An activity based management methodology for evaluating business processes for environmental sustainability

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Abstract

Purpose – This paper seeks to introduce a conceptual methodology to support decisions about environmental systems.

Design/methodology/approach – The methodology incorporates activity-based costing and management, the analytic hierarchy process, and business process modeling using the IDEF0 method.

Findings – An illustrative example that applies the methodology to a semiconductor manufacturing facility is presented in the paper. The company used the results to analyze a process improvement.

Research limitations/implications – The complexities and nuances of the approach will require facilitation and support. Making the technique more transparent and available to management is a barrier to its diffusion and application.

Practical implications – Potential managerial application and implications include areas such as product cost management, business process design and technology selection.

Originality/value – Application of the methodology encourages management to more fully assess the environmental implications of their decision in evaluating alternative technological processes while also allowing for the inclusion of other organizational decision dimensions.

Keywords Environmental management, Activity based costs, Activity based management, Analytical hierarchy process, Business process re-engineering

Paper type Research paper

Introduction

Environmental sustainability has recently received significant global and competitive attention among for-profit organizations. Sustainability or sustainable development is defined as economic activity that meets the needs of the present generation without compromising the ability of future generations to meet their needs and is based upon economic, social, and environmental components. Organizations are becoming increasingly aware that choices made about products, processes and services can have profound environmental implications (Day and Arnold, 1998). Organizations face

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a quandary on how to address issues pertaining to environmental friendliness, social consciousness towards workers, consumers, and communities, as well as ensuring a fair return and long-term viability to the manufacturer.

The focus of this paper will be on the environmental/economic sustainability aspect of managerial decisions and management facing organizations striving for sustainability. The approach represented here may be extended to incorporate additional sustainability and organizational factors. A conceptual model is developed that aids in environmental systems decision making with a particular focus on business process analysis and the application of activity-based management techniques. The model utilizes the analytic hierarchy process (AHP) (Saaty, 1980) as a framework for evaluating business processes for environmentally conscious business decision-making and business process design. AHP allows for both quantitative and qualitative criteria to be integrated into the model and offers an overall solution for the model with costing mechanisms that may be integrated based on AHP criteria evaluation. The costing mechanism can be used within a broader total cost management approach that has been supported by corporate environmental economists for appropriate evaluation of environmental costs for process and product design and evaluation. The integration of AHP and cost management principles will be taken one step further by showing how these two business decision tools can be mapped to IDEF0, a systems analysis and design approach used for business process modeling, to provide a general activity-based management approach for evaluation of environmental aspects of organizational decisions. Actual case study information will show the utility of the technique and potential practical limitations. Managerial implications related to the methodology and applications are also defined.

Corporate environmental sustainability

The evaluation of environmental management decisions requires analysis on multiple dimensions, including economic, societal and political impacts. When analyzing multiple dimensions there exist interacting and often conflicting goals that make the integration of the dimensions difficult. There are also organizational barriers to environmental change such as attitudes from staff and top management as well as industrial barriers such as technical availability and knowledge, information, and regulatory constraints (Epstein and Roy, 1997). The interaction and often-conflicting nature of these aspects makes these decisions difficult, as does the requirement to integrate the needs and desires of multiple constituencies and stakeholders.

If incentives in the marketplace are given, companies tend to innovate toward greener processes (Sharfman *et al.*, 2000). However, sustainable practices that aid in making a company more competitive including waste reduction, recycling, reuse and waste diversion are being pursued by more companies as they locate inefficiencies in their processes. Sustainability has become a strategic weapon and an imperative for most businesses in the twenty-first century and has become a fundamental market force affecting long-term financial viability and success (Preston, 2001). Companies are pursuing sustainability because they are finding business value in it (McMullen, 2001).

A major issue in environmentally focused sustainable development is how to operationalize its concepts. To executives, adopting and implementing environmental sustainable development requires identifying how their organization fits within the larger ecological and economic environment and identifying the actions required for its survival.

Proactive organizational policies such as total quality environmental management (TQEM) and environmental management systems with continuous improvement as their core philosophy are all heavily reliant on the operationalization of environmental performance and practice. Central to this performance evaluation is the issue of economic and cost measurement and evaluation of processes. Indeed, one of the major difficulties in environmental management is the determination and allocation of costs, tangible and intangible, across organizational activities and processes. Costing and cost management is also relevant to reengineering organizational processes, since it is these processes that determine the financial and environmental implications that will be faced by the organization.

The methodology and its elements

As described in the previous section, given that:

- various external forces are playing a role in corporate environmental decision making;
- internal operational decisions and measures will be helpful for managing in this environment; and
- various systems exist to help management

then tools to aid in this decision-making environment are essential for environmentally conscious organizational management. We introduce one such tool set. In the following sections we will overview the primary elements of our evaluation methodology. After a discussion of environmental costing in general, our foundation models used for the activity based management evaluation framework are briefly described. These modeling approaches include AHP, activity based costing (ABC), and IDEF0 modeling. Their integration is then discussed and illustrated by a supporting case study example.

Environmental costing

Full cost accounting, total cost accounting and environmental cost accounting are all terms that have been used to describe the integration of environmental costs into organizational decisions. Whether or not the complete and true environmental costs are all internalized into an organization is a matter of debate. Yet, environmental costs for organizations have been increasing at a great rate over the past three decades and are due to a number of reasons ranging from social and customer requirements to regulatory requirements (Kitzman, 2001). Economic reasons are also prevalent, Roussey (1992) noted that with respect to the pollution control practices of 29 chemical industry plants, those with environmental cost accounting systems on average saved $3.49 for each dollar spent.

Environmental accounting was conceived to address limitations of conventional accounting approaches for management decisions involving significant environmental costs and/or impacts. The goal of environmental accounting is to provide more accurate and comprehensive information to decision makers, thus enabling better decisions on issues that impact both the organization's financial health and the environment. There is an argument that many environmental externalities (societal costs) are not integrated into the true costs of products or services offered. When the social costs are greater than the costs paid by the firm that produces and sells it, then this becomes a negative externality. There are some efforts by governmental agencies to internalize social environmental costs through mechanisms such as taxing, permitting requirements and fines. Some of these measures do allow for organizations to help identify environmental costs and appropriately cost products and processes. These can be direct measures, but are typically costs estimated through a variety of indirect valuation approaches, which are still not perfect valuation tools themselves (see Pethig, 1994 for an overview of economic environmental valuation methods and their limitations). Other internal costing issues such as potential risk and pursuant liabilities of some environmental costs of products and processes are more difficult to measure.

The spectrum of costs ranges from explicit direct costs to embedded costs. One of the more popular categorizations developed by the EPA (1995) is a hierarchy of costs based on their ease of measure and integration into corporate cost evaluations. A summary of these cost measures is shown in Table I. There are two levels of categorizations, internal and external costs. The internal costs are costs that are, or potentially can be, accrued by the organization, while the external costs are typically not accrued directly by the organization. The focus of our evaluation model will be on internal costs. The internal costs include conventional, hidden, contingent, and image/relationship costs as described below.

Conventional costs are typical costs found in most organizational accounting ledgers such as material, equipment, and labor costs. Even though these costs are not typically environmental, decisions facing them will have environmental repercussions in areas such as scrap reduction and energy efficiency.

Ease of measure	Type of cost	Examples
Easier to measure	*Internal/private*	
↓	Conventional	Capital equipment Materials Labor Utilities
	Hidden	Upfront Regulatory Voluntary Back-end
	Contingent	Future compliance Remediation Liability
	Relationship/image	Corporate image Supplier relationship Stockholder relationship
	External/public	
More difficult to measure	Societal	Environmental degradation Non-legal damages to property and people

Source: Adapted from EPA (1995)

Table I.
Various environmentally related costs faced by organizations

Hidden costs are categorized into four major areas:

(1) upfront costs such as site studies and preparation;

(2) regulatory costs such as paper work preparation and database management;

(3) voluntary costs such as internal auditing or ISO 14001 certification; and

(4) back-end costs such as facility closure.

Many times these types of costs are pooled into administrative or overhead costs and must be allocated. They are relatively measurable, but their allocation to a product, service or activity is the part that becomes more difficult.

Contingent costs can best be termed as future risk management costs that may have a probability of occurrence or non-occurrence. Future lawsuits or penalties that may occur and their probability of occurrence must be determined. Thus, the amount and type of costs that are incurred must be determined; their allocation can be to insurance requirements or as resource pools for future payments due to contingent liabilities. For a detailed analysis of accounting issues related to contingent costs see (Roberts, 1994).

Relationship and image costs are the most intangible and difficult to measure of the internal private organizational environmental costs. The valuation of corporate environmental image is something that is difficult to measure, but may include the value of organizational goodwill, less regulatory pressure, and other benefits of a good environmental image. The relationship costs may include loss of customers and suppliers due to poor environmental performance.

Overall, while some costs can be easily identified as environmental, some are more fuzzy in that they can have environmental implications but may not be as direct. Thus, many times the true environmental costs are not completely known, but there are still requirements for rational measurement and allocation of these costs. To even consider and evaluate these costs from a broader and more complete perspective can be valuable to the organization seeking to be more environmentally conscious.

Components of the methodology

In the following sections, the models and techniques (AHP, IDEF0 and ABC and management) to be integrated into the overall activity-based management methodology are briefly discussed. The purpose of this discussion is to provide sufficient background on these topics to allow the reader to better understand their use and integration in our methodology.

AHP – multiattribute decision modeling

Saaty (1980, 1999) developed the AHP for decision structuring and decision analysis. AHP allows a set of complex factors that have an impact on an overall objective to be compared with the importance of each factor relative to its impact on the solution of the problem. AHP is a comprehensive framework that is designed to cope with the intuitive, the rational, and the irrational when making multi-objective, multi-criterion and multi-actor decisions – exactly the decision-making situation found with environmental management. While AHP is conceptually easy to use, it is decisionally robust so that it can incorporate the complexities of many real world problems. AHP models a decision-making framework that assumes a unidirectional hierarchical relationship among decision levels. AHP has three basic steps:

(1) Development of a decision hierarchy. The top element of the hierarchy is the overall goal for the decision model. The hierarchy decomposes to a more specific attribute until a level of manageable decision criteria is met. The hierarchy is a type of system where one group of factors influences another set of factors.

(2) Pair-wise comparisons are conducted to estimate the relative importance weights (or allocations) of the various elements on each level of the hierarchy.

(3) The weights obtained are integrated to develop an overall ranking of decision alternatives.

In our model the core factors of the hierarchy will be business processes or activities that are influenced by the managerial decision or improvement to the process. The AHP approach will help identify the amount of allocation to be made of whatever resources across activities, facilitating an activity based management approach. This methodology is further described below.

IDEF0 – business process modeling

IDEF0 is a systemic functional modeling method developed by the Air Force's Integrated Computer Aided Manufacturing initiative (Marca and McGowan, 1988). There are five fundamental elements to the IDEF0 functional model (Figure 1): activities are represented by boxes; inputs, outputs, controls, and mechanisms are represented by the arrows shown at the left hand side, right hand side, top, and bottom of the boxes, respectively. The flow of the arrows shows the flow of information and material from one activity to another. A characteristic of the IDEF0 modeling technique is that activities and arrows can be decomposed into hierarchical levels of analysis. This characteristic is shown in Figure 2. Each diagram contains detail about an activity from a more general (or parent) activity. The process or product model that is developed by IDEF0 may be easily and directly mapped to other tools and techniques. In our case the decompositional characteristics are helpful for linkage to AHP. Part of the IDEF0 methodology involves the documentation of each activity and process where descriptive text for each of the activities is developed. Additional information pertaining to environmental aspects should be included in these descriptions and glossaries. IDEF0 has been a popular tool in the business process reengineering of organizations (Gingele *et al.*, 2002; Kettinger *et al.*, 1997).

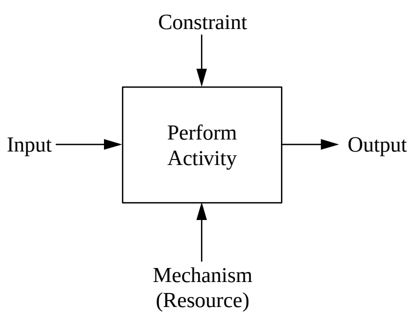

Figure 1.
The graphical IDEF0 element representation

Activity based costing and management

ABC is an approach used to allocate costs across activities of an organization's processes and then accrue those costs based on products/services, or cost objects. It can also be used to help evaluate performance of activities and cost objects. ABC began as a methodology to allocate overhead costs more effectively taking into consideration the amount of resources used by an activity for the manufacture of a product or service. The methodology has been extended to focus on a more complete activity based management approach, where general resources, not just costs, may be allocated across activities (Berliner and Brimson, 1988).

The most relevant ABC concepts for our discussion include (Cooper and Kaplan, 1999; Emblemsvag and Bras, 2000):

- *Activity*. A group of related actions that form the process.
- *Cost (Resource) drivers*. Factors that cause a change in the cost of an activity. For example, temperature of heating and length of time of heating an element may be a factors that cause the energy cost of an activity to increase, it could also be considered an energy cost driver.
- *Cost object*. Any product or service where separate cost assessments are needed. In the case study to follow it will be a semiconductor chip.
- *Resource*. An item that is consumed by the activity. In our case it will be various categorizations of environmental costs.

The integrative activity based business process management methodology

AHP and ABC (Angelis and Lee, 1996; Partovi and Burton, 1993), and IDEF0 and ABC (Ben-Arieh and Li, 2003; Moravec and Yoemans, 1992) have been recommended and applied separately as synergistic methodologies for activity-based management and

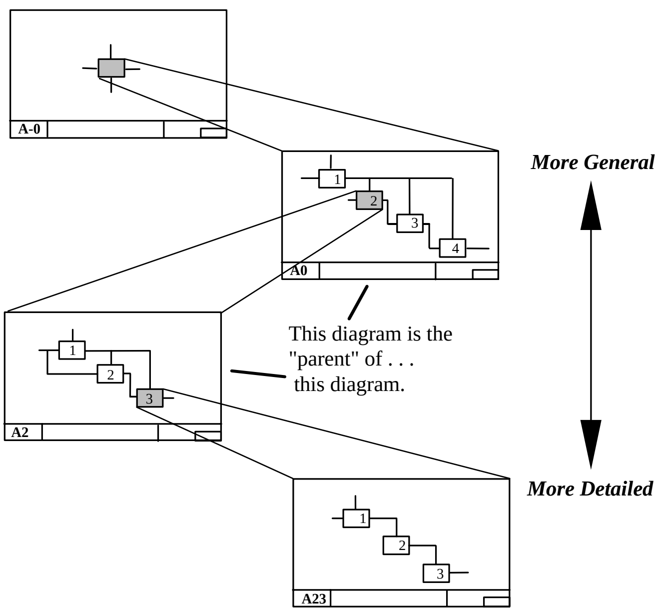

Figure 2.
An IDEF0 decomposition overview

business process reengineering approaches. Yet, the synergistic relationship of all three tools ABC, AHP and IDEF0, have yet to be investigated, much less applied. Thus, we see these tools as helpful to the analysis of environmental costs and environmental management of business processes using an activity-based management approach. We integrate the three using a general business process evaluation approach with an environmental perspective.

The general methodological (and integrative) framework is as follows:

- Define a hierarchy of activities using IDEF0. Only one hierarchy is needed for all activities that will be carried out in all process scenarios, with activities not needed for analysis of a new process reduced to a zero activity driver value.
- A sub-hierarchy for each of the major environmental costs/resources (costs may not need to be known) is developed. Each sub-hierarchy is defined by an environmental cost resource (i.e. liability costs, contingent costs, public image costs). An example sub-hierarchy that integrates the IDEF0 identified processes, the AHP hierarchy and how they relate to ABC elements is shown in Figure 3.
- At the bottom of each sub-hierarchy there will be alternative processes or technologies. These are the alternative technologies that "cost objects" will flow through and will consume the resources. In the case study the cost objects will be semi-conductor chips. The evaluation will be a relative evaluation of the processes that will consider the relative influence of the various resource drivers on each of the cost objects.
- Allocations are developed across activities to determine the activity "consumption index" for each cost and activity. These values will be the resource drivers.
- The performance of each alternative on activities for each sub-hierarchy are determined as normalized sum value or normalized total consumption index value for the sub-hierarchy.
- The AHP scores for all environmental costs/resources are aggregated if sub-hierarchies are available; otherwise the full evaluation can be completed in

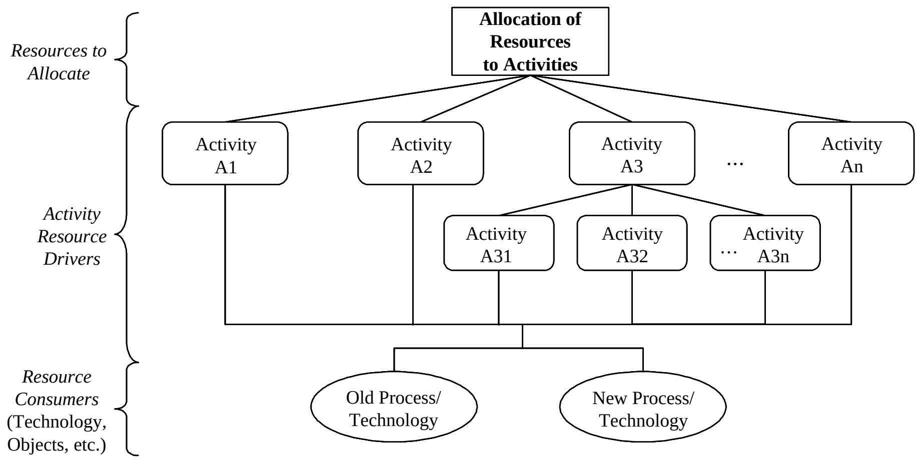

Figure 3.
Generalized AHP allocation hierarchy for activity and process based resource management

one hierarchy into a total process index (TPI). The differences in final aggregate and normalized environmental consumption scores (TPI) will define which alternative process or technology is more economically and environmentally sound. The result is expected to be a generic percentage value. If actual differences in costs are known based on simulations or pilot tests, a normalized score on actual values can be included in the evaluation directly. More intangible costs, such as liability and public image costs, will use managerial perception and judgment. These latter, more difficult to determine, costs are the primary reason for applying AHP.

Each of these steps is now detailed in our case example. The company and process characteristics are first defined. Then the example is applied to one situation where a decision is to be made that influences the process. As the technology that is under evaluation is proprietary company's identity is disguised, as are some of the actual numbers used.

The case study company and illustrative example

Company A is a global, independent semiconductor company that designs, develops, manufactures and markets a broad range of semiconductor integrated circuits and discrete devices. There products are used in a variety of microelectronic applications. The company employs approximately 50,000 people at its approximately 20 manufacturing sites worldwide with net revenue over $5 billion (USD) for 2002. It operates under a vision statement for environmental responsibility and sustainable development. The environmental practices and policies of this company are broad-based, as exemplified by having all of its manufacturing sites Eco-Management and Audit Scheme (EMAS) validated and ISO 14001 certified. Since, 1998 they have reduced their chemical consumption per manufacturing unit from 6.28 to 4.29 kilograms per 8″ wafer. By creating an emphasis and priority on environmental initiatives the company has won more than 40 major awards recognizing its successful implementation of environmental policies.

A senior equipment engineer employed at the company aided in determining the efficacy of the proposed methodology. One of its US-based manufacturing facilities is contemplating a change in its current semiconductor cleaning processes. The process being analyzed in the case study is the etching of semiconductor wafers. This process is one activity in the larger process of fabricating a semiconductor wafer. The new technological approach and supporting process has been adopted in other facilities, but the US facility is only in the initial stages of considering its adoption.

As the objective of this discussion is not to the present the two techniques for wafer etching *per se,* but to use it as an example for the analysis methodology being introduced in this paper, the processes will be generically described. The models and descriptions were developed from several sources including the company itself as well common industry practice.

The fabricate wafer process is shown in Figure 4 and is numbered A0 in the IDEF0 convention. The process itself is one of many steps for semiconductor manufacturing. Over a hundred steps are typically used to define semiconductor production. Integrated circuits (also know as ICs or chips) are formed onto a single wafer. The company in this case study purchases the wafers from a vendor and fabricates the semiconductors to

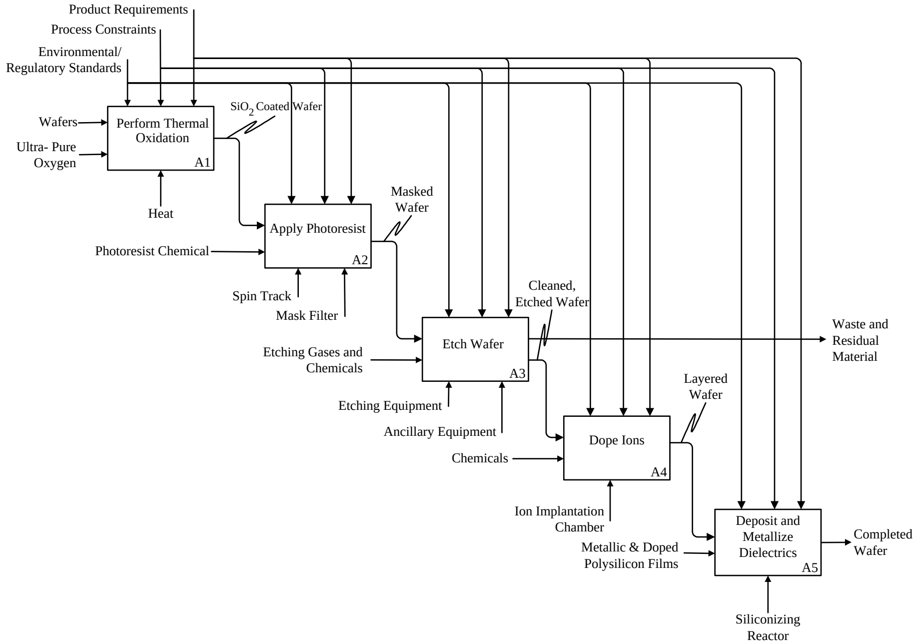

Figure 4.
A0 high-level IDEF0diagram of processes for fabricate wafer

exacting customer requirements. The primary output is a completed wafer that then enters a separate packaging process.

At this level, the fabricate wafer process consists of the following five high (Ax) level activities. In the A1 perform thermal oxidation activity, a thin layer of silicon dioxide (SiO_2) glass is deposited (or grown) on the wafer by exposing it to oxygen at high temperatures. Later, this layer will be etched to selectively remove the dielectric to form channels for conducting materials. The SiO_2-coated wafer then goes through photolithography, similar to the process used to create photographic images in A2 apply photoresist where the wafer is coated with a thin layer of light-sensitive polymer called photoresist. Ultraviolet light projected on the wafer through a patterned template called a mask causing portions of the resist to harden and become more resistant to certain chemicals relative to the non-exposed resist. In the A3 etch wafer process the wafer then is sent to an etch area where the exposed or excess photoresist material is washed from the wafers. Activities A1-A3 may actually be repeated several times for any wafer until the characteristics required of it have been achieved. Once completed, the etched wafers then undergo the A4 dope wafers process in which impurity atoms such as boron and phosphorous are used to alter the electrical conductivity of the areas exposed by the etch process. Finally in A5: deposit and metallize dielectrics, thin metallic and doped polysilicon films are added to form the interconnections among individual transistors and other devices.

Further discussion of activity A3: etch wafer process

As stated earlier the process being further examined in this case study is the A3 etch wafer process. To analyze the differences between the traditional and new method utilizing deionized ozone water, the same A0 fabricate wafer diagram will serve as the parent for the two decomposition diagrams. In addition, so as to form a consistent basis of comparison, the four activities in the A3 decomposition (to the A3x level) as required in the traditional method will also be used to describe the new method. The differences will be seen in how these four activities are performed, the equipment and chemicals required of the activities, and the waste outputs of the activities.

The traditional method for accomplishing etching wafers is shown in the A3 diagram in Figure 5 as etch wafer (traditional method). For over 30 years, the semi-conductor industry has used environmentally hazardous chemicals to remove photo-resist and organic residues from wafers in the manufacturing of semi-conductors process. The chemicals and processes include the use of sulfuric acid (H_2SO_4) to wash off the photo resist and the use of hydrogen peroxide (H_2O_2) to clean the wafer. These chemicals are not only hazardous, but also create waste management issues.

The new method entitled etch wafer (DIO_3) is shown as an IDEF0 diagram in Figure 6. The company is considering a proposal to implement the new process at a facility in the USA. The proposed procedure has actually been accepted for use at a sister plant in Europe. As indicated in the figures the process names have not been changed, however, some of the inputs, outputs, controls, and resources have been changed. Both of the old procedure's hazardous chemicals are replaced with "ozone water." The new procedure takes a mixture of DIW (deionized water) and O_3 (ozone), also known as DIO_3 in which ozone is mixed in ultra pure water resulting in an environmentally benign mixture. The new ozone process is not only less expensive but

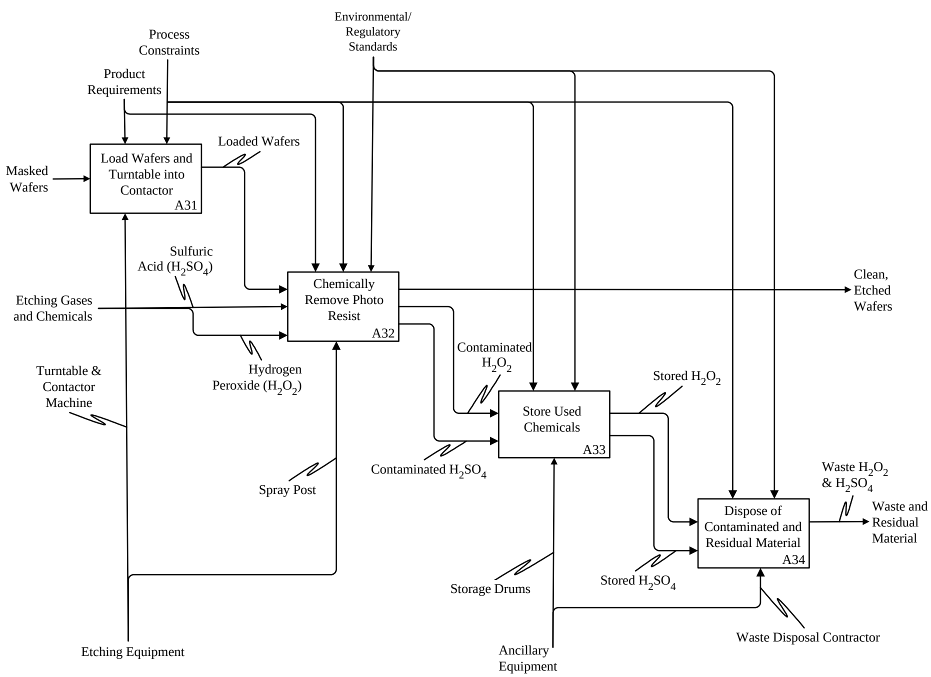

Figure 5.
A3 etch wafer decomposed process description (traditional method)

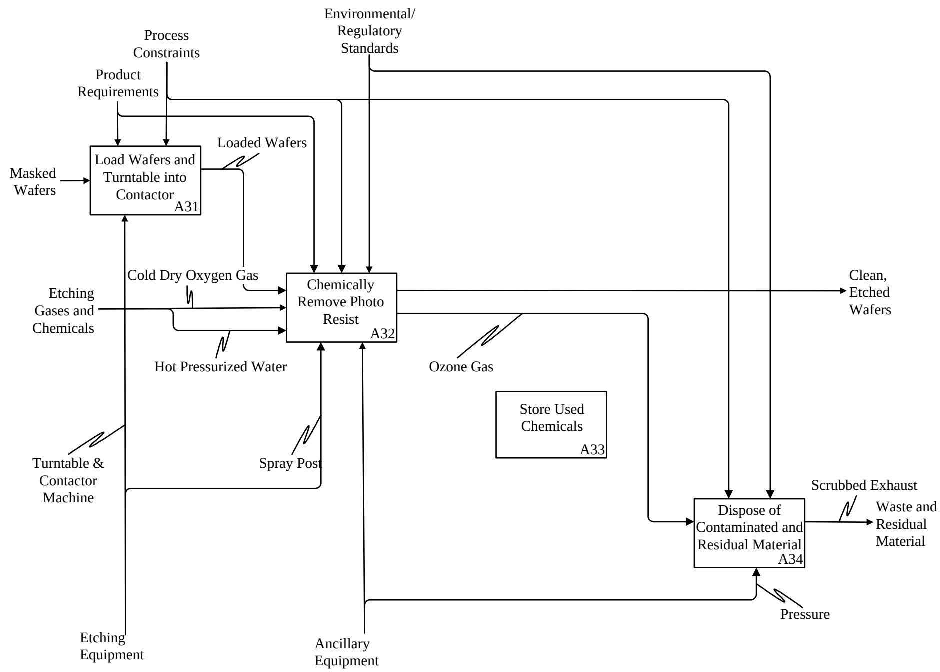

Figure 6.
A3 etch wafer decomposed process description (DIO_3 method)

it also uses less chemicals, is more environmentally safe, faster than the sulphuric recipe and produces an equivalent or better yield performance.

We next present a summary of the processes to be used in this case study within a hierarchical diagram, as shown in Figure 7, the sub-hierarchical diagram for contingent costs allocations. The AHP analysis will utilize this hierarchy. Notice that in

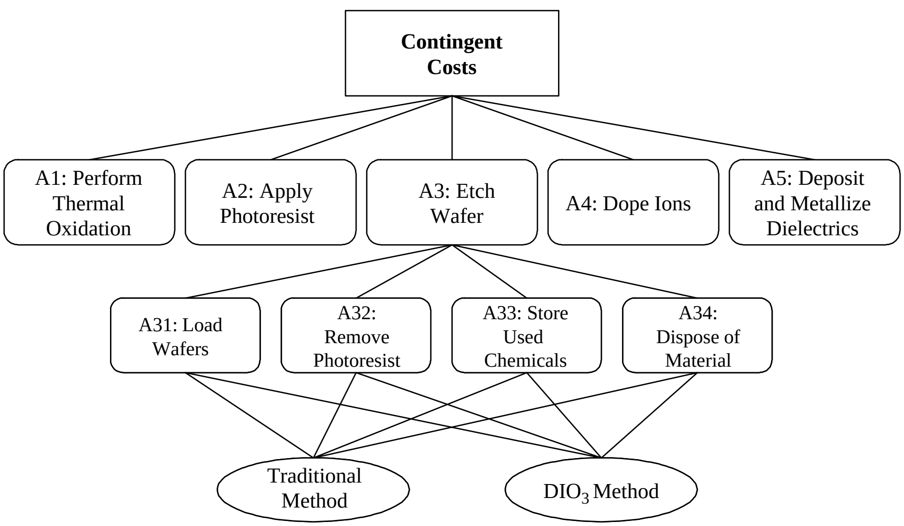

Figure 7.
Case AHP allocation sub-hierarchy for activity and process based resource management approach for contingent costs resource

Figure 7, we are only concerned with the influences of activity A3 and its sub-activities since this is the boundary of direct influence by the two alternative approaches under evaluation by the engineering team.

AHP to determine activity resource drivers

As described earlier in the general methodological framework AHP and ABC are used in conjunction to determine the difference in the aggregated resource consumption index scores (total process indices) which allow us to evaluate whether the new process is indeed better in terms of resource consumption than the old process. There are a number of resources (costs, manpower, material) from which activity drivers could be allocated. In this case, since the focus is on environmental issues, we can borrow from the variety of environmental categories discussed earlier (e.g. conventional costs, hidden costs, contingent costs, and relationship/image costs). However, in the pursuit of a clearly defined illustrative case, three of the inclusive general environmental costs categories have been selected: conventional, contingent, and environmental image costs. The methodology could also be applied to examine the decomposition of the costs on the business processes, for example conventional costs may be disaggregated, hierarchically, into material, equipment, and labor costs, and serve as separate activity drivers with their own sub-hierarchies.

Table II shows the relative consumption indices for resources by each activity (these are the relative activity driver values). These consumption index values were obtained through the application of the AHP pairwise comparison technique to determine relative importance values for the drivers. Each column within Table II represents the weights determined for each resource by a pairwise comparison matrix. Thus, three pairwise comparison matrices, each with 10 pairwise comparison questions were used to derive all the weights within Table II. The first set of pairwise comparisons, results are shown in the first numerical column, was conducted by asking the questions: "In terms of contingent costs, how much more impact does activity A1 have over activity A2?" The responses would range from extremely less impact to extremely more impact. Thus, these evaluation results show relative performance where larger values for an activity means potential influence of that activity is greater, rather than an actual cost allocation. We applied an easily accessible internet-based AHP tool called web-Hipre (located at www.hipre.hut.fi; see Mustajoki and Hämäläinen, 2000) for determination of these weights. Table II shows that the activity of concern (activity A3) has the largest relative potential image costs (with a value of .457), while the relative influence of the contingent or conventional costs for activity A3 are in the middle level of the major activities.

Table III is an allocation valuation of each of the resources (activity resource drivers) over the activities that make up the etch wafer process. The process for value determination used a pairwise comparison matrix for each cost category. This step

Activity	Contingent costs	Environmental image costs	Conventional costs
A1	0.177	0.268	0.101
A2	0.092	0.042	0.036
A3	0.192	0.457	0.224
A4	0.224	0.090	0.241
A5	0.316	0.142	0.398

Table II. Consumption indices for each of the major resource sub-hierarchies for the fabricate wafer process required three additional pairwise comparison matrices of six questions each. A sample question asked was "Within Activity A3 how much more does sub-activity A31 influence contingent costs when compared to Activity A32?" The answer could range from extremely less to extremely more influence. The results here show that activities A33 and A34 have greater potential contingent costs, while activities A31 and A32 seem to be more influential on conventional costs.

Table IV shows the results at the lowest level of the AHP hierarchy. These results show the percentages of the difference in resource consumption between the old system and the new system. An example question here would be "For contingent costs, how much better is the old system when compared to the new system?" The range would go from extremely worse to extremely better. The larger values would be better performance. As shown in the table, A31 old and A31 new (Load wafers and turntable into contactor) have the same relative values of performance for all costs since this sub-activity is not influenced by the changes (0.5, 0.5, respectively). However, A34 (Dispose of contaminated and residual material) changes significantly between the old and the new process, especially in the environmental image costs category. Twelve total pairwise comparison questions were used to arrive at the values shown in Table IV.

The final step in the integrative methodology is to calculate the aggregated weighted analysis of the old process versus the new process. In Table V's first column with values (labeled R_w) we have the relative importance weights of the three major sub-hierarchies of resources. In this case it was decided that importance levels for the organization were 0.2, 0.4, and 0.4 for contingent, environmental image and conventional costs, respectively. These weights could be easily determined using a pairwise comparison matrix. A sensitivity analysis on these weights is presented in the next section to determine how the solution changes; however, the final aggregation is completed here first. The next column in Table V shows the relative importance weights of the AX level activities. In this case we are only concerned with Activity A3. The values at this level, since there is only one set per cost, do not really influence the final decision since we are just weighting the original resource importance values the same across all activities.

Table III. Allocation valuation for each activity at (A3x level) resource driver (for the A3 activity: etch wafer)

Current process	Contingent costs	Environmental image costs	Conventional costs
A31	0.061	0.054	0.311
A32	0.096	0.087	0.518
A33	0.450	0.312	0.107
A34	0.393	0.547	0.065

Table IV. Total relative consumption index values by A3x level activity for each sub-hierarchy and alternative technological process

Activity	Contingent costs		Environmental image costs		Conventional costs	
	Old	New	Old	New	Old	New
A31	0.500	0.500	0.500	0.500	0.500	0.500
A32	0.300	0.700	0.120	0.880	0.256	0.744
A33	0	1.000	0	1	0	1
A34	0.137	0.863	0.106	0.894	0.583	0.417

Table V. Weighted analysis for determination of total process indices of the old process vs the new process

Resource	R_w	A_{3w}	A3X	A_{3xw}	C_{13xw}	C_{23xw}	TPI_1	TPI_2
Contingent	0.2	0.192	A31	0.061	0.5	0.5	0.0049	0.0049
	0.2	0.192	A32	0.096	0.3	0.7	0.0019	0.0141
	0.2	0.192	A33	0.45	0	1	0.0000	0.0570
	0.2	0.192	A34	0.393	0.137	0.863	0.0106	0.0894
Image	0.4	0.457	A31	0.054	0.5	0.5	0.0049	0.0049
	0.4	0.457	A32	0.087	0.12	0.888	0.0019	0.0141
	0.4	0.457	A33	0.312	0	1	0.0000	0.0570
	0.4	0.457	A34	0.547	0.106	0.894	0.0106	0.0894
Conventional	0.4	0.224	A31	0.311	0.5	0.5	0.0049	0.0049
	0.4	0.224	A32	0.518	0.256	0.744	0.0019	0.0141
	0.4	0.224	A33	0.107	0	1	0.0000	0.0570
	0.4	0.224	A34	0.065	0.583	0.417	0.0106	0.0894
Total process indices							0.0510	0.2600

If there were values needed for influences of other activities at this level (e.g. activity A41), then the inclusion of these level values will need to be considered. The A3 values are included, at this time for illustrative purposes. The next column of weights shows the relative importance weights associated with the A3x level activities for the different cost hierarchies. The next two sets of columns are the weights for each alternative technology to be evaluated. Alternative 1 is the old process technology, alternative 2 is the new process technology. The final two columns are the TPI of the old and new technologies, respectively, the final total values appear on the bottom of these columns. The TPI for each alternative are calculated using expression (1):

$$\mathrm{TPI}_i = \sum_w \sum_x \sum_i \mathrm{R}_w \mathrm{A}_{3w} S_{3xw} C_{i3xw} \tag{1}$$

where, TPI_i is the TPI of alternative *i*, R_w is the relative importance weight for resource w when compared to other resources, A_{3w} is the relative allocation valuation (driver) of Ax level activities for resource w for activity 3 (a generic index can be included in place of 3 (e.g. y) for a more generic formulation), A_{3xw} is the relative allocation valuation (driver) for each subactivity x of activity 3 for resource w, C_{i3xw} is the value of the relative consumption index for an alternative i, resource w for each subactivity x of activity 3.

As can be seen in Table V the TPI for the old process technology ($\mathrm{TPI}_1 = 0.094$) is quite a bit lower than the TPI for the new process ($\mathrm{TPI}_2 = 0.369$). The higher the TPI the more desirable the process.

A sensitivity analysis

Because the values determined here are based on perception and subjective evaluation, the results will require additional evaluation to determine how sensitive they are to changes in perceptions. Thus, we present a method to complete a sensitivity analysis.

Table VI shows the results of a sensitivity analysis with changes to the final scores for both the old and the new technological process. The focus of the changes will be on the conventional costs resource, where relative factor importance ranges from "nonexistent" with a value of zero to "fully dominant" with a value of one, increasing in 20 percent increments (six sets of sensitivity weights as shown in Table VI). The ratio of the other two resources (contingent and environmental image costs) is kept constant ratio of 1:2, as they were in the initial valuations of the resources as shown in Table V, where the summation of all three resources are equal to 1. This ratio relationship keeps image costs at twice the relative important values of the contingent costs, except when conventional costs are at one hundred percent, then the other two values are set at 0. The results of the total process indices (rows TPI_1 and TPI_2 in Table VI) show that the new process TPI_2 is the best solution over the assumed range of weights. Yet, as we see when we compare the ratio of TPI_1/TPI_2, there is an increasing relative improvement of the old process. This can be a sign to management that they may be undervaluing the new process if they tend to emphasize the conventional environmental costs.

Managerial input and use

Company A has adapted the new process at one of its European manufacturing facilities. The engineering manager involved in this case study is currently validating and justifying the new process for adaptation at a manufacturing facility in the USA. The methodology was presented to the engineer who agreed to the initial rankings of the activities and the researchers then conducted the pairwise comparisons. The results of this methodology could be used to influence the justification of this environmentally friendly new process as the decision will be made in the next few months. The other plant that has adapted the new technology has actually realized a cost savings of $0.07 per wafer and has processed over 8.7 million wafers to give a total savings of $609,000; furthermore over 272,000 liters of toxic chemicals (hydrogen peroxide, ammonia peroxide, and sulfuric acid) have not been used. The business case justification of the new etching process still needs to be presented to management since skepticism still exists on the technology's capabilities in the USA The activity-based management methodology described in this paper may prove valuable for the engineering manager to further develop a business case that explicitly incorporates the environmental dimensions of the new technological process.

The technique does initially require significant modeling and data acquisition efforts. However, if an organization is completing documentation with respect to environmental management system processes, much of this data can be available. The use of the IDEF0 modeling tool is a valuable tool to help document processes, especially for environmental management system certification programs such as ISO 14000. Management may still be critical and skeptical of the results since a significant portion of the methodology requires subjective and perceptual input rather than "hard numbers". Yet, many of the decisions and inputs faced by management do require intuition, formalizing this intuition is a capability that this technique offers. A major

Table VI.
Sensitivity analysis over importance ranges for conventional costs from 0 to 1

	Sensitivity weight sets					
Resource	1	2	3	4	5	6
Contingent	0.333	0.267	0.200	0.133	0.067	0
Image	0.667	0.533	0.400	0.267	0.133	0
Conventional	0	0.200	0.400	0.600	0.800	1
TPI_1	0.108	0.101	0.094	0.087	0.080	0.073
TPI_2	0.514	0.441	0.369	0.296	0.223	0.151
Ratio of TPI_1/TPI_2	0.210	0.229	0.255	0.294	0.359	0.483

advantage of this approach is that it helps management explicitly structure the decision to incorporate the major environmental factors. The use of sensitivity analysis may mitigate some of the concerns of using subjective data. In this situation the environmental aspects of the decision are pretty clear. Yet, in some situations, with less data and information about processes available, the decision may not be as clear. In this model and case example we only focused on one technology affecting a relatively small subset of activities. If the technological or process change was more strategic and influenced a larger portion of the organization, the decision process and the tool will tend to become more complex, requiring additional input and time from managers and other parties. The process may need to be adjusted depending on the level of analysis, time and resource availability for such a decision. A good rule of thumb is that the decision process should not require more resources than the decision itself.

Summary and conclusions

Justification of organizational decisions using environmental considerations is an increasingly important factor in holistic business decisions. To executives, adopting and implementing environmentally sustainable development requires identifying how their company fits in the larger ecological and economic environment and identifying the actions required for its survival. Today's companies are concerned about the environment whether the pressure comes from internal or external situations. Management should be aware of organizational environmental implications, using a more complete total cost management approach which can integrate conventional costs, hidden costs, contingent costs, and relationship and image costs is something that can make their decisions more environmentally informed.

To be able to help management make and evaluate decisions related to their business processes, especially from an ecological perspective, we introduced a methodology. This methodology enables decision makers to consider the major (if not all) costs and resources involved in enhancing a particular process. The robust methodology consists of mapping out process activities and decomposing each activity into sub-activities. Based on the selected consideration factors (in this case conventional and intangible environmental costs), the activities are weighted in terms of their importance as well as the utilization of resources. One of the benefits of the hierarchical AHP and ABC approach, based on the IDEF0 modeling of the process, is that exact costs need not be fully known. An illustrative case study from an actual decision facing a semiconductor manufacturer provided some insight into the applicability of the methodology. Initial feedback is that the technique may be useful for management to help them integrate sustainability factors into the decision.

As with any modeling approach and initial model development limitations exist and future extensions can be considered. First, the technique can be extended to incorporate other decision factors, beyond the environmental sustainability issues. The inclusion of operational and strategic decision factors (e.g. improved flexibility, quality) as dimensions can be included as with other social factors (equity and charity). Sub-hierarchies can be developed with resources defined by these other factors and integrated into a more complete business and social justification of business decisions. Integration of hierarchies of resources and hierarchies of activities needs to be studied and evaluated.

Second, we developed the technique from actual data and had feedback from engineering management. The development team is very aware of this technique and quite capable in its application. The complexities and nuances of the approach will require facilitation and support. Making the technique more transparent and available to management is a barrier to its diffusion and application.

Third, the modeling approach and application of AHP can be extended to incorporate the interdependencies of activities and resource determination. Utilizing a systems-with-feedback approach to more completely evaluate a decision and its environment can be used in the extension. An investigation of this extension with the current approach presented here may provide additional insight into the application of the technique.

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