondence.

Special handling - The special equipment and time associated with transporting the used materials or substances because they are hazardous.

Annual manifesting - The labeling, placarding, shipping, and tracking documents that are mandatory for hazardous waste transportation.

Permits - The actual costs of the permits and the time and effort involved in obtaining the permits.

Legal consultation - The cost of legal consultation to direct efforts for everyday procedures and special problems that may occur because the material is hazardous.

Insurance - The increased or decreased cost of insurance associated with the use of certain hazardous materials or processes.

ILL-DEFINED OUTPUTS

Noncompliance - The cost of fines and corrective action required when appropriate compliance is not taken.

Waste water leak - The cost of cleanup efforts and damage that occurs when a water tank, line, or valve breaks.

Transportation spill - The cost of a spill outside of a company's property lines.

Employee health - The cost associated with employees becoming ill or hurt because of a process or material used. The costs should include lost work time, productivity, and quality.

Employee perception - The cost of employee negative feelings toward the company's activities. The feelings produce costs when they create an adversarial relationship between employees and management. If the employees know the company is making changes to minimize health and environmental problems, these costs will decrease.

Fines - The cost of fines and corrective action required when an organization is found operating out of compliance.

Environmental pollution - The cost of cleanup when hazardous wastes reach and cause damage to the environment.

Societal perception - The goodwill associated with the processes organizations use. A company that switches to an environmentally safe process may increase their goodwill.

Employee accidents - The cost associated with employees being injured while working. This should include lost work time, productivity, and quality, and employee medical and rehabilitation costs.

Figure 3 contains a form that can be used for identifying the elements in two different alternatives. The standard elements in each category have been inserted. Figure 3 also includes space for additional elements affecting the process. The purpose of this form is to give an overview of the elements affecting each alternative. Ill-defined output elements are not on this list because they will be covered extensively in another section. The form has a column for a "Y" or "N" to be placed by each element under alternate 1 or 2 stating that yes, the process alternative affects the element or no, it does not. Thus, each element that is affected at all by the alternative will be marked with a "Y." All direct elements with a "Y" mark should be specified as a positive or negative dollar value. Also, elements that have previously been affected by the process and their costs and that are still being consumed are identified with a "Y." These costs are for initial investments that have a multi-year life. All "N" elements have no present effect and previous investment costs are no longer being consumed. Any element which has an "N" listed for both alternatives should not be considered further.

Figure 4

Change identification form for two alternative processes

Process ____________________

Present

DIRECT INPUTS ---->

DEFINED	1	2
Raw material		
Water		
Capital investment		
Installation labor		
Energy		
Investment maintenance		
Process labor		
Material handling		
Process training		
Research & development		
Testing		
________		
________		

MANAGEMENT COMPLIANCE ---->

ILL-DEFINED	1	2
Employee safety program		
Management		
OSHA, RCRA training		
1st RCRA contigency		
Annual RCRA contingency		
1st emergency equipment		
Annual emergency equip.		
1st storage area		
Annual storage area		
Record keeping		
Special handling		
Annual manifesting		
Permits		
Legal consultation		
Insurance		
________		
________		

P R O C E S S ---->

DIRECT OUTPUTS

DEFINED	1	2
Haz. solid waste disposal		
Haz. solid waste transport		
Haz. solid waste storage		
Haz. solid waste testing		
Recycle		
Waste storage		
Water disposal		
Water testing		
Water treatment		
Water storage		
Emissions		
Scrap material		
Product revenue		
Product quality		
Material handling		
________		
________		

Alternate 1 ____________________

Alternate 2 ____________________

At this point, the process in its present state has been thoroughly reviewed. Now one has to determine what changes will develop in the future. The future costs of the definable inputs and outputs are unknown. However, based on previous historical data and information, the analyst can estimate these costs. Estimating the future costs is beyond the scope of this report. Therefore, the future direct inputs and outputs are considered non-defined elements. The present indirect elements are generally driven by environmental regulations, health findings, and many other market and internal factors. Such forces will create new elements of great concern and could possibly eliminate some existing elements in the future. These forces create difficulties with identifying elements and makes developing costs impossible. Thus, the costs for the known and unknown future indirect elements should be considered non-defined.

3.4 Determination of Present Process Costs

Many organizations track costs extremely well, while others may follow only the major costs, allowing other costs to be consumed in overhead. The purpose of this section is to form a basis for cost analysis. Many companies have their own methods for cost allocations but management and compliance costs are often not included. The extension to management and compliance costs of hazardous materials and wastes in this research should be helpful.

Generally, the costs of direct input and output elements are calculated and recorded. These cost are straightforward and can be calculated by multiplying the quantity used by the cost per unit. The amount of direct inputs and outputs can be obtained for each process through production records and receipts. When the total costs are found, organizations have a number of ways that they can allocate the costs. Labor hours, quantity of finished products, and value added are examples of cost allocation methods. For this study, the cost will be considered on a cost per finished goods basis. Costs per finished good is very flexible, as it can be used with whatever forecast production rate. Because allocating direct costs is straightforward, the majority of this section will be focused on analyzing and allocating the cost of indirect inputs.

The costs of indirect input elements are much more difficult to account for because they are generally intangible. Complying with environmental regulations may require employees to work many hours. The environmental coordinator, operation manager, purchasing, maintenance, and secretarial staff are among the employees that are required to do most of the study, paperwork, and plan implementation. Most of the costs associated with the indirect input elements are attributed to the time employees require to accomplish their tasks. Organizations often have more than one process in operation that generate various types of waste. That makes it difficult to differentiate the elements' costs for each waste or process that generates it. Obtaining the total cost for the indirect input elements is possible. Once the costs have been generated, they need to be properly accounted for by allocating them to each product or process. Determining and allocating the costs are the topics that are analyzed in the remainder of this section.

The total time and capital spent on management and compliance issues can be captured with good record keeping or figured by using estimates of total hours and capital spent. It would be ideal to determine the costs for each individual indirect input, but it is not necessary. These costs are all relevant because of the presence of hazardous materials and wastes used in processes to help produce products. To simplify the indirect cost allocation, only the hazardous wastes are considered. Often, the number of hazardous materials used in a process is large, and it may be difficult to track all the hazardous material usage. The total ill-defined costs and the amount of hazardous wastes are needed before one can allocate the costs to the appropriate processes or products. The total amount of hazardous waste is easily obtained from records. An average ill-defined cost per unit of hazardous substance can be calculated from the total management and compliance costs and the quantity of hazardous wastes.

Avg. ill-defined costs = (Current ill-defined costs)/(Current quantity hazardous wastes) Eq. 1

Next, we need to allocate these costs to processes or products. The amount of hazardous wastes that goes into each process is easily determined.

Avg. ill-defined process cost = (Amt. of process hazardous wastes)(Avg. ill-defined costs) Eq. 2

Next, the process costs can be allocated over the total number of products produced in a process.

Avg. ill-defined product cost = (Amount of process waste per products)(Avg. ill-defined process cost) Eq. 3

The average ill-defined product costs can be used to determine the total cost for whatever production rates are expected. This cost is only for the present operations and will change if the process changes or different types or mixes of products are produced in each process. These cost allocation formulas serve as a beginning point where the effects from changes in the processes can be determined.

Correctly allocating the costs of indirect input (ill-defined) elements is important for determining how much a product costs to produce and what portion of the total cost is attributed to compliance with environmental regulations. The formulas presented in this section estimate the indirect input costs for each product for the present type of process.

The indirect output of processes are elements or events that are governed by risk. These events are probabilistic and their costs are variable. Most organizations don't determine what these risk factors have cost them in the past and are unable to estimate their future expenses. This study focuses on the influence that new process alternatives will have on the costs of these elements. As for the present costs, additional research is needed to better determine the indirect outputs' actual and expected costs.

3.5 The Influence That New Process Alternatives Can Have on Costs and Risks

This section explores the changes to the current costs that are a result of implementing new process alternatives. The study divides the cost influencing into three areas that cover the different types of process inputs and outputs. The direct process inputs and outputs are the first type, where cost changes can be directly measured. The second type is indirect inputs, where changes in costs can be estimated and distributed. The third type is indirect outputs, where changes to these elements will be considered more qualitatively. Each of these types requires its own methodology because of the unique nature of their effects.

Often, one cannot measure direct cost changes. This occurs when the analyst is forced to measure what he or she can and then determine costs based on the measured changes. The changes in volumes or amounts of consumption are numbers that can be turned into revised costs. Changes to direct input and output quantities for new process alternatives can be found in a number of ways. Vendor information or case studies are usually the first step in obtaining more information. Next, testing and trial runs can provide direct information about the quantity of inputs required for each alternative process. The costs associated with the direct inputs and outputs can be directly related to the quantity of certain measurable elements. Table 3 shows the cost elements that are generally affected by changes in inputs and outputs.

Table 3

The impact of key input and output elements

Inputs & Outputs	Direct Input and Output Cost Elements				
Raw Materials Usage	Raw Materials	Material Handling			
Water Usage	Water				
Energy Consumption	Energy				
Maintenance hours	Maintenance				
Process Labor hours	Process Labor				
Recycling	Recycling				
Solid Waste Generation	Disposal	Transportation	Storage	Testing	Material Handling
Waste Water Outputs	Disposal	Treatment	Storage	Testing	
Scrap Material Generation	Scrap Material				
Products Produced	Product Revenue				
Number of defects	Product Quality				

Next, the new costs of these elements can be calculated proportionally to the change in the quantity of certain key factors. The key measurable elements are those listed under the input and output columns. Each of the other cost elements will be calculated based on these key elements. The new costs are increased or decreased proportionally, based on the percent change in these key elements. The only other costs that can be directly accounted for are the capital costs and installation costs. The capital cost is a one-time expense, and it should be distributed over the life of the investment.

The effects that a new process can have on indirect input and output cost elements are great. When a new process is considered, one should weigh its effects on all of these elements. Some of its effects are obvious, and the resulting cost changes can be easily calculated. From an environmental compliance cost standpoint, one should consider the changes that the new process has on the hazardous materials purchased and wastes generated. The change in costs are not as straightforward for the management, compliance, and risk issues as with direct inputs and outputs. Effects that processes have on hazardous materials and wastes can be categorized as follows:

Elimination of all hazardous materials and wastes

Elimination of a hazardous material and/or waste stream

Reduce hazardous material and/or waste

Increase hazardous material and/or waste

Add hazardous material and/or waste

Add the first hazardous material and/or waste.

These categories differentiate between eliminating the only hazard and eliminating one hazard. Greater savings can be realized when all wastes are no longer produced. Thus, larger benefits are received for eliminating the only hazard than for eliminating one of many hazards. Likewise, adding the first hazard is more costly than adding an additional hazard. Elements' costs either increase or decrease when more or less compliance effort is needed. This may be due to a changed waste volume. It may also mean that only certain elements' costs are affected. These cost changes are almost totally related to the number and amount of hazardous materials and wastes used and generated. These changes have major effects on management, compliance, and risk elements.

However, the effects on these elements will not be consistent. Figure 5 shows how the changes to hazardous materials and wastes are likely to affect the cost of the indirect output elements.

Figure 5 is based on several insights. All first costs for RCRA contingency, emergency equipment, and the storage area will not be affected unless new hazardous material or waste is added. This is because the investment has already been made and until replacement is needed, these expenses have already occurred. Next, the cost of most elements will not be affected significantly by an increase or decrease in the amount of hazardous material and wastes. Once a new hazard is added, the costs will change significantly due to increased management and compliance efforts. Likewise, when a hazard is no longer used, management and compliance efforts will be reduced resulting in lower costs. In the next two sections, the indirect inputs and outputs will each be considered.

A method is needed to quantify the cost changes in the indirect input elements. Figure 5 presents only a summary of expected effects. There are five main types of effects that an alternate process may have on the company's management and compliance costs. The management and compliance elements and associated costs can be added, subtracted, decreased, or increased, or no change can occur. The two main factors that influence these costs are the changes in the number or type of hazardous materials and the wastes and amounts of each. Many hazardous materials do not become hazardous wastes. It would be ideal to consider both the hazardous materials and the hazardous wastes that include some hazardous materials individually. Because the amount and number of hazardous materials only affects the safety program, it will not be included in the methodology. The fact that many companies have hundreds of hazardous materials on hand also makes it difficult to determine the changes in indirect input costs.

Figure 5

The effect of changing the amount of hazardous material used and waste generated

	Possible events
1	Eliminate all hazardous materials and wastes
2	Eliminate a hazardous material and/or waste
3	Reduce a hazardous material and/or waste
4	Increase a hazardous material and/or waste
5	Add a hazardous material and/or waste
6	Add the first hazardous material and/or waste

		POSSIBLE EVENTS					
	ELEMENTS	1	2	3	4	5	6
MANAGEMENT COMPLIANCE	Employee safety program	--	-	0	0	+	++
	Management	--	-	0	0	+	++
	OSHA, RCRA training	--	-	0	0	+	++
	1st RCRA contigency	0	0	0	0	+	++
	Annual RCRA contingency	--	-	0	0	+	++
	1st emergency equipment	0	0	0	0	+	++
	Annual emergency equip.	--	-	0	0	+	++
	1st storage area	0	0	0	0	+	++
	Annual storage area	--	-	0	0	+	++
	Record keeping	--	-	0	0	+	++
	Special handling	--	-	0/-	+/0	+/0	++
	Annual manifesting	--	-	0	0	+	++
	Permits	--	-	0/-	+/0	+/0	++
	Legal consultation	--	-	0/-	+/0	+/0	++
	Insurance	--	-	0/-	0	+	++
RISKS	Noncompliance	--	-	0	0	+	++
	Waste water leak	--	-	0	0	+	++
	Transportation spill	--	-	0	0	+	++
	Employee health	--/-	-	0/-	0/+	+	++/+
	Employee perception	--	-	0/-	0/+	+	++
	Fines	--	-	0	0	+	++
	Environmental pollution	--	-	0/-	0/+	+	++
	Societal perception	--	-	0/-	0/+	+	++
	Employee accidents	--	-	0/-	0/+	+	++

	Key
--	Eliminates all costs for this function
-	Significantly reduces costs
0/-	Slightly reduces costs
0	No affect to costs
0/+	Slightly increases costs
+	Increases costs
++	Adds all costs for this function

The indirect inputs include elements whose costs are not linearly related to the amounts of wastes. OSHA and RCRA training, first and annual RCRA contingency, and emergency equipment require additional efforts when monthly hazardous waste generation passes the 100 and 1000 kilogram (kg) marks. The annual manifesting efforts are present when monthly waste exceeds 100 kg. When monthly hazardous waste volumes increase to levels greater than 100 and 1000 kg, compliance costs will increase incrementally. There are similar decreasing costs if present consumption rates can be reduced below 1000 and 100 kg per month. Generally, other ill-defined input costs increase proportionally as the hazardous wastes increase. Thus, an incremental compliance cost increase or decrease exists when hazardous wastes are added or eliminated and when waste volumes exceed 100 and 1000 kg per month. Otherwise, the costs will increase or decrease linearly as volumes of hazardous wastes become larger or smaller.

The amount of effort required for management and compliance issues is also dependent on the type of hazardous wastes generated. The wastes that are considered the most dangerous have the most regulations and require the most effort to control. Waste listing and determination divides wastes into five major classifications. Table 4 is a summary of the waste classifications. The classifications are F, K, P, U, and D. The P wastes are always acutely hazardous and the F waste may be acute. When acutely hazardous wastes are generated, only 1 kg produced in a month is needed for a company to have generator status. Generator status adds various regulations that must be followed. A company can produce as much as 100 kg of monthly hazardous waste before small quantity generator status is obtained and 1000 kg until full quantity generator status is met.

Table 4

Waste summary

Waste Type	Hazardous	Acutely Hazardous	Description
F	Yes	Possibly	Used or spent or non-specific sources
K	Yes	No	Used or spent or non-specific sources
P	Yes	Yes	Spill of a pure commercial chemical product
U	Yes	No	Spill of a pure commercial chemical product
D	Yes	No	Test hazardous characteristic

Based on the information and assistance of an expert in hazardous wastes, ratings were given to the listed, characterized, and water wastes. Table 5 describes the ratings. The wastes were rated on a 0 to 10 scale, with 10 being the greatest management and compliance effort required. The wastes that require the most management and compliance effort is acutely hazardous wastes P and F. These wastes were rated a 10. Hazardous wastes F require a little less effort, but they are still extremely dangerous; therefore, they were given an 8 rating. Wastes K and U follow next in the amount of compliance effort they require. A rating of 6 was assigned to these wastes. All the wastes F, K, P, and U can become very big problems because of the "derived from" rule. This rule prevents one from ever treating away an F, K, P, or U listed waste. Also, the "mixture" rule forbids one from diluting away an F, K, P, or U waste listing. Thus, the characteristic waste D has an advantage because one can treat away the D listing, leaving an unhazardous waste. This advantage led to only a 4 rating for the D waste. The final waste considered was waste water which is governed by the Clean Water Act or National Pollutant Discharge Elimination System (NPDES). These wastes are treatable and can generally be disposed of inexpensively; thus, a rating of 2 was assigned.

Table 5

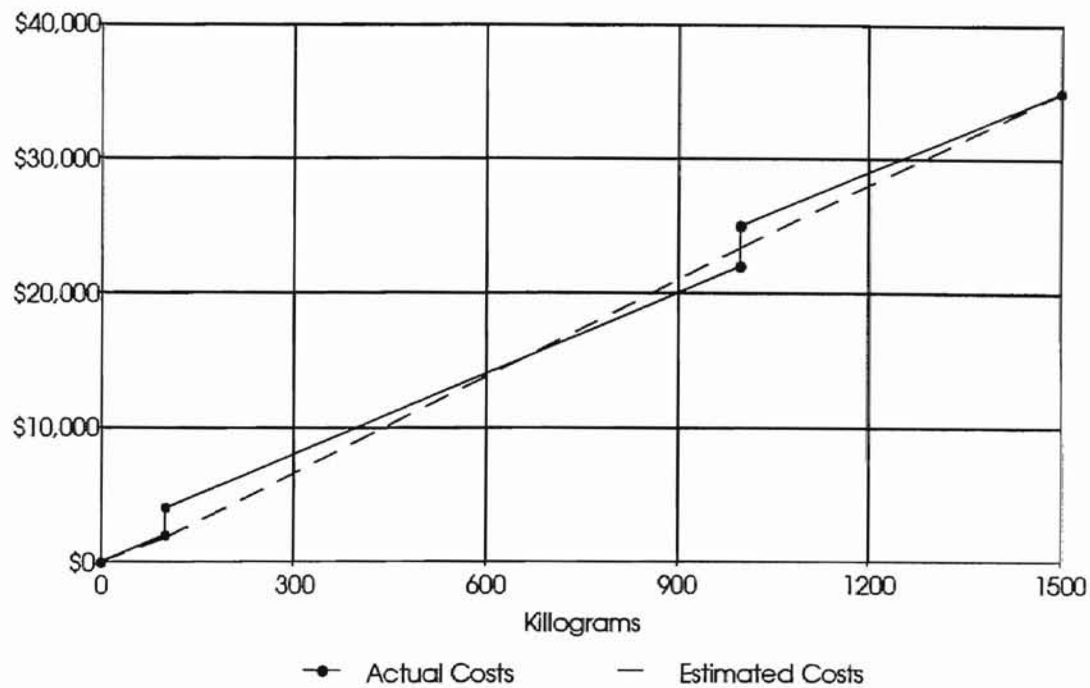
Waste ratings

Waste Type	Hazardous	Acutely Hazardous
F	8	10
K	6	-
P	-	10
U	6	-
D	4	-
Waste water	2	-

The cost model for distributing the total management and compliance costs should include allowances for all the factors presented previously. First, it was decided to divide the costs attributed to the presence of hazardous wastes and the costs attributed to the volumes of hazardous wastes. All the ill-defined element's costs are dependent on the number of hazardous wastes. Major savings or expenditures are realized when hazardous wastes are eliminated or added. For this reason, half of the management and compliance costs are be distributed over the number of wastes generated. The other half are be divided into the volume of waste. The presence and volume of waste are also weighted for the type of wastes that are being generated. The volume of hazardous wastes and the related costs are not linearly related because of the incremental costs at 100 kg and 1000 kg of monthly generation when hazards are added or eliminated. Figure 6 depicts the ill-defined costs versus the amount of hazardous waste generated.

Figure 6

Typical management and compliance cost per kilogram of hazardous waste generated



The actual cost line is linear with the exception of a $2000 incremental increase at 100 and 1000 kilograms. This is a piece wise linear line. The estimated cost line is linear from zero to the total ill-defined input cost at the total volume of waste. For these calculations, the linear line approximates the actual costs sufficiently. By linearizing these costs, the equations will be simplified without losing very much accuracy.

The reasoning behind allocating the total amount of ill-defined inputs has been presented earlier in this research. Half of the ill-defined input costs are for the presence of hazardous wastes, and the other half for the quantity of wastes generated. The type of wastes is a factor in allocating the costs. There are times when hazardous materials will enter a process as a listed U or P hazardous waste and leave the process as a listed F, K, or D characteristic waste. In these equations, the type of waste is the listing or characteristic a waste received after the process. The after-process waste of waste is the listing or characteristic a waste received after the process. The after-process waste ratings are most important because the majority of the management and compliance costs for wastes occur during and after the process. It is also easier to monitor the outgoing wastes since each waste generally includes several hazardous substances. The equations for estimating the new ill-defined input costs are as follows.

X = Hazardous wastes F, F acute, K, P acute, U, D, and waste water.

Current waste volume = Sum[(Weight of X)(X Rating)] Eq. 4

Proposed waste volume = Sum[(Proposed weight of X)((X Rating)] Eq. 5

Current number of wastes = Sum[(Current number of X wastes)(X Rating)] Eq. 6

Proposed number of wastes = Sum[(Proposed number of X wastes)(X Rating)] Eq. 7

New Costs = Present Costs [(Proposed waste volume)/(2(Current waste volume))

+ (Proposed number of wastes)/(2(Current number of wastes))] Eq. 8

By solving equations 4, 5, 6, and 7 and inserting them into equation 8, the total new costs can be determined.

An example for calculating a proposed processes ill-defined costs follows.

Table 6

Process hazardous waste information

Current Process Wastes Current ill-defined costs = $100,000			**Proposed Process Wastes**		
Hazardous Waste X	Weight of X	X Rating	Hazardous Waste X	Weight of X	X Rating
F acute	10,000 Lb.	10	F acute	2,000 Lb.	10
K	20,000 Lb.	6	K	15,000 Lb.	6
P acute	5,000 Lb.	10	D	30,000 Lb.	4
D	15,000 Lb.	4			

Current waste volume = (10,000 Lb.)(10) + (20,000 Lb.)(6) + (5,000 Lb.)(10)

+ (15,000 Lb.)(4) = 330,000 Lb. rating   Eq. 4

Proposed waste volume = (2,000 Lb.)(10) + (15,000)(6) + (30,000 Lb.)(4)

= 230,000 Lb. rating   Eq. 5

Current number of wastes = (1)(10) + (1)(6) + (1)(10) + (1)(4) = 30 quantity rating   Eq. 6

Proposed number of wastes = (1)(10) + (1)(6) + (1)(4) 20 quantity rating   Eq. 7

New Costs = $100,000/year [(230,000 Lb. rating)/(2(330,000 Lb. rating))

+ (20 quantity rating)/(2(30 quantity rating))] = $68,182/year   Eq. 8

The example's current ill-defined costs are the total expenses for management and compliance efforts. The present costs are $100,000/year, while the proposed costs are calculated to be $68,182/year. This decrease of $31,818/year ($100,000/year - $68,182/year) is a result of the reducing the number of wastes, amounts of wastes, and hazardness of wastes.

Only ill-defined outputs are left to determine what changes the new process alternatives can make. There is not a dollar figure for this category of costs. However, one can determine whether a change will increase or decrease risk and liability. Figure 7 contains a major portion of the information from Figure 5. The information in Figure 7 presents a point system for the ill-defined output factors. The risk elements were developed with the assistance of individuals with a strong environmental background. This impacted the type of risk elements that were included. There are additional risk elements the are non-quantifiable in dollars. Thus, the list should be modified to best match an industry's specific situation. The risk elements must be standardized. The elements should be appropriate for the company's different processes and alternatives. Standardizing the elements enables one to compare the risk scores between different process analyses. Periodic risk element updates may be necessary, but this will eliminate the ability to compare risk scores of new process analyses with previous ones.

The system is designed for one to analyze the affect that each change in waste creates. To allow for each waste to be individually analyzed, the scoring system definitions had to be changed. Three states of changes are used to base a ranking system for new alternatives. The point system is detailed in the next paragraph. The information contained in these figures are generalizations. Individual cases will bring slightly different scores. Figure 7 should be used to help score the risks associated with new process alternatives.

Figure 7

The effect that changing the amount of hazardous wastes generated has on ill-defined outputs

Possible events

1	Eliminate a hazardous material or waste from all processes
2	Eliminate a hazardous material and/or waste from the process
3	Reduce process hazardous material and/or waste
4	Increase process hazardous material and/or waste
5	Add a hazardous material and/or waste to the process
6	Add the first process hazardous material and/or waste

		POSSIBLE EVENTS					
	ELEMENTS	1	2	3	4	5	6
	Noncompliance	--	-	0	0	+	++
	Waste water leak	--	-	0	0	+	++
	Transportation spill	--	-	0	0	+	++
RISKS	Employee health	--/-	-	0/-	0/+	+	++/+
	Employee perception	--	-	0/-	0/+	+	++
	Fines	--	-	0	0	+	++
	Environmental pollution	--	-	0/-	0/+	+	++
	Societal perception	--	-	0/-	0/+	+	++
	Employee accidents	--	-	0/-	0/+	+	++

Key		Points
--	Eliminates all costs for this function	-3
-	Significantly reduces costs	-2
0/-	Slightly reduces costs	-1
0	No affect to costs	0
0/+	Slightly increases costs	1
+	Increases costs	2
++	Adds all costs for this function	3

One should first individually analyze each hazardous waste eliminated, added, increased, or decreased for each new alternative to see if it agrees with the effects that are listed in Figure 8 and to make any necessary changes. Knowledge of process can lead an expert to assign the correct ratings for cost changes. Knowledge of process provides insight on changes in employees' interaction with the wastes and the methods used to store, transport, and dispose wastes. Each hazardous waste change should be analyzed as to its affect on the risk elements - these affects are assigned as point values. Eliminating or adding a hazardous material or waste associated with any of the companies' processes should be worth -3 or 3 points, respectively. Eliminating or adding a hazardous material and/or waste associated with the process under consideration is equal to -2 or 2 points, respectively. Reducing or increasing the process hazardous material and/or waste is a -1 or 1 point, respectively. No change in costs to the elements is equal to no points. Points should be accumulated for each hazardous material and/or waste that is affected by a new alternative. Additional points will be added when all costs or the first costs are added to the elements. The total number of points accumulated should depict whether the new alternative will reduce risks (negative) or increase risks (positive). This should be used as a deciding factor to be considered after the changes in costs have been calculated.

In summary, the total cost and changes in cost can be calculated for the defined inputs and outputs and the ill-defined inputs. A cost comparison for the present and the alternative processes provides helpful information for making a decision on what action to take. It is also important to compare the alternatives risk factor scores. Reducing risks will clearly decrease costs, but it is very difficult to measure the actual cost differences. Depending on the manager's philosophy toward risk, a project that pays for itself but increases risk may not be accepted. Another alternative that does not pay for itself but decreases risk may be accepted by other managers. A decision table of the possible outcomes and the expected decisions are in Table 7.

Table 7

Decision table

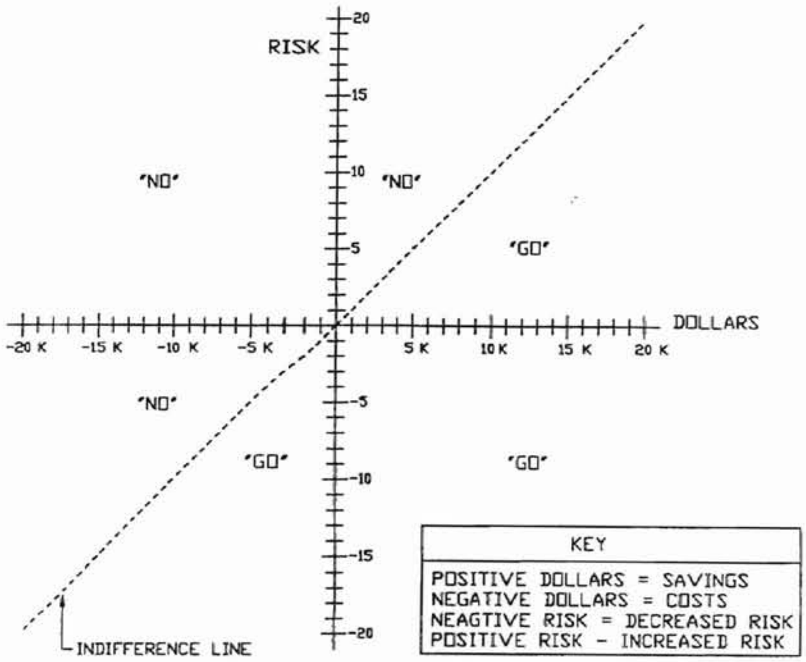
Situation	Decision
Dollar expenditure and risk increased	Reject alternative
Dollar expenditure increased and risk decreased	?
Dollar expenditure decreased and risk increased	?
Dollar expenditure and risk decreases	Accept alternative

Note that the question marks state that there is no clear decision and the risk factor must be weighed against the monetary value of the alternatives. A major factor in making the decisions is whether the manager or company is risk averse or risk seeking. Risk averse managers and companies may accept an alternative that has increased costs but reduced risk. A risk seeker will probably reject the same alternative. Generally, the difference in risk and process costs for each alternative will help lead managers and companies to their decision.

A pictorial representation of the decision process is contained in Figure 8. The vertical axis represents the risk score of the proposed alternative. The horizontal axis depicts the cost difference between the two alternatives. As stated previously, positive dollar impacts are savings and negative risk scores are risk improvements. Areas of the graph that indicate a decision to proceed with the proposed alternative are marked with a "GO." Areas where the new decision should not be accepted are labeled "NO." The dotted line shows where there is an indifference between the two alternatives. This line can be developed by associating a dollar value to each risk point. Figure 8 shows that each risk point is worth $1,000. Actual management decisions deviate from Figure 8 because of the managers' view on risk. A risk averse manager's non-preference line is curved toward the vertical axis. The indifference line for a risk seeking manager is curved toward the horizontal axis. The weight given to risk points will vary but understanding the risk and cost trade-off should help one to make a more informed decision.

Figure 8

The decision process for comparing both dollar and risk impacts



3.6 Determining the Cause and Effect Relationships of the Elements

The cause and effect relationships are important in determining the individual elements that have an impact on costs. Previously, this report has focused on the cost changes brought about by alternative processes. There are times when these alternatives will not be considered due to lack of capital funds, or lack of effective alternatives. When this is the case, small changes to the inputs and outputs of the process may provide significant savings. Knowing the cause and effect relationship should help managers concentrate their organizations' efforts to major cost affecting elements.

There are twelve major factors that trigger cost changes in the defined inputs and outputs. Table 3 (page 34) defines the twelve factors and the costs that are affected as a result of the factors being changed. There are three factors that control the majority of the elements. These factors are raw material usage, solid waste, and waste water generation. When these are affected, many cost factors will change. The new cost can be calculated with the previously presented formulas.

The ill-defined input and output elements cost can also be affected greatly with small changes in hazardous materials and wastes. As with the ratings given to the ill-defined outputs, eliminating all hazardous materials and waste provide the most savings. Costs can be significantly increased or decreased by adding or eliminating hazardous wastes or materials. The increase or decrease in hazardous materials and wastes will have the same effect on the ill-defined costs. Thus, one should first try to eliminate all hazards, then eliminate some hazards, and finally reduce consumption and generation of hazardous material and waste. The hazards should also be worked according to the waste determination. Hazards should be analyzed according to the wastes ratings (Table 5, page 40). Thus, F acute, P, F, K, U, D, and waste water is the order in which they should be considered.

The changes in process costs can be calculated for these process adjustments as the new process alternative is figured. It is important that these changes be secondary to new process alternatives, because they limit the options one can take. However these problems are easier to solve and require only small investments. If an organization is in need of immediate help, process adjustments in the form of process input and output changes, can provide significant cost and risk improvements.

3.7 Study of the Future Elements' Costs and Risks

The defined and ill-defined input and output costs for processes change constantly. The costs of defined inputs and outputs can increase or decrease due to changing market prices. The ill-defined input and output costs change when new regulative laws are added and when materials and wastes are classified as hazardous when they previously were not. Often, studies on materials and wastes will show that they are more or less dangerous than previously expected. These studies will frequently lead to the creation of new regulations. As more materials and wastes become regulated, companies' ill-defined input and output costs will increase.

If process alternatives have been analyzed and they are found unattractive, there is a possibility that the new alternatives may become more attractive with time. It is very important to reevaluate the cost equations to determine if process alternatives are becoming more or less attractive. Generally, the trend will continue as time passes. For example, if a brand new process alternative is effective at reducing hazardous materials and waste but very expensive, it may not be attractive at this time. One year later, the capital investment cost may decrease, and an increase in environmental regulations may make the new process alternative even more attractive.

A manager of operations must watch for trends in costs, new regulations, and new findings in material and waste dangers. When process alternatives are analyzed but not implemented, they should be reevaluated every six months to a year. One should also use the cost evaluation equations periodically to track the current costs. If the current costs show a trend in a present process becoming more expensive, then effort should be increased to find new process alternatives.

Companies should analyze each process that significantly impacts environmental and health concerns and determine if alternative processes exist. The desire to change a process does not ensure that a suitable alternative exists. Process alternatives will often fail to be cost effective. The following procedure should be used to determine when the process should be analyzed again.

1. A change in an element's cost that has a major impact on the process cost (either a negative for the current process or a positive for the proposed process costs).
2. Significant increases in the production volume or change in the product mix.
3. New or anticipated environmental or health regulations that impact the process.
4. Identification of a new alternative process.
5. Six months since the previous evaluation.

The process should be reevaluated after one of the events have occurred. Any of the five conditions may make an alternative process more desirable.

3.8 Methodology Synopsis

This section explains how the methodology presented should be applied. The specific areas in the report that apply are referenced. This section divides the methodology into five main steps to be followed chronologically. The steps include the question of whether or not the methodology is appropriate, and how it should be incorporated in analyzing process alternatives.

1. Process Analysis: The methodology is only effective when the process under consideration affects environmental and health concerns (or other ill-defined and non-defined concerns). Section 3.2 describes these types of processes and assists in determining if a process fits this constraint. If the process affects environmental and health concerns, the methodology is applicable. The identified process alternatives should be studied thoroughly. The best alternatives should be selected for further consideration.

2. Defining Inputs and Outputs: The alternative processes must be analyzed as to what elements they affect. Section 3.3 includes a methodology to identify and categorize the elements that process alternatives affect. Figure 4 (page 29) is instrumental in helping one to identify and categorize these elements.

3. Determining Costs: The methodology includes approaches to determine the cost of defined (direct inputs and outputs) and ill-defined (indirect inputs) process elements. The defined element's cost can be determined with available information for both the present and proposed alternatives. Calculating the current ill-defined element's cost requires identifying all of the time and materials required for management and compliance issues. Four steps are followed to determine the ill-defined element's cost of the proposed processes. First the current ill-defined costs should be calculated on a per unit or per pound of waste basis using equations 1, 2, and 3 (page 32). Identifying the types and amounts of wastes for the present process is the second step. The third step is estimating the types and amounts of waste for the proposed process. Considering the hazardous material and waste information, the proposed ill-defined element's cost can be calculated using equations 4 through 8 (page 42).

4. Determine Risk Rating: The same hazardous material and waste information used in calculating indirect elements' costs are needed to determine the change in the proposed process risk. The change in risk between the current and proposed process is decided for each change in waste. Figure 7 (page 45) provides general guidelines for assigning risk ratings. Process knowledge provides additional information that may require one to change the risk ratings from the general rules provided.

5. Summary of Costs and Risks: Finally, the total of the direct costs and indirect input costs should be calculated. This cost and the change in risk rating should be used to determine

whether or not the proposed process should be analyzed further. Section 3.5 contains some information to assist this decision making.

Three case studies are located in Chapter 4. In each case study, the defined and ill-defined elements costs are shown as annual dollar amounts. The one time investment element's (capital investment, installation labor, process training, research and development, and testing) costs are annualized by dividing the first costs by the length of the investment (in years). This is a simple but rough estimate of the annual costs. More accurate annual costs can be calculated by incorporating the tax impact and engineering economics. The annual costs of capital investments can be replaced with an after-tax amount that includes the economic equivalent of the initial costs. This will increase the accuracy of the one-time investment costs.

The case studies follow the five step procedure outlined in this section and discussed in detail in the methodology section. The summary table from the first case study (page 65) is reproduced below. In this table all the numbers without parenthesis show revenue (positive values). All numbers with parenthesis are costs (negative). Thus, the proposed alternative shows

1. An increase in net revenues from \$392 to \$12,376 or a revenue of \$11,986 per unit.
2. A decrease in ill-defined costs from \$668 to \$139 per unit for a change of \$529 per unit.
3. Total revenue (ill-defined and defined) increases from a net cost of (\$276) to a net revenue of \$12,237 for an increase of \$12,513/unit.
4. The risk score shows a drop of 20 risk units (-20 indicates a favorable drop in risks).

In this case, all measures indicate to select the proposed alternative. Many different combinations are possible. For example, the net revenue impact could be negative (proposed alternative costs more) and the risk score negative (reduced risk). Then, the expert would have to make the decision.

Table 8

Cost summary for the current and proposed alternative

	Solvent paint stripping	Plastic bead paint stripping	Proposed change
Risk Score	0 (Base)	-20	-20
Defined Revenue or Costs	$392/unit	$12,376/unit	$11,986/unit
Quantifiable Ill-defined Costs	($668/unit)	($139/unit)	$529/unit
Total Revenue or Costs	($276/unit)	$12,237/unit	$12,513/unit

4 Case Studies

4.1 Introduction

The purpose of including case studies is to detail how the methodology presented can be used. In each case study there is one present process and a new alternative process under consideration. Each alternative will be described and any advantages or disadvantages will be presented. The alternatives will be analyzed using the methodology in this report.

4.2 Case Study #1

Deciding whether or not to switch from conventional paint stripping to plastic media stripping.

Process: Stripping paint from aircrafts (Office of Technology Assessment, 1986, page 79 - 80)

1. Process Analysis

Current Method: Aircraft are currently being stripped with a solvent, generally methylene chloride. Methylene chloride has a hazardous waste number U080. Thus in its pure state, it is a U listed waste. The application of the solvent is followed by scrapping, washing, hand scraping, and buffing. The chemical stripping is time consuming and expensive. The operation releases noxious fumes and generates large volumes of hazardous waste. This spent hazardous waste is listed as a F002 waste. The waste water is governed by the Clean Water Act (CWA). After treating the water to the standards set by CWA, it is disposed in the sewer.

Proposed Method: The alternative process removes paint with modified sand blasting equipment using recoverable plastic beads. The only waste is pulverized paint; the beads mixed with the paint can be recovered and used again. Limitations include its inability to strip rain eroded coating and possible damage to soft cadmium coating and windows. Extra precautions must be exerted when stripping carbon composite, fiberglass, and light weight aluminum surfaces. These limitations are considered minor. The dry paint chips fail a TCLP[1] test and are D characteristic waste.

2. Defining Inputs and Outputs

This process begins by analyzing the defined inputs and outputs and the ill-defined inputs and outputs. Figure 4 (page 29) is used to help identify the factors affecting the two processes and the result is shown in Figure 9. The factors that are affected by the processes are marked with a "Y," or a "N" if the element is not present. Note that five ill-defined elements were completely eliminated with the second alternative.

3. Determining Costs

The next step is determining the costs of the defined elements and the total cost of ill-defined inputs. Since the F-4 aircraft is the typical product to be stripped, all defined elements' costs were for one F-4. Some important information is as follows:

Annual production rate = 100 units/year

Length of investment = 5 years

The present investment has lasted longer than its expected life; thus, all one time costs have already been prorated over the expected life of the present process.

The summary of the defined elements is that the solvent process stripping results in an earning of $392/ unit and the plastic media results in a revenue of $12,376/unit. All of the defined input and output costs for each process are contained in Figure 10 and Figure 11. Figure 12 displays the cost difference between the two alternatives.

1. TCLP is a leach test that measures the concentration of elements and determines whether or not they are hazardous waste.

Figure 9

Change identification for two alternative paint stripping processes

Process: Paint Stripping

Present PROCESS

DIRECT INPUTS	DEFINED	1	2
	Raw material	Y	Y
	Water	Y	N
	Capital investment	N	Y
	Installation labor	N	Y
	Energy	Y	Y
	Investment maintenance	Y	Y
	Process labor	Y	Y
	Material handling	Y	Y
	Process training	N	Y
	Research & development	N	Y
	Testing	N	Y

MANAGEMENT COMPLIANCE	ILL-DEFINED	1	2
	Employee safety program	Y	Y
	Management	Y	Y
	OSHA, RCRA training	Y	Y
	1st RCRA contigency	Y	Y
	Annual RCRA contingency	Y	Y
	1st emergency equipment	Y	Y
	Annual emergency equip.	Y	Y
	1st storage area	Y	Y
	Annual storage area	Y	Y
	Record keeping	Y	Y
	Special handling	Y	N
	Annual manifesting	Y	N
	Permits	Y	N
	Legal consultation	Y	N
	Insurance	Y	N

DEFINED	1	2	DIRECT OUTPUTS
Haz. solid waste disposal	Y	Y	
Haz. solid waste transport	Y	Y	
Haz. solid waste storage	Y	Y	
Haz. solid waste testing	Y	Y	
Recycle	N	Y	
Waste storage	N	N	
Water disposal	Y	N	
Water testing	Y	N	
Water treatment	Y	N	
Water storage	Y	N	
Emissions	Y	N	
Scrap material	N	N	
Product revenue	Y	Y	
Product quality	Y	Y	
Material handling	Y	Y	

Alternate 1: Solvent Paint Stripping

Alternate 2: Plastic Media Paint Stripping

Figure 10

The costs for solvent paint stripping of one F-10

ELEMENT	Alt. #1 Solvent Stripping Costs	Total	Notes
Raw material	$5422/unit	($5,422)	1
Water	200000 gal * $0.003/gal	($600)	2, 3
Capital investment	0	$0	
Installation labor	0	$0	
Energy	$231/unit	($231)	1
Investment maintenance	20 hrs * $15/hr	($300)	4, 6
Process labor	341 hrs * $15/hr	($5,115)	1, 6
Material handling	$100/unit	($100)	3
Process training	0	$0	
Research and development	0	$0	
Testing	0	$0	
Haz. solid waste disposal	9767 lb/2000/lb/ton($200/ton)	($977)	2, 3
Haz. solid waste transport	9767 lb / 2000/lb/ton($40/ton)	($195)	2, 3
Haz. solid waste storage	200 sqft($50/sqft / 500 units)	($20)	3, 5
Haz. solid waste testing	9767 lb/2000/lb/ton * 20/ton	($98)	2, 3
Recycle	0	$0	
Waste storage	0	$0	
Water disposal	200000 gal * $0.003/gal	($600)	2, 3
Water testing	200000 gal * $0.001/gal	($200)	2, 3
Water treatment	200000 gal * $0.0074/gal	($1,480)	2, 1
Water storage	200 sqft($50/sqft)/ 500 units	($20)	3, 4
Emissions	$50/unit	($50)	3
Scrap material	0	$0	
Product revenue	$16500/unit	$16,500	3, 7
Product quality	$500/unit	($500)	
Material handling	$200	($200)	3
TOTAL		$392	

1. Given in article
2. Quantity given in article
3. Estimated cost
4. Estimated number of hours
5. 500 units, 5 years of production, 5 years length of investment.
6. Labor hour cost
7. Value added to the metal parts from stripping painting

Figure 11

The costs for plastic bead paint stripping of one F-10

ELEMENT	Alt #2 Plastic Media Costs	Total	Notes
Raw material	$346/unit	($346)	1
Water	0	$0	1
Capital investment	$647389 / 500 units	($1,295)	1, 5, 8
Installation labor	$60000 / 500 units	($120)	3, 5, 8
Energy	$127/unit	($127)	1
Investment maintenance	20 hrs * $15/hr	($300)	4, 6
Process labor	39 hrs * $15/hr	($585)	2, 6
Material handling	$10/ unit	($10)	3
Process training	10(5 hrs * $15hr)/ 500 units	($2)	4-6, 8
Research and development	50 hrs * $20/hr / 500 units	($2)	4-6, 8
Testing	$5,000 / 500 units	($10)	3, 5, 8
Haz. solid waste disposal	(320 lb /2000/lb/ton)$150/ton	($24)	2, 3
Haz. solid waste transport	320 lb /2000/lb/ton * $40/ton	($6)	2, 3
Haz. solid waste storage	50 sqft * $50/sqft /500 units	($5)	3, 5, 8
Haz. solid waste testing	(320 lb /2000/lb/ton)$20/ton	($3)	2, 3
Recycle	$250/unit	($250)	3
Waste storage	0	$0	
Water disposal	0	$0	
Water testing	0	$0	
Water treatment	0	$0	
Water storage	0	$0	
Emissions	0	$0	
Scrap material	0	$0	
Product revenue	$16500/unit	$16,500	3, 7
Product quality	$1000/unit	($1,000)	3
Material handling	$40	($40)	3
TOTAL PER UNIT	=	$12,375	

1. Price given in article
2. Quantity given in article
3. Estimated cost
4. Estimated number of hours
5. 500 units, 5 years of production, 5 years length of investment.
6. Labor hour cost
7. Value added to the metal parts from stripping painting
8. Cost of the investment is estimated by first cost divided by the total production or an annual equivalent

Figure 12

Changes in cost from switching to the proposed paint stripping method for one F-10

ELEMENT	Proposed Cost	Present Cost	Cost Difference
Raw material	($346)	($5,422)	$5,076
Water	$0	($600)	$600
Capital investment	($1,295)	$0	($1,295)
Installation labor	($120)	$0	($120)
Energy	($127)	($231)	$104
Investment maintenance	($300)	($300)	$0
Process labor	($585)	($5,115)	$4,530
Material handling	($10)	($100)	$90
Process training	($2)	$0	($2)
Research and development	($2)	$0	($2)
Testing	($10)	$0	($10)
Haz. solid waste disposal	($24)	($977)	$953
Haz. solid waste transport	($6)	($195)	$189
Haz. solid waste storage	($5)	($20)	$15
Haz. solid waste testing	($3)	($98)	$94
Recycle	($250)	$0	($250)
Waste storage	$0	$0	$0
Water disposal	$0	($600)	$600
Water testing	$0	($200)	$200
Water treatment	$0	($1,480)	$1,480
Water storage	$0	($20)	$20
Emissions	$0	($50)	$50
Scrap material	$0	$0	$0
Product revenue	$16,500	$16,500	$0
Product quality	($1,000)	($500)	($500)
Material handling	($40)	($200)	$160
TOTAL	$12,375	$392	$11,983

Next, the ill-defined inputs were analyzed. Since the costs cannot be completely separated for each element, a summary of the major costs are listed below.

1. Environmental coordinator who spends 50% of his/her time on this process, costing $20,000.
2. Environmental health and safety committees, including 10 employees and 100 hours/year, costing $30,000.
3. Secretarial assistance for 500 hours/year, costing $5,000.
4. Supplies, costing $4,000.
5. Equipment, costing $1,000/ year for 5 years.
6. Training expenses for 10 employees at 24 hours and 10 employees at 8 hours, costing $4,800.
7. Permits, costing $1,000.
8. Legal consultation, costing $1,000.

The total present ill-defined input costs equal $66,800 per year. Using equations from the methodology, the new costs will be calculated. There are presently two hazardous wastes, a solid waste and waste water. The waste water is treated before disposal and, therefore, is no longer a waste. In this equation, the waste water will not be considered a waste in the volume portion, but it should be included as a waste in the number of present wastes. Table 9 contains a summary of the process hazardous waste information.

Table 9

Process hazardous waste information

Current Process Wastes Current ill-defined costs = $66,800			**Proposed Process Wastes**		
<u>Hazardous Waste X</u>	<u>Weight of X</u>	<u>X Rating</u>	<u>Hazardous Waste X</u>	<u>Weight of X</u>	<u>X Rating</u>
F (Spent solvent)	9,767 Lb.	8	D (Paint chips)	320 Lb.	4
Waste water	0	2			

Current waste volume = Sum[(Weight of X)(X Rating)] Eq. 4

Current waste volume = (9,767 lb.)(8) = 78,136 Lb. rating

Proposed waste volume = Sum[(Proposed weight of X)((X Rating)] Eq. 5

Proposed waste volume = (320 lb.)(4) = 1,280 Lb. rating

Current number of wastes = Sum[(Current number of X wastes)(X Rating)] Eq. 6

Current number of wastes = (1)(8) + (1) (2) = 10 quantity rating

Proposed number of wastes = Sum[(Proposed number of X wastes)(X Rating)] Eq. 7

Proposed number of wastes = (1)(4) = 4 quantity rating

New Costs = Present Costs [(Proposed waste volume)/(2(Current waste volume))

+ (Proposed number of wastes)/(2(Current number of wastes))] Eq. 8

New Costs = ($66,800)[((1,280 lb. rating) /2(78,136 lb. rating))

+(4 quantity rating /2(10 quantity rating))] = $13,907

Avg. ill-defined costs = (Current ill-defined costs)/(Current quantity hazardous wastes) Eq. 1

Present average ill-defined input costs = ($66,800/ 9,767 lb. rating/unit (100 units/year)

= $0.0684/lb. rating

Avg. ill-defined product cost = (Amount of process waste per products)(Avg. ill-defined process cost) Eq. 3

Present Average product costs = ($0.0684/lb. rating)(9767 lb. rating/unit) = $668/unit

Proposed average ill-defined input costs = ($13,907 / (320 lb. rating/unit (100 units/year))

= $0.4346/lb. rating

Proposed average product costs = ($0.4346/lb. rating)(320 lb. rating/unit) = $139/unit

The ill-defined input savings for each production unit is $529 ($668 - $139).

4. Determine Risk Rating

Next, the ill-defined output changes scored according to their risks. Referring back to Figure 5 (page 37), and the scoring system developed in the methodology (page 45), a score for the new alternative can be calculated. The change to the new process would eliminate two hazardous wastes and add one hazardous waste. Each waste that is affected will be considered individually. The result of this analysis is found in Table 10.

Change #1: Eliminating 9,767 pounds of sludge, F listed waste.

Change # 2: Eliminating 200,000 gallons of waste water, D characteristic waste.

Change #3: Adding 320 pounds of dry paint chips, D characteristic waste.

Table 10

Risk changes

	Changes			
Ill-defined Outputs	#1	#2	#3	Totals
Noncompliance	-2	-2	2	-2
Waste water leak	-2	-2	2	-2
Transportation spill	-2	-2	2	-2
Employee health	-2	-2	2	-2
Employee perception	-2	-2	0	-4
Fines	-2	-2	2	-2
Environmental pollution	-2	-2	2	-2
Societal perception	-2	-2	2	-2
Employee accidents	-2	-2	0	-4
Totals	-18	-18	12	-20

A rating of plus or negative 2 is the maximum rating because other processes continue to affect these factors. There were only a few times when general rules presented in the methodology were not followed. The dry waste should not affect waste water leaks and employee accidents and perception. The proposed process results in a total risk improvement (reduction) of 20 points.

5. Summary of Costs and Risks

Table 11 summarizes the changes in the defined, ill-defined, and non-defined elements. The risk score is zero for the current method and is negative twenty for the proposed method. Each aircraft stripped using the current method results in a loss of $276. The proposed paint stripping method results in an earnings of $12,237 per aircraft. Because the new process alternative is very successful, the possible effects from slightly modifying the present process were not analyzed. Future rules and regulations will only make the new alternative more attractive. The final result is a new process alternative that reduces costs and risks. Thus, accepting the change to plastic bead paint stripping is the better alternative.

Table 11

Cost summary for the current and proposed alternative

	Solvent paint stripping	Plastic bead paint stripping	Proposed change
Risk Score	0 (Base)	-20	-20
Defined Revenue or Costs	$392/unit	$12,376/unit	$11,986/unit
Quantifiable Ill-defined Costs	($668/unit)	($139/unit)	$529/unit
Total Revenue or Costs	($276/unit)	$12,237/unit	$12,513/unit

4.3 Case Study #2

Deciding whether or not to switch from manual painting to computer-controlled robotic painting.

Process: Painting metal parts in naval weapon systems (Springer, Johnny, Jr., Waste Minimization, Destruction and Disposal Research Division Risk Reduction Engineering Laboratory, April 1992, page 10 - 12)

1. Process Analysis

Current Method: The current operations use manual mixing and hand spraying to paint metal parts. The paint facility uses both oil- and water-based paints. The water-based paints are mixed with a thinner containing isopropyl alcohol and xylene. The oil-based paint is mixed with polyurethane thinner. The thinner is also used for equipment cleaning. Currently, the painting consumes 6,530 gallons of paint and 2,500 gallons of the three solvents (polyurethane, alcohol, and xylene). The paint waste of the present system is 42 tons annually. The water-based paint waste is a listed F003 due to the presence of xylene. The oil-based paint waste fails a TCLP[1] test and thus is a D characteristic waste. Equal amounts of oil- and water-based paints are consumed in this process.

Proposed Method: Computer-controlled robotic painting will require 5,230 gallons of paint and 1,080 gallons of the three solvents. The new system includes parts' conveyors, computer-controlled robots, electrostatic spray guns, and proportional paint mixing. This investment will cost $1,000,000 for equipment and $200,000 for installation. The paint waste is reduced to 17 tons. The new method will result in paint, waste disposal, and labor savings, and a decrease in part rejects. The paint usage mix will remain at fifty percent.

1. TCLP is a leach test that measures the concentration of elements and determines whether or not they are hazardous waste.

2. Defining Inputs and Outputs

This process begins by analyzing the defined inputs and outputs and the ill-defined inputs and outputs. Figure 4 (page 29) is used to help identify the factors affecting the two processes and the result is shown in Figure 13. No additional factors could be identified. The raw materials include both paint and solvents. The factors that are affected by the processes are marked with a "Y," or a "N" if the element is not present.

3. Determining Costs

The next step is determining the costs of the defined elements and the total cost of ill-defined inputs. Since the types and number of naval parts painted is unknown, the defined elements' costs were stated for one year's typical operations. The length of investment is 5 years. The present investment has lasted longer than its expected life; thus, all one time costs have already been prorated over the expected life of the process.

All of the defined input and output costs and revenues for each process are contained in Figure 14 and Figure 15. The sum of the defined elements is a revenue of $192,019/year for manual painting and $143,719/year for computer-controlled painting. Figure 16 displays the dollar difference between the two alternatives. Note that the proposed process does not eliminate any of the elements in the present process. But many of the elements have major decreases in costs for the proposed alternative. The elements are raw materials, process labor, material handling, emissions, product quality, hazardous waste disposal, transportation, and storage.

Figure 13

Change identification for two alternative painting processes

Process: Painting naval weapon parts

Present

DIRECT INPUTS

DEFINED	1	2
Raw material	Y	Y
Water	N	N
Capital investment	N	Y
Installation labor	N	Y
Energy	Y	Y
Investment maintenance	Y	Y
Process labor	Y	Y
Material handling	Y	Y
Process training	N	Y
Research & development	N	Y
Testing	N	Y

MANAGEMENT COMPLIANCE

ILL-DEFINED	1	2
Employee safety program	Y	Y
Management	Y	Y
OSHA, RCRA training	Y	Y
1st RCRA contigency	Y	Y
Annual RCRA contingency	Y	Y
1st emergency equipment	Y	Y
Annual emergency equip.	Y	Y
1st storage area	Y	Y
Annual storage area	Y	Y
Record keeping	Y	Y
Special handling	Y	Y
Annual manifesting	Y	Y
Permits	Y	Y
Legal consultation	Y	Y
Insurance	Y	Y

----> P R O C E S S ---->

DIRECT OUTPUTS

DEFINED	1	2
Haz. solid waste disposal	Y	Y
Haz. solid waste transport	Y	Y
Haz. solid waste storage	Y	Y
Haz. solid waste testing	N	N
Recycle	N	N
Waste storage	N	N
Water disposal	N	N
Water testing	N	N
Water treatment	N	N
Water storage	N	N
Emissions	Y	Y
Scrap material	N	N
Product revenue	Y	Y
Product quality	Y	Y
Material handling	Y	Y

Alternate 1: Manual painting

Alternate 2: Computer-controlled robotic painting

Figure 14

The costs for one year of manually painting metal parts

ELEMENT	Alt. #1 Manual Painting Costs	Total	Notes
Raw material (Paint)	6,530 gal * $25/gal	($163,250)	2, 3
Raw material (Solvent)	2,500 gal * $15/gal	($37,500)	2, 3
Water		$0	
Capital investment		$0	
Installation labor		$0	
Energy	$500/yr	($500)	3
Investment maintenance	75 hrs * $15/hr	($1,125)	4, 6
Process labor	5,000 hrs * $15/hr	($75,000)	4, 6
Material handling	250 hrs * $15/hr	($3,750)	4, 6
Process training		$0	
Research and development		$0	
Testing		$0	
Haz. solid waste disposal			
Paint and solvent	42 tons * 4 drms/ton * $420/drm	($70,560)	2, 1
Haz. solid waste transport	42 tons * 4 drms/ton * $87/drm	($14,616)	2, 1
Haz. solid waste storage	500 sqft * $50/sqft / 5 yrs	($5,000)	3, 5
Haz. solid waste testing		$0	2, 3
Recycle		$0	
Waste storage		$0	
Water disposal		$0	
Water testing		$0	
Water treatment		$0	
Water storage		$0	
Emissions	$5,000/yr	($5,000)	3
Scrap material		$0	
Product revenue	$600,000/yr	$600,000	3, 7
Product quality	$30,000/unit	($30,000)	3
Material handling	42 tons * 4 drms/ton * $10/drm	($1,680)	2, 3
TOTAL PER YEAR		$192,019	

1. Price given in article
2. Quantity given in article
3. Estimated cost or amount
4. Estimated number of hours
5. Five years of production (projected life)
6. Labor hour cost
7. Value added to the metal parts from painting

Figure 15

The costs for one year of painting metal parts with robots

ELEMENT	Alt #2 Robot Painting Costs	Total	Notes
Raw material (Paint)	5,230 gal * $25/gal	($130,750)	2, 3
Raw material (Solvent)	1,080 gal * $15/gal	($16,200)	2, 3
Water		$0	
Capital investment	$1,000,000/5 yrs	($200,000)	3,5,8
Installation labor	$200,000/5 yrs	($40,000)	3,5,8
Energy	$1,100/yr	($1,100)	3
Investment maintenance	200 hrs * $15/hr	($3,000)	4, 6
Process labor	1000 hrs * $15/hr	($15,000)	4, 6
Material handling	100 hrs * $15/hr	($1,500)	4, 6
Process training	[5(25hr)($15/hr)+50hr($20/hr)]/5yr	($575)	4-6, 8
Research and development	$20,000/5 yrs	($4,000)	3,5,8
Testing	$5,000/5 yrs	($1,000)	3,5,8
Haz. solid waste disposal			
Paint and solvent	17 ton * 4 drms/ton * $420/drm	($28,560)	2, 1
Haz. solid waste transport	17 ton * 4 drms/ton * $87/drm	($5,916)	2, 1
Haz. solid waste storage	200 sqft * $50/sqft / 5 yrs	($2,000)	3,5,8
Haz. solid waste testing		$0	
Recycle		$0	
Waste storage		$0	
Water disposal		$0	
Water testing		$0	
Water treatment		$0	
Water storage		$0	
Emissions	$1,000/yr	($1,000)	3
Scrap material		$0	
Product revenue	$600,000/yr	$600,000	3, 7
Product quality	$5,000/unit	($5,000)	3
Material handling	17 tons * 4 drms/ton * $10/drm	($680)	2, 3
TOTAL PER YEAR	=	$143,719	

1. Price given in article
2. Quantity given in article
3. Estimated cost or amount
4. Estimated number of hours
5. Five years of production (projected life)
6. Labor hour cost
7. Value added to the metal parts from painting
8. Cost of the investment is estimated by first cost divided by the total production or an annual equivalent

Figure 16

Changes in cost from switching to the proposed robotic painting method for one year's production

ELEMENT	Proposed Income or Cost	Present Income or Cost	Difference
Raw material (Paint)	($130,750)	($163,250)	$32,500
Raw material (Solvent)	($16,200)	($37,500)	$21,300
Water	$0	$0	$0
Capital investment	($200,000)	$0	($200,000)
Installation labor	($40,000)	$0	($40,000)
Energy	($1,100)	($500)	($600)
Investment maintenance	($3,000)	($1,125)	($1,875)
Process labor	($15,000)	($75,000)	$60,000
Material handling	($1,500)	($3,750)	$2,250
Process training	($575)	$0	($575)
Research and development	($4,000)	$0	($4,000)
Testing	($1,000)	$0	($1,000)
Haz. solid waste disposal	($28,560)	($70,560)	$42,000
Haz. solid waste transport	($5,916)	($14,616)	$8,700
Haz. solid waste storage	($2,000)	($5,000)	$3,000
Haz. solid waste testing	$0	$0	$0
Recycle	$0	$0	$0
Waste storage	$0	$0	$0
Water disposal	$0	$0	$0
Water testing	$0	$0	$0
Water treatment	$0	$0	$0
Water storage	$0	$0	$0
Emissions	($1,000)	($5,000)	$4,000
Scrap material	$0	$0	$0
Product revenue	$600,000	$600,000	$0
Product quality	($5,000)	($30,000)	$25,000
Material handling	($680)	($1,680)	$1,000
TOTAL	$143,719	$192,019	($48,300)

Next, the ill-defined inputs were analyzed. Since the costs cannot be completely separated for each element, a summary of the major costs are listed below.

1. Environmental coordinator spends 25% of his/her time on this process, costing $10,000.
2. Environmental health and safety committees, including 5 employees at 75 hours/year, costing $11,250.
3. Secretarial assistance for 300 hours/year, costing $3,000.
4. Supplies, costing $3,000.
5. Equipment, costing $1,500/ year for 5 years.
6. Training expenses for 5 employees at 24 hours/year and 5 employees at 8 hours/year, costing $4,800.
7. Permits, costing $1,000.
8. Legal consultation, costing $500.
9. Insurance premium increases, costing $5,000.

The total present ill-defined input costs equal $37,650 per year. Using equations from the methodology, the new costs are calculated. There are presently two hazardous solid wastes. The wastes are an equal volume of oil-based and water-based paints. The used oil-based paint is a D characteristic waste, while the used water-based paint is a F characteristic waste. Table 12 contains a summary of the process hazardous waste information.

Table 12

Process hazardous waste information

Current Process Wastes Current ill-defined costs = $37,650			**Proposed Process Wastes**		
Hazardous Waste X	Weight of X	X Rating	Hazardous Waste X	Weight of X	X Rating
F (Water-based paint)	21 tons	10	F (Water-based paint)	8.5 tons	10
D (Oil-based paint)	21 tons	4	D (Oil-based paint)	8.5 tons	4

Total waste volume = Sum[(Weight of X)(X Rating)] Eq. 4

Total waste volume = [(21 tons)(10) + (21 tons)(4)](2,000 lb./ton) = 588,000 Lb. rating

Proposed waste volume = Sum[(Proposed weight of X)((X Rating)] Eq. 5

Proposed waste volume = [(8.5 tons)(10) + (8.5 tons)(4)](2,000 lb./ton) = 238,000 Lb. rating

Total number of wastes = Sum[(Total number of X wastes)(X Rating)] Eq. 6

Total number of wastes = (1)(10) + (1) (4) = 14 quantity rating

Proposed number of wastes = Sum[(Proposed number of X wastes)(X Rating)] Eq. 7

Proposed number of wastes = (1)(10) + (1)(4) = 14 quantity rating

New Costs = Present Costs [(Proposed waste volume)/(2(Total waste volume))
+ (Proposed number of wastes)/(2(Total number of wastes))] Eq. 8

New Costs = ($37,650)[((238,000 Lb. rating) /2(588,000 Lb. rating))
+ (14 quantity rating /2(14 quantity rating))] = $26,445

The ill-defined input savings for one years production is $11,205 ($37,650 - $26,445).

4. Determine Risk Rating

Next, the ill-defined output changes are scored according to their risks. Referring back to Figure 5 (page 37), and the scoring system developed in the methodology (page 45), a score for the new alternative can be calculated. The change to the new process would decrease the amount of two generated hazardous wastes. Each waste that is affected will be considered individually. The result of this analysis is found in Table 13.

Change #1: Eliminating 12.5 tons of water-based paint waste, F listed waste.

Change # 2: Eliminating 12.5 tons of oil-based paint waste, D characteristic waste.

Table 13

Risk Changes

	Changes		
Ill-defined Outputs	#1	#2	Totals
Noncompliance	-2	-2	-4
Waste water leak	0	0	0
Transportation spill	-1	-1	-2
Employee health	-2	-2	-4
Employee perception	-2	-2	-4
Fines	-1	-1	-2
Environmental pollution	-1	-1	-2
Societal perception	-1	-1	-2
Employee accidents	-2	-2	-4
Totals	-12	-12	-24

In this example, knowledge of the process was used to alter the point values given to certain elements. Generally, reducing the amount of a hazardous substance receives a negative one rating. But reducing the volume of wastes is only one benefit. A major risk improvement is also realized, because employees are removed from a potentially harmful working environment (spray painting). In this case, a rating of negative two is given to the elements that directly involve employees. The other element's risk is reduced by one point because the hazardous wastes are reduced. The proposed process results in a total risk improvement (reduction) of 24 points.

5. Summary of Costs and Risks

Table 14 summarizes the changes in the defined, ill-defined, and non-defined elements. The risk score is zero for the current method and is negative twenty-six for the proposed method. Each year's production using the current method results in a revenue of $154,369. The proposed painting method results in a revenue of $117,274 per year of production. The proposed method is less attractive when only considering defined and ill-defined costs. But after considering that the risk rating has improved 24 points, the decision becomes more complicated. It is necessary to weigh the benefit of eliminating the undesirable and hazardous job of manual painting and reducing risks associated with this operation versus the $37,095 per year difference in revenue. In this case, the proposed alternative should be worth more than the revenue difference to remove operators from the potentially hazardous work environment while improving other process risk elements. Future rules and regulations will only make the new alternative more attractive. An expert could explore the option to switch to a less hazardous paint. But the paint requirements for parts used in naval weapon systems will eliminate most alternatives. Although a different type of paint could provide a cost effective alternative, it is unlikely that it would meet all the paint requirements. For this reason, no other alternatives were explored.

Table 14

Cost summary for the current and proposed alternative

	Manual painting	Robot painting	Proposed change
Risk Score	0 (Base)	-26	-26
Defined Revenue or Costs	$192,019/year	$143,719/year	($48,300/year)
Quantifiable Ill-defined Costs	($37,650/year)	($26,445/year)	$11,205/year
Total Revenue or Cost	$154,369/year	$117,274/year	($37,095/year)

4.4 Case Study #3

Deciding whether or not to switch from a chemical process to a mechanical process for cleaning metal sheeting.

Process: Cleaning copper sheeting used in electronic circuits (Husingh, Donald, Larry Martin, Helene Hilger, Neil Seldom, page 165 - 167).

1. Process Analysis

Current Method: Copper sheeting metal is presently being cleaned with chemicals before being used in electronic circuit boards. The metal is cleaned by spraying ammonium persulfate, phosphoric acid, and sulfuric acid. The process uses 40,000 pounds of the three chemicals. This results in 40,000 pounds of hazardous wastes each year. The amount of each chemical purchased is equal to the amount of waste that is generated. Pure phosphoric acid and sulfuric acid are P041 and P115 listed wastes respectively. Phosphoric acid and sulfuric acid fail a TCLP[1] test and are D characteristic waste after the process. The process results in 15,000 pounds of both acids. Also 10,000 pounds of ammonium persulfate waste is generated. Ammonium persulfate also fails a TCLP[1] test and is a D characteristic

Proposed Method: New equipment can be used to replace the chemical cleaning process. The new process utilizes a machine with rotating brushes that mechanically clean the metal. The brushes use a fine abrasive pumice to assist the cleaning process. Ten thousand pounds of pumice will be required for the year's production. The spent pumice sludge (ten thousand pounds) is not a hazardous waste. It can be placed in a conventional landfill. This method significantly reduces material, disposal, and labor costs.

1. TCLP is a leach test that measures the concentration of elements and determines whether or not they are hazardous waste.

2. Defining Inputs and Outputs

This process begins by analyzing the defined inputs and outputs and the ill-defined inputs and outputs. Figure 4 (page 29) is used to help identify all the factors affecting the two processes and the result is Figure 17. Waste disposal and waste transportation are additional factors identified. The factors that are affected by the processes are marked with a "Y," or a "N" if the element is not present.

3. Determining Costs

The next step is determining the costs of the defined elements and the total cost of ill-defined inputs. Since the number of copper sheets cleaned is unknown, the defined elements' costs were stated for one year's typical operations. The length of investment is 4 years. The present investment has lasted longer than its expected life; thus, all one time costs have already been pro-rated over the expected life of the process. Also, there is no income associated with cleaning the copper sheeting because it is only one part of the finished product.

The defined elements of the chemical cleaning process results in a cost of $66,325/year while mechanical cleaning costs $67,769/year. All of the defined input and output costs for each process are contained in Figure 18 and Figure 19. Figure 20 summarizes the cost difference between the two alternatives.

Figure 17

Change identification for two alternative cleaning processes

Process: Cleaning copper sheets

Present

DIRECT INPUTS ----> PROCESS

DEFINED	1	2
Raw material	Y	Y
Water	N	N
Capital investment	N	Y
Installation labor	N	Y
Energy	Y	Y
Investment maintenance	Y	Y
Process labor	Y	Y
Material handling	Y	Y
Process training	N	Y
Research & development	N	Y
Testing	N	Y

MANAGEMENT COMPLIANCE ----> PROCESS

ILL-DEFINED	1	2
Employee safety program	Y	N
Management	Y	N
OSHA, RCRA training	Y	N
1st RCRA contigency	Y	N
Annual RCRA contingency	Y	N
1st emergency equipment	Y	N
Annual emergency equip.	Y	N
1st storage area	Y	N
Annual storage area	Y	N
Record keeping	Y	N
Special handling	Y	N
Annual manifesting	Y	N
Permits	Y	N
Legal consultation	Y	N
Insurance	Y	N

PROCESS ----> DIRECT OUTPUTS

DEFINED	1	2
Haz. solid waste disposal	Y	N
Haz. solid waste transport	Y	N
Haz. solid waste storage	Y	N
Haz. solid waste testing	N	N
Recycle	N	N
Waste storage	N	Y
Water disposal	N	N
Water testing	N	N
Water treatment	N	N
Water storage	N	N
Emissions	N	Y
Scrap material	N	N
Product revenue	N	N
Product quality	Y	Y
Material handling	Y	Y
Waste disposal	N	Y
Waste transportation	N	Y

Alternate 1: Chemical cleaning

Alternate 2: Mechanical cleaning

Figure 18

The costs for one year of chemically cleaning metal sheeting

ELEMENT	Alt. #1 Chemically Cleaning Costs	Total	Notes
Raw material	40,000 lbs * $1/lb	($40,000)	2, 3
Water		$0	
Capital investment		$0	
Installation labor		$0	
Energy	$300/yr	($300)	3
Investment maintenance	50 hrs * $15/hr	($750)	4, 6
Process labor	1,000 hrs * $15/hr	($15,000)	4, 6
Material handling	100 hrs * $15/hr	($1,500)	4, 6
Process training		$0	
Research and development		$0	
Testing		$0	
Haz. solid waste disposal	40,000 lbs * $0.1/lb	($4,000)	2, 3
Haz. solid waste transport	40,000 lbs * $0.01/lb	($400)	2, 3
Haz. solid waste storage	100 sqft * $50/sqft /4 yrs	($1,250)	3, 5
Haz. solid waste testing		$0	
Recycle		$0	
Waste storage		$0	
Water disposal		$0	
Water testing		$0	
Water treatment		$0	
Water storage		$0	
Emissions	$250/yr	($250)	3
Scrap material		$0	
Product revenue		$0	3
Product quality	$1000/yr	($1,000)	3
Material handling	125 hrs * $15/hr	($1,875)	4, 6
Waste disposal		$0	
Waste transportation		$0	
TOTAL PER YEAR		($66,325)	

1. Price given in article
2. Quantity given in article
3. Estimated cost or amount
4. Estimated number of hours
5. Four years of production
6. Labor hour cost

Figure 19

The costs for one year of mechanically cleaning metal sheeting

ELEMENT	Alt #2 Mechanically Cleaning Costs	Total	Notes
Raw material	10,000 lb * $3.75/lb	($37,500)	2, 3
Water		$0	
Capital investment	$59,000/4 yrs	($14,750)	1, 5, 7
Installation labor	$3,000/4 yrs	($750)	3, 5, 7
Energy	$200/yr	($200)	3
Investment maintenance	50 hrs * $15/hr	($750)	4, 6
Process labor	500 hrs * $15/hr	($7,500)	4, 6
Material handling	50 hrs * $15/hr	($750)	4, 6
Process training	25hrs($15/hr))+50hr($20/hr/4yr)	($719)	4 - 7
Research and development	$5,000/4 yrs	($1,250)	3, 5, 7
Testing	$2000/4 yrs	($500)	3, 5, 7
		$0	
Haz. solid waste disposal		$0	
Haz. solid waste transport		$0	
Haz. solid waste storage		$0	
Haz. solid waste testing		$0	
Recycle		$0	
Waste storage	50 sqft * $50/sqft / 4 yrs	($625)	3, 5, 7
Water disposal		$0	
Water testing		$0	
Water treatment		$0	
Water storage		$0	
Emissions		$0	
Scrap material		$0	
Product revenue		$0	3
Product quality	$1,000/unit	($1,000)	3
Material handling	75 hrs * $15/hr	($1,125)	4, 6
Waste disposal	10,000 lb/2000 lb/ton * $50/ton	($250)	
Waste transportation	$100/yr	($100)	
TOTAL PER YEAR	=	($67,769)	

1. Price given in article
2. Quantity given in article
3. Estimated cost or amount
4. Estimated number of hours
5. Four years of production
6. Labor hour cost
7. Cost of the investment is estimated by first cost divided by the total production or an annual equivalent

Figure 20

Changes in cost from switching to the proposed metal cleaning method for one year's production

ELEMENT	Proposed Income or Cost	Present Income or Cost	Difference
Raw material	($37,500)	($40,000)	$2,500
Water	$0	$0	$0
Capital investment	($14,750)	$0	($14,750)
Installation labor	($750)	$0	($750)
Energy	($200)	($300)	$100
Investment maintenance	($750)	($750)	$0
Process labor	($7,500)	($15,000)	$7,500
Material handling	($750)	($1,500)	$750
Process training	($719)	$0	($719)
Research and development	($1,250)	$0	($1,250)
Testing	($500)	$0	($500)
Haz. solid waste disposal	$0	($4,000)	$4,000
Haz. solid waste transport	$0	($400)	$400
Haz. solid waste storage	$0	($1,250)	$1,250
Haz. solid waste testing	$0	$0	$0
Recycle	$0	$0	$0
Waste storage	($625)	$0	($625)
Water disposal	$0	$0	$0
Water testing	$0	$0	$0
Water treatment	$0	$0	$0
Water storage	$0	$0	$0
Emissions	$0	($250)	$250
Scrap material	$0	$0	$0
Product revenue	$0	$0	$0
Product quality	($1,000)	($1,000)	$0
Material handling	($1,125)	($1,875)	$750
Waste disposal	($250)	$0	($250)
Waste transportation	($100)	$0	($100)
TOTAL	($67,769)	($66,325)	($1,444)

Next, the ill-defined inputs were analyzed. Since the costs cannot be completely separated for each element, a summary of the major costs are listed below.

1. Environmental coordinator spends 10% of his/her time on this process, costing $4,000.
2. Environmental health and safety committees, including 5 employees at 25 hours/year, costing $3,750.
3. Secretarial assistance for 300 hours/year, costing $1,000.
4. Supplies, costing $1,000.
5. Equipment, costing $500/ year for 4 years.
6. Training expenses for 3 employees at 24 hours/year and 2 employees at 8 hours/year, costing $1,320.
7. Permits, costing $1,000.
8. Legal consultation, costing $500.
9. Insurance premium increases, costing $1,000.

The total present ill-defined input costs equal $14,070 per year.

4. Determine Risk Rating

Using equations from the methodology, the new costs will be calculated. There are presently three hazardous wastes. Including 15,000 pounds of used phosphoric acid and sulfuric acid, that are D characteristic wastes. Also 10,000 pounds of ammonium persulfate, a D characteristic waste is generated. The proposed method results in 10,000 pounds of waste (spent pumice) that is not hazardous. Since this waste is not hazardous it is not included in this equation. Table 15 contains a summary of the process hazardous waste information.

Table 15

Process hazardous waste information

Current Process Wastes Current ill-defined costs = $11,400			**Proposed Process Wastes**		
Hazardous Waste X	Weight of X	X Rating	Hazardous Waste X	Weight of X	X Rating
D (Phosphoric acid)	15,000 Lb.	10	None		
D (Sulfuric acid)	15,000 Lb.	10			
D (Ammonium persulfate)	10,000 Lb.	4			

Total waste volume = Sum[(Weight of X)(X Rating)] Eq. 4

Total waste volume = [(15,000 Lb.)(4) + (15,000 Lb.)(4) + (10,000 Lb.)(4)] = 160,000 Lb. rating

Proposed waste volume = Sum[(Proposed weight of X)((X Rating)] Eq. 5

Proposed waste volume = 0 Lb. rating

Total number of wastes = Sum[(Total number of X wastes)(X Rating)] Eq. 6

Total number of wastes = (2)(4) + (1)(4) = 12 quantity rating

Proposed number of wastes = Sum[(Proposed number of X wastes)(X Rating)] Eq. 7

Proposed number of wastes = 0 quantity rating

New Costs = Present Costs [(Proposed waste volume)/(2(Total waste volume))

+ (Proposed number of wastes)/(2(Total number of wastes))] Eq. 8

New Costs = ($11,400)[((0 Lb. rating) /2(160,000 Lb. rating))

+(0 quantity rating /2(12 quantity rating))] = $0

The ill-defined input savings for one year's production is $11,400. Next, the ill-defined output changes are scored according to their risks. Referring back to Figure 5 (page 37), and the scoring system developed in the methodology (page 45), a score for the new alternative can be calculated. The change to the new process would eliminate three generated hazardous wastes while adding one non-hazardous waste. Each waste that is affected will be considered individually. The result of this analysis is found in Table 16.

Change #1: Eliminating (10,000 pounds) ammonium persulfate, a D characteristic waste.

Change #2: Eliminating (15,000 pounds) phosphoric acid, a D listed waste.

Change #3: Eliminating (15,000 pounds) sulfuric acid, a D listed waste.

Change #4: Adding (10,000 pounds) pumice, a non-hazardous waste.

Table 16

Risk changes

	Changes				
Ill-defined Outputs	#1	#2	#3	#4	Totals
Noncompliance	-2	-2	-2	0	-6
Waste water leak	-2	-2	-2	0	-6
Transportation spill	-2	-2	-2	0	-6
Employee health	-2	-2	-2	0	-6
Employee perception	-2	-2	-2	0	-6
Fines	-2	-2	-2	0	-6
Environmental pollution	-2	-2	-2	0	-6
Societal perception	-2	-2	-2	0	-6
Employee accidents	-2	-2	-2	2	-4
Totals	-18	-18	-18	2	-52

The general rules presented in the methodology were followed exactly for the three wastes that are eliminated from the current process. Eliminating three hazardous wastes resulted in a reduction of two points in risk for each element. The pumice is not a hazardous waste so risk points were only added for employee accidents. Employee accidents for the new process were dangerous because the operators must operate the new mechanical equipment.

5. Summary of Costs and Risks

Table 17 summarizes the changes in the defined, ill-defined, and non-defined elements. The risk score is zero for the current method and is negative fifty-two for the proposed method. Each year's production costs using the current cleaning method's defined costs are $66,1325. The proposed cleaning method's defined costs are $67,769/year of production. The proposed cleaning method is less attractive when only considering defined costs. But the proposed method becomes less expensive after considering that the ill-defined costs are reduced by $11,400/year. A 56 point risk improvement provides an extra incentive to change to the new method. Future rules and regulations will only make the new alternative more attractive. The improvement in risks and reduction of costs should lead to a more in-depth economic study of the two alternatives.

Table 17

Cost summary for the current and proposed alternative

	Chemical cleaning	Mechanical cleaning	Proposed change
Risk Score	0 (Base)	-56	-56
Defined Revenue or Costs	($66,325/year)	($67,769/year)	($1,444/year)
Quantifiable Ill-defined Costs	($11,400/year)	$0/year	$11,400/year
Total Revenue or Cost	($77,725/year)	($67,769/year)	$9,956/year

5 Summary

5.1 Recommendations for Further Research

This research is one of the first to identify and quantify the activities and costs associated with a company using and generating hazardous substances. Many important issues were addressed and cost data was incorporated into information that can help make process change decisions. The research focused on the present impact of hazardous wastes and the effect that process changes will have on their costs. It also measured differences between present and proposed processes risks due to the presence of hazardous waste. To focus on the effects that process changes have on a wide range of elements, some in-depth evaluation was omitted. The omitted areas provide excellent opportunities for further research. Areas that, if incorporated, would make this research more complete are life cycle assessment, costs associated with risk elements, and engineering economy. The methodology in this thesis revolves around the identified process elements. Research that identifies additional process elements could be incorporated into the methodology to make it more thorough. Also the management and compliance cost allocation method and risk analysis procedure should be tested for accuracy with further research.

Life cycle assessment studies process costs from cradle to grave. This is an ideal analysis approach, but it is difficult to implement because the future required activities are unknown, and thus their costs cannot be determined. Research that enables experts to predict what the future requirements and their associated costs will be will make this problem easier to address.

One could add engineering economy (discount factors, depreciation, tax breaks) to the process cost equations in this thesis. This research has created a methodology to identify elements and determine costs associated with the usage of hazardous materials and the generation of hazardous wastes. These costs are weighted against the operation and investment costs. Since the focus is not placed on the investment costs, engineering economy was not inserted into the formulas. The calculations would be more comprehensive if discount factors, depreciation and tax breaks were considered. Currently, the methodology in this research is appropriate to determine if a need for a more in-depth evaluation exists.

The costs for the risk elements could be estimated based on a probabilistic evaluation of the frequency of occurrence and magnitude of effect. There are many factors that affect the probability of an activity occurring. Examples of these factors include the type and age of equipment and employee experience and training. Incorporating these factors with estimates of future costs of accidents would improve the evaluation of the risk elements.

The management and compliance costs are not easily identifiable for each element so an allocation method was incorporated. Several important cost affecting factors were identified to determine the change in management and compliance costs. Further research could help to determine the individual costs for some of these elements. This would reduce the number of elements that must have their costs allocated. Also, case studies would be helpful to determine if the allocation procedure was accurately estimating the actual costs.

The risk analysis procedure is a relative measure that is dependent on the number and amount of hazardous substances and process knowledge to determine risk ratings. Case studies and an analysis of historical records could be used to verify the effectiveness of the method used. Also, additional risk factors may be identified and incorporated into the risk analysis.

5.2 Conclusion

Hazardous materials and wastes are requiring increased management and compliance activities and costs. Presently, these costs are generally unknown, and often, companies take little action to attempt to reduce them, but there are many methods to reduce these costs. Some organizations are concentrating on reducing or eliminating these hazardous materials and wastes. An effective means of accomplishing this is to change manufacturing processes, which can be effective in reducing companies' waste disposal cost and compliance activities. The methodology provided helps to identify the elements that process changes have impacted. These elements include direct and indirect process inputs, management and compliance costs, and risk elements. Costs can easily be identified for the directly affected input and output elements, but for most hazardous material and waste compliance issues a cost allocation procedure must be used. Cost allocation is needed because the hazardous substance management and compliance costs are often not directly assignable to specific elements. Thus, a cost allocation procedure is used to determine an estimate of the future costs for alternative process methods. Changes in the number, amount, and type of hazardous substances were identified to be important factors that affect these costs. Changes in management and compliance costs were simplified by using a linear cost equation incorporating the changes in these factors. Included are equations to calculate compliance costs for new process alternatives.

The final contribution of this research is a method to compare cost and risk rating of a proposed process to the present process. It was chosen to measure a relative difference to determine the risk associated with different alternatives. Thus, the proposed process alternatives risk would be compared to the current method (base risk). The elements' risks are also closely related to the presence of hazardous substances. The number and amount of hazardous substances required or generated by the process greatly affect the risk elements. Based on this fact, rules were developed to assign risks for processes. One must also consider process knowledge that may require deviating from the general rules stated. Decreasing the number and amount of hazardous substance in a process will improve the risk involved with the process. Increasing hazardous substances will have the a negative effect on risk elements.

The methodology allows one to determine the costs and risks associated with process alternatives. Using this information, a company should be able to determine whether to further analyze an alternative. This research enables one to organize easily obtainable information in a systematic way. The information can then be used to determine if an alternative process appears to be better than a present method. If it is, then further economic analysis should be done to confirm the preliminary analysis. If not, then other alternatives should be explored and/or the current proposed alternative could be analyzed again after a certain time period.

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