AN ABSTRACT OF THE THESIS OF

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With growing concerns on environment impact of industrial product development, the product developers are seeking better solutions to achieve desired environmental benign requirements by the regulators and customers besides economic growth. During the last decade, some of the most successful product development companies (such as HP) have established their own Design for Environment (DfE) programs. The DfE programs are playing a more and more important role in enforcing environmental concerns in product development process. However, there are numerous industrial examples to show that the quality of environment design often times depends on if a DfE program can work effectively with other existing units, in particular, supply chain management through a certain interaction strategy. The existing literatures provide limited discussions on the interactions in general. It is not clear how to define and represent an interaction strategy, and how to quantifiably measure its impact on Environmental Impact (E), Quality (Q), and Cost (C), of developing a product.

In my thesis, I focus on 1) formulating and representing several typical interaction strategies based on the classification of information exchange by its content and extent, and 2) quantitatively evaluate their

effectives using an Activity Based Modeling approach. Information exchange has been identified as a major factor to affect the effectiveness of interactions between the DfE program and supply chain. The content and extent of information exchange is used to define an interaction strategy space. In this space, existing interaction strategies are represented. The major design activities and information are identified and defined by different groups, including: Marketing, Design, Manufacturing, Supply Chain Management and Stewardship Group. To evaluate the different interaction strategies, the quality consideration are added into Bras' Activity-Based Model and expand it to the Three View Activity Based Model which simulates the process and activities occur in the product development and supply chain. Quality is treated as a driver as environment and cost for the activities, which enables quantitative performance assessment of the product development activities. The activities act the carrier of the information in our three view model. Through the activity roadmap, E.Q.C. performance could be traced and the evaluation for every interaction strategies could be accomplished. The thesis, I also provide a case study, to allow the reader to see how the model and evaluation method are applied into the application and what the result is.

The results from this work provide necessary knowledge for DfE group and supply chain to examine and identify holes in their current interaction strategy that may have negative impact on environmental design. On the other hand, they allow management to screen and select a suitable interaction strategy for a particular DfE program with its supply chain. The thesis directly contributes to the betterment of environmental design.

Evaluating the Effectiveness of Interaction Strategies Between Product Developer And Supply Chain Using Activity Based Modeling In Environmental Benign Product Design

by

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I want to give this thesis as a gift to my parents, for their love and support.

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CHAPTER 1
INTRODUCTION

1.1 Motivation

To protect human health and sustain the environment of this world for our generation and future generation, the U.S. Environmental Protection Agency (EPA) and the state, tribal and local government partners have made progress to keep the air and water clean and protect our planet environment in this century. [EPA,2003]. Legislation such as environmental laws has established itself in certain regions due to environmental issues which are raised by anthropic and social concerns world wide. Many more such legislations will start to form and this trend will force industrial companies, especially the manufacturing companies to care about environmental issues at some level because of possible litigation. For an industrial company, they need to obey the above environmental mandatory factors and rules from the government and society. From the considering of the company's benefit, they also need to make their products more appealing to the customers and competitive in a global marketplace. With more and more customers expect environmental benign products, accompanied by their lifestyle changes. The industrial companies need to make more efforts on controlling the environmental impact of their products along a life cycle. As a result, minimizing environmental impact has become a design objective as important as quality and cost in many industries' product development [Thurston, 2003], including electronics, automobiles, polymer, and other companies, whose products affect environment directly. Furthermore, it is widely recognized that the largest gain in reducing environmental impact can be made through design effort, particularly at the early stages of design [Herrmann, 2003].

To involve the environmental consideration into the product development process, there are many useful tools, e.g. DFE [Herrmann, 2003], LCA [Huang, 1996] and so on. With the help of this design tools, the designers are forced to pay attention to the environmental impact in the whole product life-cycle and try to reduce the negative influence to the environment in the early product development process stage. The designers transfer the customer environmental benign needs to the product environmental benign requirements, and may add it into the product quality matrix.

1.2 Problem Description

In the product developers, they prefer to produce their product with the corporation of other suppliers. In the popular business mode, the leading companies just purchase parts from the suppliers who have the more competitive technological advantages, then assembly the parts with their own core technology parts to build up the final product [Handfield, 1999]. Most famous computer developers are running their business with their suppliers, for examples HP, IBM and DELL. Because the business strategies, organization structures of corporations and companies' culture are different, the environmental benign solutions are different too. As I investigated, in European developers, they assign the environmental specialists to influence the design decision in every design phase along the design development process.

But in United States, the situation is different. For example, the famous computer developer, HP, they establish a special group to deal with the environmental benign consideration, the group is called "Stewardship Group".

The Stewardship Group cooperates with the product Design Group to generate the environmental benign design decision, also helps suppliers to reduce the impact to environment and satisfy the environmental benign requirements of buyer and customer. Because of the

Stewardship insertion to the traditional design process, the possible interaction strategies are generated between the product developer and supplier. The different interaction strategy may influence the design decision for E.Q.C. performance (**E**nvironment Benign, **Q**uality and **C**ost). However, from the face to face meeting with HP, the concurrent industrial companies are still seeking the optimum interaction strategy to integrate the Stewardship Group into the whole product development process. To achieve this, the factors which cause the difference of the interaction strategies need to be clarified first. Information Overlap is one of the major reasons. In this work, I discuss this factor as cut-in point to demonstrate the effectiveness of different interaction strategy. I will discuss the interaction strategies and information overlap in chapter four.

1.3 Objectives

To solve the above industrial problem and develop a workable method to evaluate the effectiveness of interaction strategy, there are four objectives:

1. Identify and define the interaction strategy;
2. Develop an approach to evaluate the E.Q.C. performance simultaneous along the produce development process;

3. Using this approach to quantitatively measure the effectiveness of interaction strategy;
4. Apply this approach in the case study to demonstrate how it works.

1.4 Thesis Outline

In my thesis, there are seven chapters to present my research.

Chapter 1: Introduction of this research topic including the motivation, problem description and objectives.

Chapter 2: Present the previous work of the other researchers on the relate topics, includes Environmental Benign Product Design introduces the main idea and tools that consider the environmental issues in design phase during the product life cycle. And, I introduce the Supply Chain Management to introduce the business consideration and the relationship between the supplier and buyer. At the end, I introduce the Activity Based Model to show how environmental and monetary consideration will be integrated in the same model.

Chapter 3: Explain my idea on Three View Activity Based Model which makes E.Q.C. consideration possible. Introduce the definition of Quality and define the Quality Driver. Develop the Three View Activity Based Model from Bras' Activity Based Model.

Chapter 4: Collect the E.Q.C. information along the product development process. I give the definition of information overlap and possible strategies. Explain how information overlap influences the interaction strategy. At last, I generate the new activity structure as the carrier of the interaction strategy and information using Object Oriented (O-O) Technique.

Chapter 5: Find a case problem to demonstrate my evaluation methodology. Create the four different interaction strategies for the case study. Collect the data, plug in the ABC model and get the results of the comparison of different interaction strategies effectiveness.

Chapter 6: Make the conclusion of this thesis, and point out what should be paid attention to in the next step.

Chapter 7: Summarize what the contribution of my thesis and research in Oregon State University.

Chapter 2
Review of Relevant Work

2.1 Environmental Benign Product Design (EBPD)

During the recent years, effort has been made to develop design processes that produce environmentally benign products. The systematic design methodology, Design for X, includes *Design for Environment*, *Design for Manufacturing and Assembly*, *Design for Quality* and *Design for Cost* [Lu and Gu, 2003][Dixon, 1995]. Design for the environment (DFE), or called *Green Design*, is a evolving design methodology that brings "green" changes to design practice [Huang, 1996]. In DFE, the product environmentally preferable attributes include recycleability, disassembly, maintainability, refurbishability, and reusability. DFE treats these attributes as design objectives rather than as constraints, and help produce products that achieve them through a well-organized design process. Besides, DFE fits the need of business, because it makes the costs of hazardous-waste disposal lower, and makes the costs associated with regulation compliance lower [Scheller, 1999]. When they are used, DFE methods establish a recycling structure and process the timely and accurate environmental data for alternative materials, processes, and technologies that designers may use to measure the environmental impact of products [Wang and Ge, 2004].

Environmentally Responsible Product Development (ERPD), also known as environmentally benign manufacturing in some literature, offers another approach. By looking at the design and manufacturing processes, ERPD considers both environmental impacts and general economic objectives, and helps to develop the energy-efficient, environmentally benign products [Herrmann, 2003]. It also uses the Design For Environment (DFE) [Huang, 1996] [Scheller, 1999] tools to reduce the impact on environment while improving product design. Herrmann *et al.* has developed a Decision Production System (DPS) to integrate DFE tools and Life Cycle Assessment (LCA) within a consistent framework. The DPS facilitates the integration of environmental information and selective use of these tools to fit into a specific product development scenario [Herrmann, 2003].

2.2 Supply Chain Management (SCM)

2.2.1 Definition of Supply Chain

"Supply Chain is a global network of organizations that cooperate to improve the flows of material and information between suppliers and customers at the lowest cost and the highest speed. The objective of a supply Chain is customer satisfaction [Govil, 2001]."

2.2.2 Motivation of SCM

Generally, the supply chain management organizes the activities associated with the flow and transformation of goods from raw materials stage to the end user, as well as the associated information flows [Handfield, 1999] and increases the efficiency of these activities [Simchi-Levi, 2004]. Technology and competitive pressures have resulted in a greater trend towards specialization [Dale, 1994]. Few companies produce the products by only their effort. The different organizations work together using their own core competitive technologies. This situation calls for the management to identify and organize the relationships between different organizations.

2.2.3 Environmental Consideration in SCM

There are several ways to achieve the Environmental Supply Chain Management. Material issues play a very important role in SCM. DLA Supply Chain Management Advanced Research Technology Laboratory provided Advanced Hazardous Materials Rapid Identification, Sorting, and Tracking, And Joint Environmental Material Management methods. They identify the hazard material, make the tags to catalog them and validate and evaluate through the product life cycle of the supply chain [National Transportation Research Center, 2002]. Some of companies also write the environmental criterias into their contracts, survey suppliers, set up coalitions, even collaborate with non-governmental organizations. Besides the contracts, the evaluation or examination for the supplier's environmental reduction are scheduled annually.

2.2.4 Relationship between the product design and SCM

Along the design process, the supply chain will be involved.

2.2.4.1 CRs-FRs

The retailers and after-sales service providers should be obtained in this process to provide the necessary information to generate the product functional requirements from consumer needs.

2.2.4.2 FRs-DPs

The product design team makes the decisions:

a) Selects the new technologies and

b) Make the decision of the components to manufacture in-house or purchase from the external suppliers.

c) Select the assembly sequence in which the components are to be put together.

In this process, the external suppliers design groups need to be involved. They may provide the latest technologies they are using, their manufacture capabilities. "Involving them at are using, their manufacture capabilities. "Involving them at this stage makes the design of the interfaces to these supplied components much less prone to errors" [Govil, 2001]

2.2.4.3 DPs-PVs

The design teams need to find the consensus between the suppliers, for examples, manufacture process and material selection.

In this process, the product development team should consult the suppliers process engineers about any new resources can be used. This greatly helps to reduce the new resources testing time, also reduces the product design time consuming. [Govil, 2001]

2.2.5 EBPD consideration in SCM

For technical issues, EBPD suggests to purchase the standard parts and design the system to use the standard parts as much as designer can. SCM and design group need to discuss the purchasing plan for the parts from the suppliers. The other consideration is communication. The design group sends the product or part specification to suppliers and collects the feedback from the suppliers. With the design going, the process meeting is highly recommended. SCM handles both the communication between the design group and parts suppliers and collect the information and precise materials specification data from the suppliers also [Dale, 1994].

If the suppliers are allowed to make their own decisions freely, assuming that these decisions meet the internal policy accepted by all the suppliers, the efficiency of the supply chain can be dramatically improved. The implementation of the internal policy in a supply chain is a "sharing process" [Govil, 2001].

This calls for the involvement of the suppliers design planning into the whole product design plan in the early design stage. This guarantees the better quality of the final product, decreases the environmental impact during the supply chain (Technical Benefit), deducts the cost in the supply chain and enhances the supply chain management efficiency (Management Benefit).

To keep the design team and the supplier's communication, HP has Stewardship group:

1. Collect the information on environmental impact from the suppliers and help design team to revise the design results.
2. Delivery the design requirements and the components criterions on environmental limitation to suppliers.
3. Select the right person in design team and suppliers
4. Build the collaboration with the engineering, financing,

marketing, supply chain management, sale, purchasing and suppliers.

2.3 Activity Based Model

Though reducing the environmental impact is the society's needs of protecting natural resources and environment, reducing the cost is important to ensure the industrial company to achieve business goals and advance technology used in better product development. In other words, environmental consideration and cost are both vital for the survival of a business firm. However, the above existing approaches tend to more focus on reducing the environmental impact in the product development, and the cost is not explicitly addressed because it is hard to attain a cost model for analysis.[Wang and Ge, 2004] The needs to a combined consideration of the cost and environmental impact calls for an activity-based cost and environmental model by Bras *et al.* [Emblemsvåg, 2002],

To facilitate the assessment on both cost and environmental impact through management and obtain the self-motivating, self-sustaining effects [Emblemsvåg, 2002], Bras *et al.* developed a model for both environmental impact management and the cost control based on an *Activity-Based Cost Model* used in business world, as shown in Figure

2.1.

Figure 2.1 illustrates the basic idea of activity-based cost model, in which the *Cost Objects* consume the *Activities*, and the *Activities* in turn consume the *Resources*. In business management, this model is very useful to help managers to monitor the accounting practice based on activities. Cost

Objects are anything for which a cost/revenue assessment is needed. Normally, a product is a cost object itself; other examples include a service delivered, an organization department, a project or a customer. Activity is the operations needed to make anything happen. For example, in order to deliver a successful product, the activities must

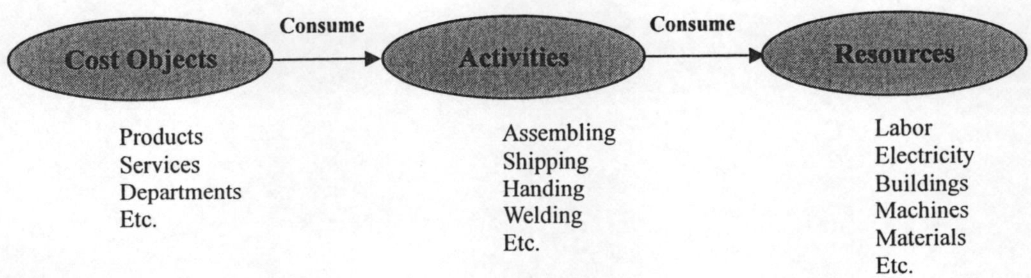

Figure 2.1 Activity-Based Cost Model

include designing the parts, handling the parts, welding the parts, assembly, shipping, and so on. Resource is something necessary to perform the activities. For instance, all the above activities (designing, handling, welding, etc.) consume the labor, electricity, water, vehicle, machines and buildings, and so on. In a product development process, resource is what designers or decision makers use and consume to make the products through a series of activities. The activity-based cost model makes it possible for managers to measure quantitatively how many resources would be consumed by the activities in order to develop certain objects [Emblemsvåg, 2002].

The activity-based cost model used in the business management mainly cares about the economic assessment. With growing concerns on environmental impact, this model cannot sufficiently fit the industrial needs any more. Bras *et al.* integrated the consideration of environmental impact into this model, and developed an *Activity-Based Cost and Environment Model* [Emblemsvåg, 2002], as shown in Figure 2.2. In the integrated model, Cost, Energy and Waste Drivers together affect the activities to obtain the multiple assessment dimensions in the horizontal direction. In vertical direction, driven by Resources and Activity Drivers, it is possible to evaluate how much resources will be consumed for achieving the 'Objects'. As a result, the environmental impact can be considered with the Cost at the same time. Bras' model can help gain insights on the current status of the operations in an organization, and come up with management strategies to achieve both economic and environmental objectives [Emblemsvåg, 2002].

There are several benefits using the activity-based cost and environment model. Using Energy and Waste Driver is an important feature of this model. The energy and the waste are the common known factors that affect the environment. Energy involves both social and economic factors [Ollson,1994] and there is a strong correlation between energy consumption and CO_2 emissions [Fowler,1990][Seki,1995]. Especially, the energy demand may double worldwide by 2020 [Holberton,1997]. The Energy Drivers affect the cost directly, for the U.S. alone, the society may save estimated $300 billion annually [Lovins,1997]. For the Waste Drivers, I separated them as Solid Waste and Emission Waste. For solid waste, only in U.S., the society generates almost 10 billion tons trash annually, the need for reducing the trash is obvious, in the mean time, the solid waste need to occupy the space and cost money for disposal at the end [Brown,1999]. Also cutting down on emissions is equally important because the emissions affect the environment in many negative ways [Herrmann, 2003] [IPCC,1993].

The drivers can be measured and accounted for. This is very important for a business firm because the decision makers cannot trade-off between the options based on a solid basis without consistent, quantitative measurement of the environmental impact. The procedure may start with the measurement and the data collection at the beginning, and then use the activity-based cost and environmental model to account for the energy consumption and waste generation as two major environmental factors, in addition to monetary costs.

Because of the objectivity, measurability and quantification of the Activity Drivers, they provide suitable assessment basis for operations in a business firm. The drivers are comprehensible and have a cause-and-effect relationship with the activities. This will help managers identify the causes of problems easily and furnish decision support. By representing these relationships in a uniform format (activity), the communication among working groups can be improved [Wiersema,1995]. Through the observation of the operations, the related data source from the database and/or the archive documents of previous products design, the number of the driver units maybe determined, and their associated performance can be measured. The drivers, therefore, can help provide qualitative and quantitative assessment of budgeting, costing, niche assessment, cost management, and improve efficiency [Wiersema,1995].

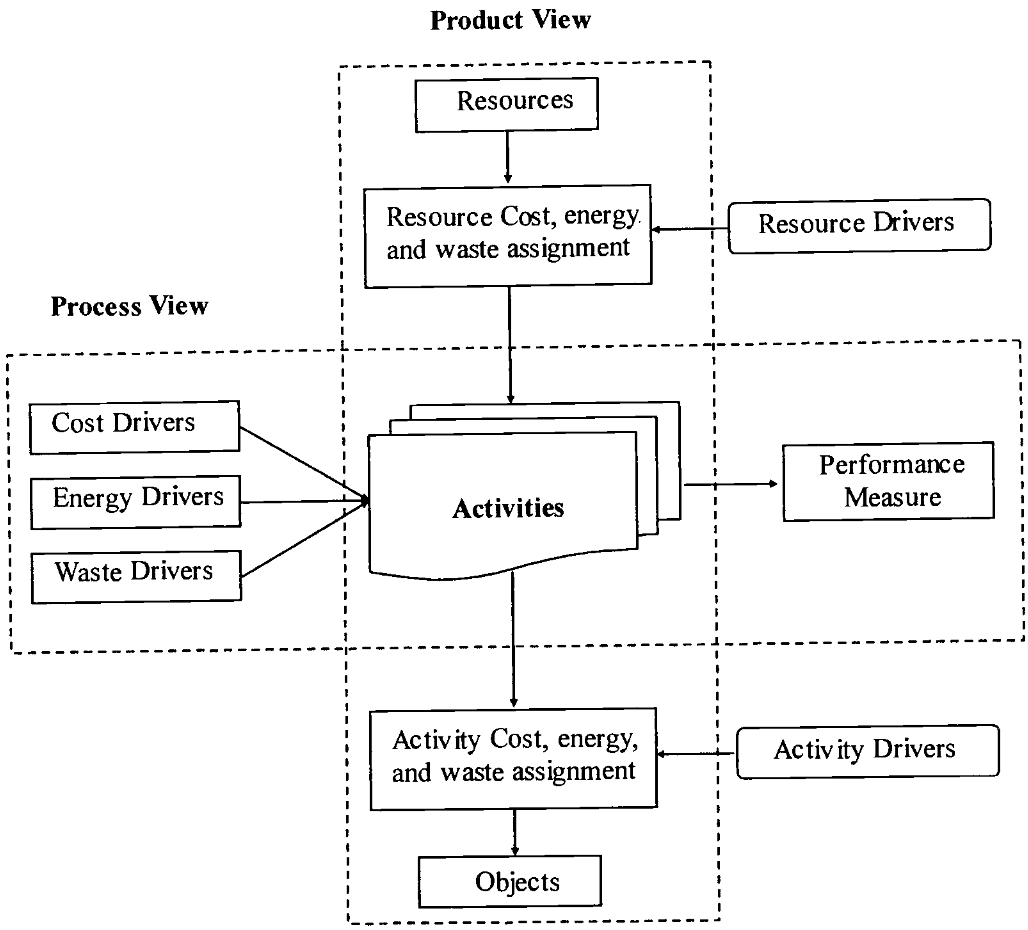

Figure 2.2 Activity-Based Cost and Environmental Model [Emblemsvåg, 2002]

Chapter 3
Three view Activity Based Modeling

3.1 What is Quality Driver?

Another important aspect in product development is: Quality. Today, the consumers desire for products with good quality, therefore, the industrial companies compete not only on the price difference but also on the quality difference [Belkaoui,1993]. In many existing design and manufacturing process, the environmental impacts is still treated as a separate part from the cost and quality issues [Thurston, 2003]. Though the existing activity-based cost and environmental model enables the consideration of both environmental impact and cost, it is still difficult to use this model to explicitly address quality concerns in product development. There are still more efforts to be made to enable the developers to take into account all the three factors, i.e., environmental impact, product quality, and cost. [Wang and Ge, 2004]

According to Kano's model, product quality is closely related to customer satisfaction. The success of product development greatly depends on the product quality. Because of the importance of the quality, many companies have implemented quality programs (such as total quality management) in responding to customer demands [Belkaoui,1993]. It may be argued that the highest priority for a business firm maybe benefit; the highest priority for the society maybe environmental impact or waste generation and energy usage; and for the customers, the highest priority maybe a combination of price, environmental impact and QUALITY. Since quality is equally important to the environmental impact and the cost, it is necessary to include the quality for performance measure of product development related activities in business firms. Though the activity-based cost and environmental model can facilitate both the economic and environmental assessment, it does not explicitly address quality related assessment in performance measure. If I can add the consideration of quality into it, the expanded model may provide a more realistic assessment to business firms' practice and their products against what customers need. [Wang and Ge, 2004]

Quality is defined in a variety of ways [Dym,2004]. Quality can be defined as the fitness of the product for the customer requirements. The requirements can include functionality, reliability, maintainability, availability, delivery, and cost effectiveness among other features. In corresponding to the different types of needs, the definition of quality may be different, such as transcendent, product-based, user-based, manufacturing-based, and value-based [Belkaoui,1993]. Usually, customer satisfaction on function-based requirements constitutes product quality. With the enhancement of life quality, customers tend to desire and pursue things that are more spiritual and meaningful for the greater good, such as a better environment and society. It is becoming important and necessary that a business firm establishes its reputation as a quality-orient organization among customers through both its contribution to better the society in terms of better environment, employment, and technology advancement, and its products that serve the customers' particular needs. As a result, the quality considered in environmental benign product development should reflect how well both a business firm's practice and its products meet the customers' expectations. In this work, I focus on addressing product development related quality issues and leave the business firm's practice related issues for future investigation. [Wang and Ge, 2004]

To incorporate quality as a performance measure in the activity-based cost and environmental model for product development, the quality need to be measurable. Here, quality concerns are introduced through the quality drivers. Similar to the existing Waste and Energy Drivers [Emblemsvåg, 2002], the Quality Driver is defined as the measure of quantity of quality contribution by an activity. Quality

Drivers are added to the activity-based cost and environmental model with Cost, Waste and Energy Drivers together. The quality drivers make it possible to measure and quantify the activities' performance against quality objectives, also monitor the quality change in the process of activities.

The addition of the quality driver makes it possible to consider environmental impact, quality and cost simultaneously for product development. In the meantime, it also addresses the challenge: how to incorporate the quality driver in product development process by which the product quality is usually deployed? Here, a product development process model by Suh [Suh,2001] is adopted, as shown in Figure 3.1. This process is function and quality oriented with cost consideration. Along a product development process, the market department will collect the customer requirements (CRs). Then, based on this information, the designers develop the Functional requirements (FRs) and Design Parameters (DPs). After that, the product will be

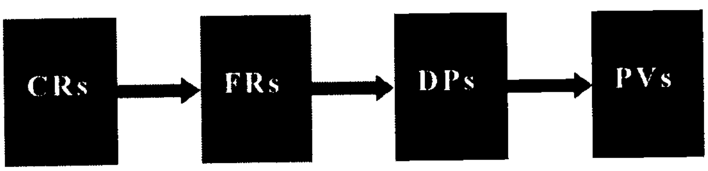

Figure 3.1 Typical Product Development Process [Suh,2001]

manufactured based on Process Variables (PVs).

Since the product quality is based on the customer satisfaction, the customers' expectations on the product quality requirements and competitive performance levels are identified in the CRs stage. In FRs stage, the engineers derive the functional requirements corresponding to customer-preferred product quality requirements and set the performance targets for them given available resources. In DPs stage, the functionality requirements are associated with certain physical embodiments and their design parameters are specified based on the performance targets. Then, PVs, i.e., manufacturing processes, are identified and developed to produce the design that achieves the desired functions and targets associated with the quality requirements. After that, the quality specialists may collect the data from the sampled parts and analyze them against a quality metrics. Based on the quality analysis results, areas of improvement are identified for better the product development process for the quality profit. Currently, this process does not account the environmental benignity of the product in the same manner as quality. The activity-based model with Cost, Waste and Energy Drivers only fulfills the need to consider economic and environmental goals. This calls for a model that encompasses life cycle environmental impact, product quality, and the economy to support design decision making. [Wang and Ge, 2004]

3.2 Integrating of Quality Driver Into Activity Based Model

During my investigation, it has come to my attention that the complexity of simultaneously considering environmental impact, product quality, and cost lies in the involvement of many different types of business activities and levels of decision-making with limited information when incorporating the environmental consideration at the early product development stage. The activities that entail environmental impact may include those within a firm and those activities outside the firm but associated with the firm through a life cycle. Though the firm is not directly responsible for the outside activities, it does play a role in contributing to certain life cycle processes of its products, and therefore, affect the total environmental impact upon the society and earth. Within the firm, the cause and control of environmental impact resides at both firm strategic planning level and daily execution level. It is important that the effect of the activities with different types and at various levels on the environmental impact, product quality and cost objectives all be reflected through modeling so the trade-off among them can be performed in producing desired design alternatives. Thurston *et al.* proposed to trade-off environmental impact, quality and cost in a consistent decision based design framework and this has resulted in a successful development of a pilot-scale *Vapor Recovery System* [Thurston, 2003]. This approach is effective for single product development driven directly by environmental efficiency. It is necessary to have a methodology that enables both firms and designers to construct a road map to represent all the accountable activities, and explicate their relationship to environmental impact, quality, and cost objectives along a product development process. Activity-based cost and environmental model has laid a good foundation for such work, and effort is needed to expand its use to simultaneously take into account all these three design objectives at early product development stage [Wang and Ge, 2004].

In this work, the needs and issues in explicitly integrating quality concerns into the existing activity-based cost and environment model are investigated. Product quality is treated as a driving factor as environment and cost for the activities. The introduction of the quality driver and life cycle considerations has led to a classification of the activities along different dimensions. As a result, a three-view (i.e., *life* *cycle, quality, economy*) activity-based model is constructed. Using this model, a clear road map of activities in a firm can be constructed and their relationship to environmental impact, product quality, and cost objectives along product development process can be identified. Such knowledge will be useful to help identify areas for development, and support a firm and its products to reach their maximum potential. On the other hand, the three-view activity-based model can be integrated with design methods and tools to generate and evaluate design alternatives against quantitative measures on environmental impact, product quality and cost at early product development stage. Currently, my investigation is still at its preliminary stage, and in the last section of the paper, critical research issues for moving forward the ongoing methodological development are summarized for further investigation [Wang and Ge, 2004].

An integration of the product development process in the activity-based model has led to an expanded model with three views: *Life Cycle*, *Quality*, and *Economy*, as shown in Figure III.2. The expanded model is positioned in a three dimensional space, which reflects three fundamental concerns in product development: life cycle consideration, product quality, and economic restraints. The original activity-based cost model and the activity-based cost and environmental model were developed from a management perspective – monitoring and control based on a consumption chain from Cost Objects to Activities to Resources. In the expanded model, Quality Drivers are integrated into the activity-based cost and environmental model for quality monitoring. The Cost, Energy, Waste, and Quality drivers act on the Activities; the Activities consume Resources and deliver Objects/Products. The effectiveness of various activities can be measured through Performance Measure against three considerations objectives. The expanded model is expected to monitoring and controlling Cost, Energy Consume, Waste Generation and Quality Change in a system, such as a business firm. My current investigation focuses on the quality change in a business firm related to the product development process associated with activities [Wang and Ge, 2004].

The Quality Drivers, Cost Drivers, Energy Drivers and Waste Drivers are used as the input of the model. The Quality Drivers act on the daily execution activities that may directly cause the quality change along the product development process. Quality driver is defined as the measure of the change of a certain performance p_i (related to specific customer-preferred quality requirements) caused by an activity, i.e.,

Δp_i/*activity*. Given the performances and quality driver corresponding to customer-preferred product quality requirements, it is possible to trace the quality changes on these performances related to the daily execution activities, and obtain the performance measure for the quality objectives. With the help of historical documentation and experimental methods, designers can identify the daily execution activities that affect a certain performance target and estimate how much the performance may be changed by the unit activity [Wang and Ge, 2004].

Bring the product quality concerns into the picture has leads to the need of clarifying: 1) if an activity directly contributes to product quality (product development activities vs. management or administrative activities); 2) at which level its contribution stands, i.e., firm strategic planning or daily execution. The activities on the daily execution level are inevitable associated with certain activities on the strategic planning level. Based on the result of performance measure for Quality and sensitivity analysis, designers may identify and adjust the "trouble" activities at daily execution level, and managers may adjust the "upstream trouble" activities accordingly at strategic planning level. This provides a means to use the quality driver incorporation to help both the product development and higher-level business decision making. This has instigated a separation of the activities' levels along the quality axis. Putting the model for environmental impact assessment in a life cycle context also resulted in the three-view activity-based model shown in Figure 3.2 provides a consistent framework to help identify, represent, and construct an activity road map, which illuminates the relationship between the activities and the three concerns. The activity roadmap may be constructed in the context of the product development process and administration organization structure in a business firm. Combined with the measurable drivers, the activity road map can be used as a basis to collect information and establish numerical analysis. The effectiveness of the activities can be quantitatively assessed against performance measure by using the numerical analysis. The performance measure includes the energy, waste, quality, and cost objectives to be achieved. Then the assessment results can be combined with design methods and tools to produce desired design alternatives.

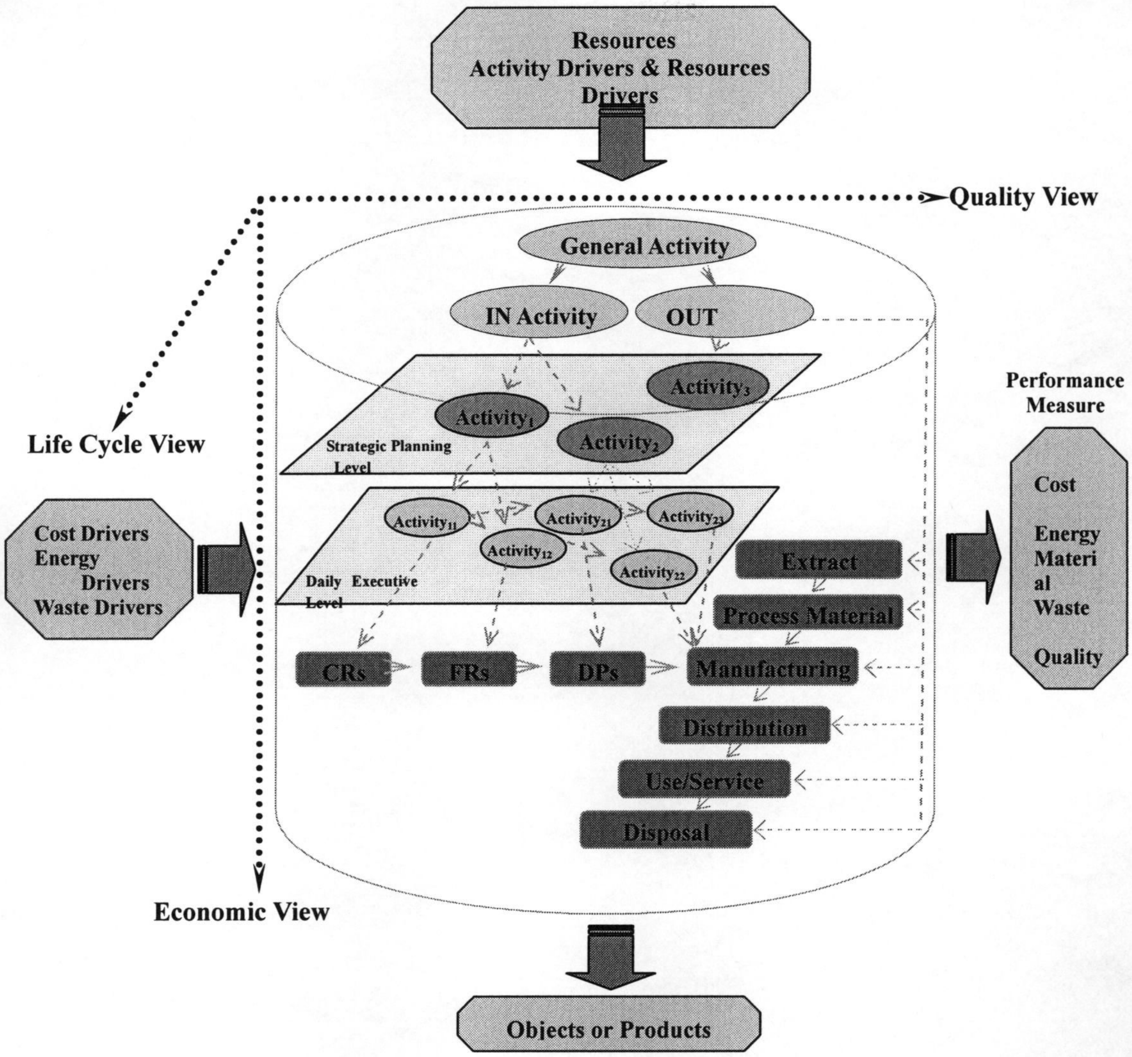

Figure 3.2 Three-View Activity-Based Model

As a simple example to illustrate how Quality Driver works, I use a motherboard manufacturing process in computer industry. The market department and the design teams identify the performance targets derived from customer-preferred product quality requirements. The electrostatic discharge on a motherboard in the manufacturing process is a major contributing factor to the defective motherboards during the manufacture process. As a result, the electrostatic discharge directly affects the motherboards' quality. It may damage the sensitive electronic components, and result in the failures, For example, CMOS, PIN diodes and so on. Assumed that the maximum test voltage at the components of the motherboard is 300V, to achieve the quality requirement, the target electrostatic discharge in the manufacturing activities should be set up as 300V. Desired motherboard quality can be expected with electrostatic discharge lower than 300V. In this example, the motherboard quality requirement is the low defective product rate in terms of electrostatic discharge. The quality metric is chosen for 100,000 parts at the end of streamline, and the sigma quality level is 6σ, and the targeted defective rate is less than $2*10^{-7}\%$ [Breyfogle,2003]. The existing tools may help to analyze the data on quality requirement, including Six Sigma [Breyfogle,2003] or Taguchi Method [Fowlkes,1995]. Here, the quality driver is defined as how many voltages the electrostatic charge is generated by a manufacturing activity. Using this quality driver, it is possible to monitor and measure the quality changes caused by a manufacturing activity through calculating the voltages of the electrostatic charges generated by that activity. In the mean time, by comparing the voltages with the target 300V, it can be determined if the monitored motherboard is defective. Then, the Six Sigma tools can be adopted to analyze the data collected from the manufacturing process. If the analysis results do not fit the 6σ level, the manufacturing processes and activities need to be improved. The designers need to identify what kinds of activities generate or accumulate the electrostatic charge, and try to control them. For instance, the designers find the most of the electrostatic charges come from the frictions between the board and the work surface on the streamline. The designers replace the old work surface with a new one made from material which has the same electrostatic potential with the material of the motherboard to reduce the generation of electrostatic charge. This simple example illustrates how to apply the quality driver to monitor the quality change, and how to use that result to improve the product quality through design [Wang and Ge, 2004].

CHAPTER 4
Characterization oF the Different Interaction Strategies

4.1 Information Identification By Different Development Groups

One of the biggest barriers is the poor communication or feedback between the supply chain units and the design groups. [Dale, 1994]. The information in this work is only the information in supply chain and only relates with E.Q.C. information which flows between the product developer and suppliers. The most of the dissatisfaction focus on the technical specifications and purchasing acceptance criterias, also, the consultation on the design and product engineering aspects. [Dale, 1994]. In the following table, I collect the information and the group which the information belongs to.

Marketing Group	
	MI. Quality Issues from Customer
	I. Identify the Customer
	Generate Customer needs on the features of product
	II. Generate Customer priority of the product features
	III. Product usage reliability (after sale service)
	MII. Environmental benignity issues from Customer feedback
	I. Energy consume satisfaction
	II. Waste generate satisfaction
	1. Emission
	2. Solid
	3. Liquid
	III. Recycling Consideration: product upgrade speed
	MIII. Cost issues from the market
	I. Price comparison with competitor
	II. Market Share Strategy

Table 4.1 E.Q.C. Information in Marketing Group

Design Group | System Level

Quality Issues

SQI. Understanding the design problem

I. Work with marketing department, translate the customer needs to function requirements:
   1. Performance - Consumer
      a. Product functional requirements
      b. Materials selection
   2. Marketing customer
      a. Attractive effect (e.g. color, fancy outlook)
      b. Geometry of the product for shipping, package and store
   3. Environment Benign - Government & consumer (detail in SEI & SEII)

II Determine relative importance priority of the above requirements based on MI.III

SQII. Product Functional Requirements

I. With help of SQI.I, Identify the functions and decomposed the functions
II. Set up the targets of the functions
III. Generate the testing methods to measure the targets
IV. Create the product architecture
V. Identify the components
VI. Make the buy-make decision
VII. Generate the Quality Matrix of the product
VIII. Set up acceptance criterions of the product
   1. the whole product acceptance performance criterions
   2. the whole product acceptance environmental benign criterions

Table 4.2 E.Q.C. Information in Design Group

System Level

Environmental Benign Issues

SEI. Geographic and Demographic consideration

I. Parts Re-use ability
II. Product upgrading ability

SEII. Environmental Benign Requirements from Customer and Government

I. The product shape is easy to manufacturing and shipping
II. Energy Consideration
   1. Total Energy consumed in product use stage
   2. Energy efficiency when product is running
   3. Total Energy consumed with product manufacturing
   4. Energy efficiency when product is manufactured
III. Material Consideration
   1. Material consumed with product manufacturing
   2. Solid waste generated from product manufacturing
   3. Water Waste generated from product manufacturing
   4. Emission generated from product manufacturing

SEIII. Materials data from the existing products

I. Material composition
II. Material Hazard ingredient
III. Material Processing attributes
   1. Energy Usage
   2. Waste Generation
   3. Emission Generation
IV. Material Manufacturing attributes
   1. Energy Usage
   2. Waste Generation
   3. Emission Generation
V. Material Recycle attributes

Cost Issues

SCI. Design Concept Development Time
SCII Designer Salary

Table 4.3 E.Q.C. Information in Design Group (Continued)

Component Level	
	Quality Issues
	CQI. Product Components Technical parameters
	I. Classify the components function II. Set up the performance requirements for the components III. Standard parts selection IV. Components interfaces requirements for internal manufacturer and external suppliers V. Detail Components design 1. structure 2. geometry 3. material VI. Supplier manufacturing capability consideration VII. Generate the Quality Matrix for the component, which can be use as acceptance criterions
	Environmental Issues
	CEI. Material Consideration
	I. Material selection for the components II. Materials recycle percentage consideration
	CEII. Energy Consideration
	I. The energy consume on the component usage II. The energy conversation of the component
	CEII. Recycle Consideration
	I. The component shape is easy to assembly and disassembly II. The component geometry is easy to manufacture
	Cost Issues
	CCI. Detailed component design Time CCII Computer Drawings Development Time CCIII Designer Salary

Table 4.4 E.Q.C. Information in Design Group (Continued)

Manufacturing Group
Quality Issues
MQI. Manufacturing Process Development
I. Existing and New manufacturing technology
II. Manufacturing Operations list for the component
III. Manufacturing Methods Selection for the operations
IV. Tools and Equipment List
V. Equipment and facilities set up
VI. Manufacturing Process Generation
MQII. Manufacturing Quality
I. Manufacturing deficiency data
II. Quality Assessment method (QA)
III. Quality Control method (QC)
1. measure method selection
2. monitor point selection
IV. Testing Method
Environmental Benignity for Manufacturing the assigned component
MEI. Material Consideration
I. Components Material list and the amount (BOM)
II. Packaging Material selection
III. Selected material's manufacturing features
1. Solid waste generated from each manufacturing activity
2. Total solid waste after manufacturing (per component)
3. Water Waste generated from each manufacturing activity
4. Total water waste after manufacturing (per component)
5. Emission generated from each manufacturing activity
6. Total emission after manufacturing (per component)
IV. Selected material's recycle features
1. Total hazard substance included
2. Select material's recycle percentage
Cost Issues
MCI. Material Purchase
MCII. Manufacturing Resource Consume
I. Electricity
II. Water
III. Lubricant
IV. Maintenance tools
MCIII. Operator Salary
MCIV. Cost of the Prototype

Table 4.5 E.Q.C. Information in Manufacturing Group

Suppliers

Quality Issues	**S_1**	**S_2**	**S_3**
SQI. Design process development			
I. Provide the existing and new technologies	X	x	
II. Review and suggest the critical specification of the subsystem/module from design group to make sure it can be worked out or not. (Material and Technology)	X		
III. Identify the detail specifications for the subsystems including the a. subsystem performance, b. Interface with other modules c. Architecture of the subsystem d. size, e. energy usage,	X		
IV. Identify the components and generate the components specifications based on the detail specifications a. component performance b. shaper and size c. energy usage d. material selection	X		
V. Review and suggest the detailed specification of the components from design group to make sure it can be worked out or not. (Material and Technology)		x	
VI. Create the quality matrix for component	X	x	
VII. Generate the bill of the material	X	x	
MQII. Manufacturing Process Development			
I. Provide Existing and New manufacturing technology	X	x	x
II. Provide the manufacturing capability	X	x	x
III. Provide the manufacturing lead time	X	x	x
IV. Same as MQI & MQII	X	x	x
Environmental Benignity for Manufacturing the assigned component			
MEI. Material Consideration			
I. Provide Components Material list and the amount (BOM) II. Packaging Material Selection III. Provide Selected material's manufacturing features 1. Total solid waste after manufacturing (per component)			

Table 4.4 E.Q.C. Information in Suppliers

2. Total water waste after manufacturing (per component) 3. Total emission after manufacturing (per component) IV. Selected material's recycle features 1. Total hazard substance included 2. Select material's recycle percentage
Cost Issues
MCI. The cost of Material Purchase MCII. Manufacturing Resource Consume I. Electricity II. Water III. Lubricant IV. Maintenance tools MCIII. Operator Salary (Time consume) MCIV. Provide Service Cost of S_1 and S_2 MCV. Provide Packaging and Storage Cost of S_1, S_2, S_3 MCVI. Provide Prototype Cost MCVII. Provide the price of the components
**S_1 is the subsystem supplier S_2 is the component supplier S_3 is the manufacturer supplier*

Table 4.6 E.Q.C. Information in Suppliers (Continued)

Stewardship Group	
	Quality Issues
	STQI. Work with the design group and supplier design specialist to decompose the product as components, consider about: 1. Components re-use ability 2. Components assembly/disassembly benign attributes 3. Components upgrade ability
	Environmental Benignity Issues
	STEI. Correct the design alternatives with the regulation of government for environmental impact constraints. STEII. Help design group to assign the environmental benign requirements to suppliers as the part of the supplier product acceptance criteria (quality matrix) STEIII. Help internal manufacturing group and external supplier on: 1. Product or Components recycling methodology 2. Material selection 3. Manufacturing technology to reduce the waster generation STEIV. Train the suppliers and design group for environmental conscious consideration
	Cost Issues (time and monetary)
	STCI. Help design group to estimate the cost to reduce the environmental impact 1. Environmental Benign Material cost 2. New technology cost(reduce the Evn impact but increase the lead time) 3. New facilities cost (reduce the Evn impact but increase the investment)

Table 4.7 E.Q.C. Information in Stewardship Group

Supply Chain Management Group

Quality Issues

SCMQI. Work with the design group and supplier design specialist to generate the design alternatives

I. System level

1. Collect the supplier's information on product features and competitive technology
2. Share the product sub-systems critical specifications to suppliers, gather the review and suggestion from the suppliers
3. Collect the suppliers manufacturing capability
4. Help designer to make the buy-make decision
5. Select the suppliers
6. Assign the critical sub-system specification to suppliers (S_1)
7. Organize the communication between the design group and suppliers to negotiate the specifications decision.

II. Component level

1. Assign the components design specifications (S_2) or the full design solution (S_3) to suppliers.
2. Assign the detail components acceptance criteria to suppliers and

   manufacturing group

   a. Components specification
   b. Allowable tolerance of the parameters
   c. Components Performance requirements

Cost Issues (time and monetary)

SCMCI. Collect the cost estimate and quotation from the suppliers

	SCMCII. Develop the supply chain process and Evaluate the cost through the supply chain including: I. Manufacturing cost II. Transportation cost III. Storage cost IV. Administration Cost (employee salary) V. Usage Cost VI. Service Cost VII. Recycling Cost

Table 4.9 E.Q.C. Information in SCM (Continued)

4.2 Information Overlap Definition

The Stewardship group is not same as SCM. Though Stewardship group works between the design group and suppliers, they also handle more technical problems, especially the environmental impact reduction problems. Because of this, Stewardship works more closely with design group than SCM.

Here, the different "overlap" relationships between "Stewardship and design group" and "Stewardship and SCM" make the different interaction strategies. The concept of "Overlap" needs to be clarified.

In the industrial company, there are many factors may affect the performance of product on Cost, Quality and Environmental impact. I call them as Performance E.Q.C.. I list the major factors in the groups as the Table 4.7:

Function	Each group has their own function, but the functions build up the Performance-E.Q.C., e.g. design group's function is: generate the product design solutions.
Information	The groups need share and exchange the information to find the comprehensive solution of the problem
Activity	The groups achieve the Performance-E.Q.C., by the operations/activities. e.g. selecting the material for the product is the activity of design group
Process	The groups have the working process to organize the activities to accomplish the product Performance-E.Q.C., e.g. in design group, they solve the problem following: problem understanding, concept design, detailed design, production design, and so on.
Administrative Organization	The different companies have their own administrative features to affect the Performance-E.Q.C., like company culture, business strategy, and administrative structure.
People	Personnel who work for the Performance-E.Q.C. have the different background, personality and skills. These differences will affect the Performance-E.Q.C too.

Table 4.10 Factors of E.Q.C. Performance

All of above factors in the industrial company may affect the final product Performance-E.Q.C.. In my research, I will discuss the information factor. We can not ignore the contribution to Performance E.Q.C. of other factors, the other researchers have discussed about these issues. I only focus on the information sharing and overlap factor. My hypothesis is:

In the product development process, if the right information is passed to the right persons and right activities as much as possible, the feedback of Performance-E.Q.C. will be better.

There are two issues: 1. how to share the information that relates to Performance-E.Q.C. 2. How to use them? I will analyze what difference between the different information sharing strategies in the groups.

In the industrial company, to achieve the business goal of the company and fit the satisfaction of the customers, the administrative units are separated by their functions. In my research, I analyze the relationship among the Product Design Group, Stewardship and Supply Chain Management (SCM).

Information is data and facts that have been organized and communicated in a coherent and meaningful manner [ITEA, 1995]. Whatever in Design Group, Stewardship Group or SCM, the information affects the final decision greatly. Along the working process in the group, the information plays a very important role. The activities carry on the information and pass the information to the right destination. From my investigation, the information in the design group mostly focuses on product features, functional requirements and physical data. The information in the Stewardship group are the environmental conscious related data which are collected from the different level suppliers, the product sub-system structure data from the sub-system suppliers, the components physical information from the components suppliers and the performance testing data from the manufacturing suppliers. Also, the Stewardship group provides the information from the government, association and customers on the environmental conscious regulation, standards or requirements (e.g. EPA's regulation, ISO14000/ISO14001). The business information of the suppliers, includes contact information of the key person, company culture, capability of the company and so on are collected by the Supply Chain Management.

These information maybe not only used by the single group, they are shared with other groups and passed on to the other groups if necessary. For examples, when the design group is trying to make the decision on a product geometry parameter and this decision will be sent to the manufacturing supplier, the designers may ask Stewardship Group to share the environmental conscious information which is collected from government and suppliers, and provide the suggestions for improving the environmental performance of the product. Meanwhile, design group and Stewardship may need the information of manufacturing suppliers' capability from SCM to make sure that the decision can be realized as they expect. To reduce the under-design and over-design opportunities in the product design process, the information sharing and exchanging, among the Design Group, Stewardship group and SCM are very valuable, they make the product design more comprehensive and reasonable, also through Stewardship group, the suppliers are involved into the product development process.

I call the information sharing and exchanging as information overlap, to make the research have a definite object in view, I define the **Information Overlap** in the following three scopes:

1. Information sharing strategy

To demonstrate how the information is shared with each other group and shared with whom?

2. Content of the sharing information

What information will be shared in the product development process?

3. Extent of information sharing

How much extent the information will be shared in the groups, totally, partially or none?

4.3 Possible Strategies In Interaction Strategy Space

After I realize the existence of information overlap in the industrial company, I need to find the interaction strategies - how Stewardship Group share and exchange the information with Design Group, SCM and suppliers. The information in the Stewardship Group may be totally involved, partially involved or none involved into the design group. There are the same possible relationships with SCM. To communicate between the Stewardship and Suppliers, the information maybe passed on directly or passed on through SCM indirectly. All the possibilities are described as the following Information Overlap Classification table.

The roadmap of my approach as Figure 4.1:

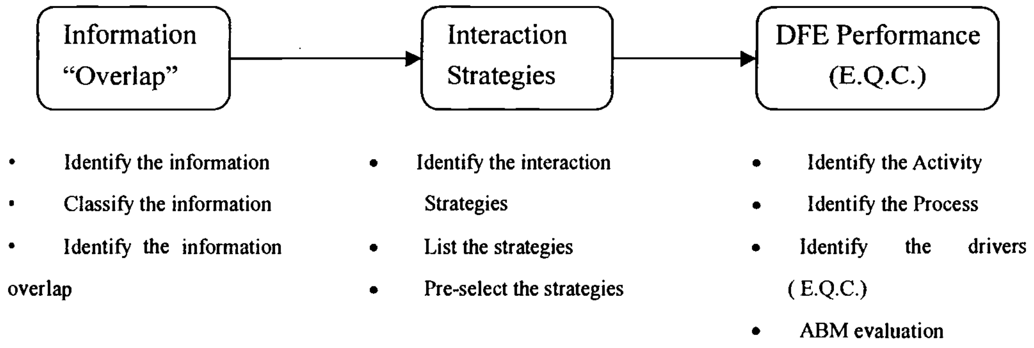

Figure 4.1 Approach Roadmap

As mentioned above, not all of the information in the group has to be shared with other group. I need identify the information along the product development process, as I did in the information lists (Table 4.1-Table 4.6). From the information lists, the information is grouped by groups as Quality Issues, Cost Issues or Environmental Issues. It is easier to find the information overlap between the groups. Once I have the information overlaps, the possible interaction strategies are generate. Activity Based Model is adopted to evaluate the difference by different interaction strategies. To use the Activity Based Model accurately, first, which activities will exchange the information, and the structure of the activity need to be identified. Then, find out the process of the activity, figure out what information is carried on by the activities and how the activities link together. The drivers are needed in the next step. The driver is the measure of the contribution on Environmental

Impact, Quality or Cost by an activity. The drivers make it possible to measure and quantify the E.Q.C performance through the process of the activities. These data are very important for the designers and the business decision maker to make the decisions with the three considerations.

As Table 4.8, the information of Stewardship group may have the overlap with the information of Design Group or SCM. The overlaps can be classified as Fully (totally overlap), Partially (part of Stewardship overlaps with design group or SCM) and None (independent with design group and SCM). For communication with Suppliers, the Stewardship group may communicate with suppliers directly by itself or collect and send the information to suppliers through SCM indirectly. These different combinations generate the different interaction strategies.

Interaction Strategy	Overlap with Design Group	Overlap with SCM	Communicate with Suppliers
1	Fully	Fully	Directly
2	Fully	Fully	Indirectly
3	Fully	Partially	Directly
4	Fully	Partially	Indirectly
5	Fully	None	Directly
6	Fully	None	Indirectly
7	Partially	Fully	Directly
8	Partially	Fully	Indirectly
9	Partially	Partially	Directly
10	Partially	Partially	Indirectly
11	Partially	None	Directly
12	Partially	None	Indirectly
13	None	Fully	Directly
14	None	Fully	Indirectly
15	None	Partially	Directly
16	None	Partially	Indirectly
17	None	None	Directly
18	None	None	Indirectly

Table 4.11 Information Overlap Classification

I plot the overlaps in interaction strategy (Design Group and SCM cooperation) space as the Figure 4.2:

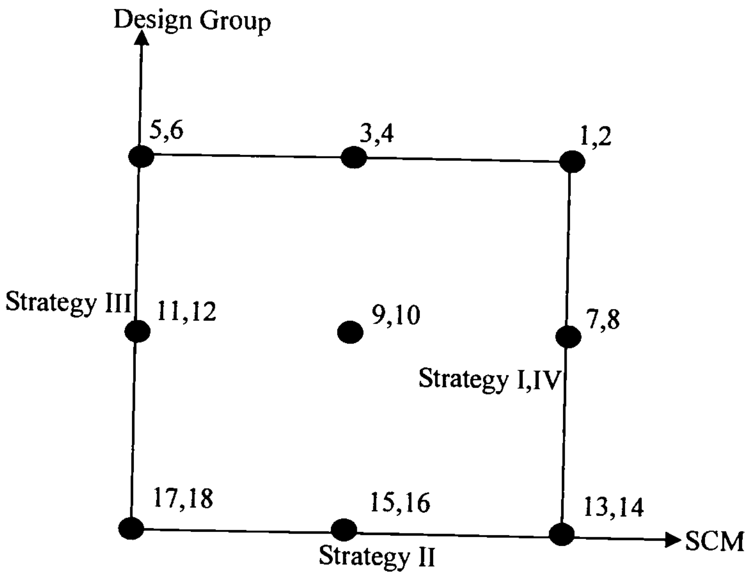

Figure 4.2 Interaction Strategy Space

Because there are 18 possibilities in the space, some of them were adopted by the industrial companies before, like 5,6, the European design groups already have this features, they have the environmental specialist assigned in the design group to reduce the environmental impact in the early stage of product design process. But in United State, few of companies do this. They'd like to build a special group to handle this within the whole product development process.

In my research, I only pick 11 as Strategy III, 17 as Strategy II, 15 as Strategy IV, and 16 as Strategy I.

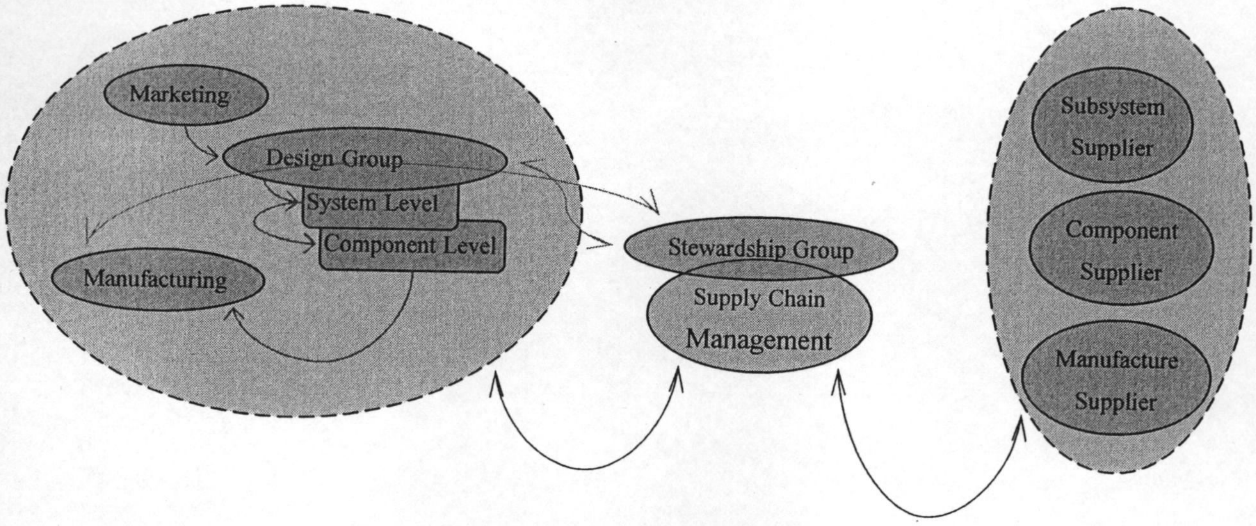

Figure 4.3 Framework of Interaction Strategy I

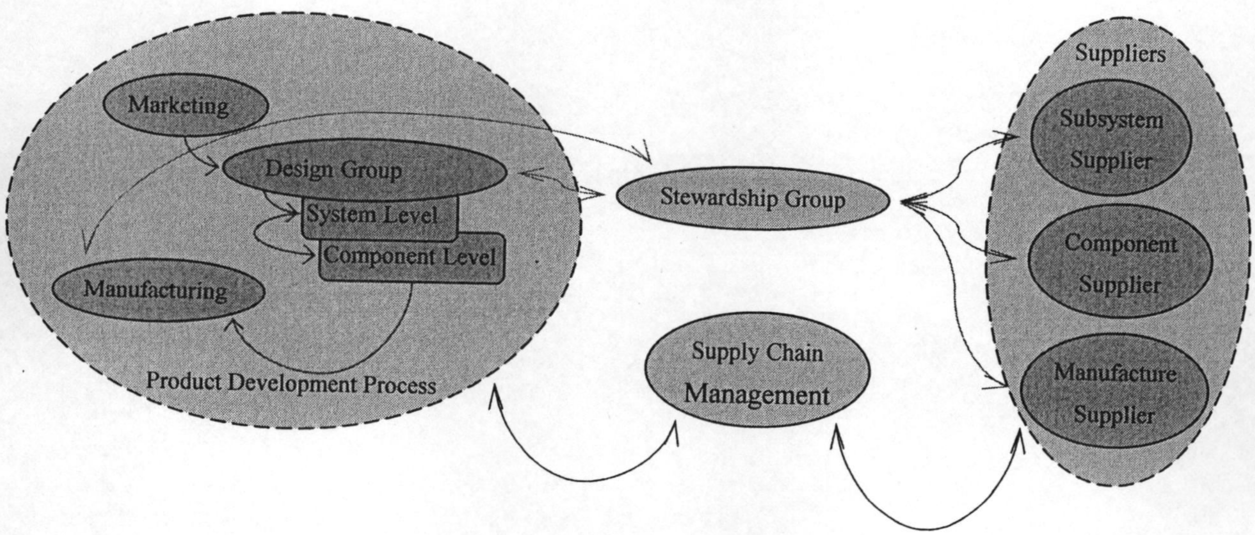

Figure 4.4 Framework of Interaction Strategy II.

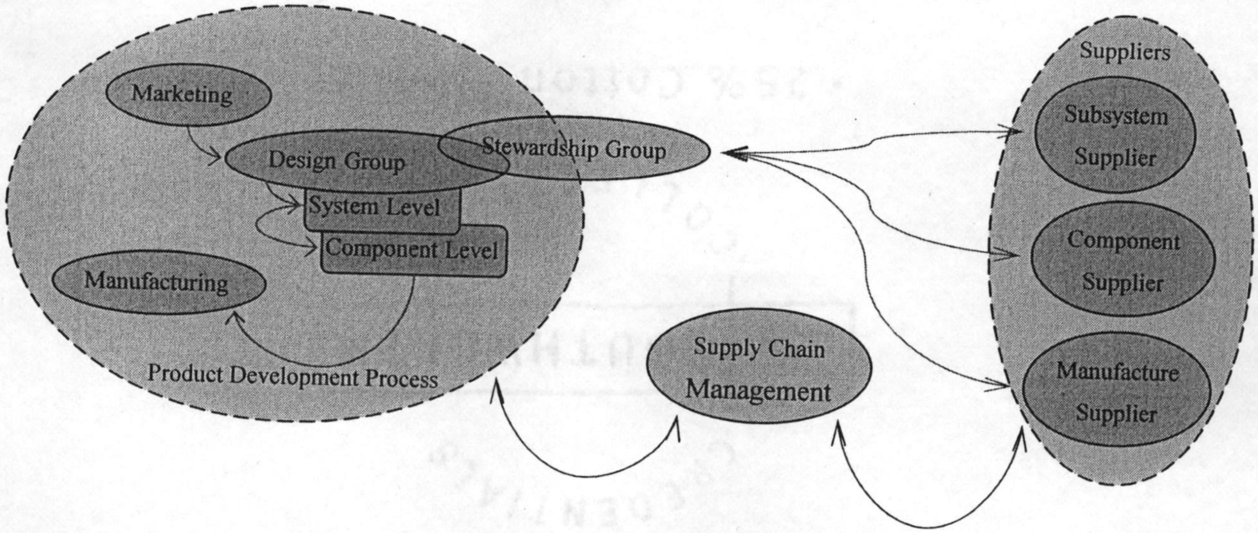

Figure 4.5 Framework of Interaction Strategy III

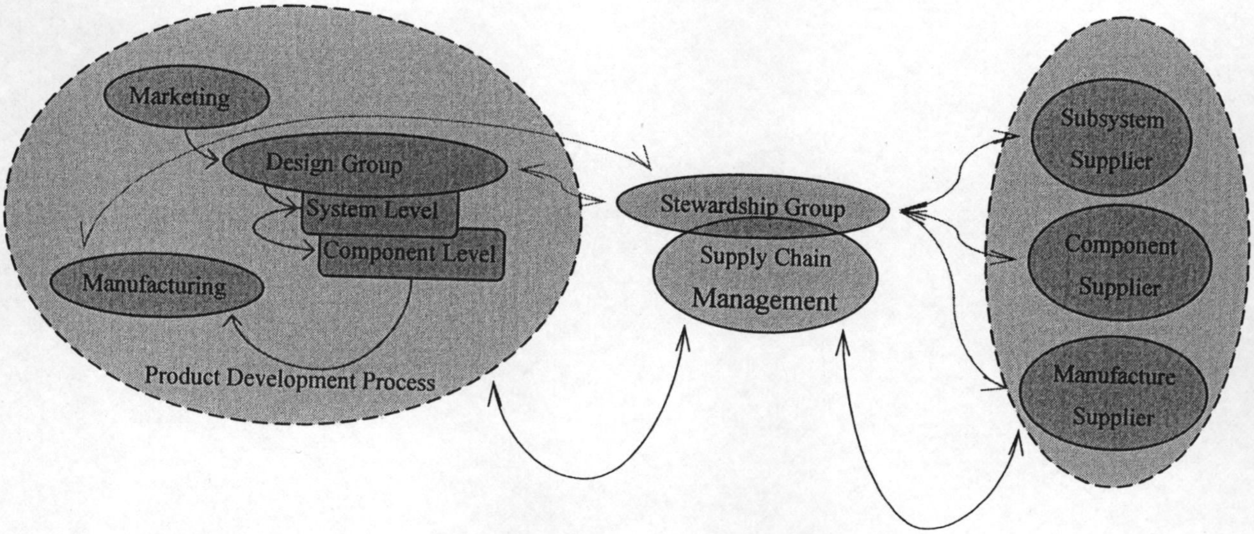

Figure 4.6 Framework of Interaction Strategy IV

4.4 Activity Structure Based On O-O Technique

In product development process, Information is the data or facts to present the decision that made by the decision maker of the group. The information is generated by the activities and used by the other activity. The information that relates to the Quality, Cost and Environmental Impact Issues can not flow freely in the product development process without carrier. The transferring needs to find a carrier - Activity. Also to share and exchange the information with other groups, the information needs to find an activity to attach. Once the information is combined with the activity, the information has the real meaning to direct the activities or the final decision.

I borrow the Object-Oriented concept to define the activity structure as Activity Class (Figure 4.7).

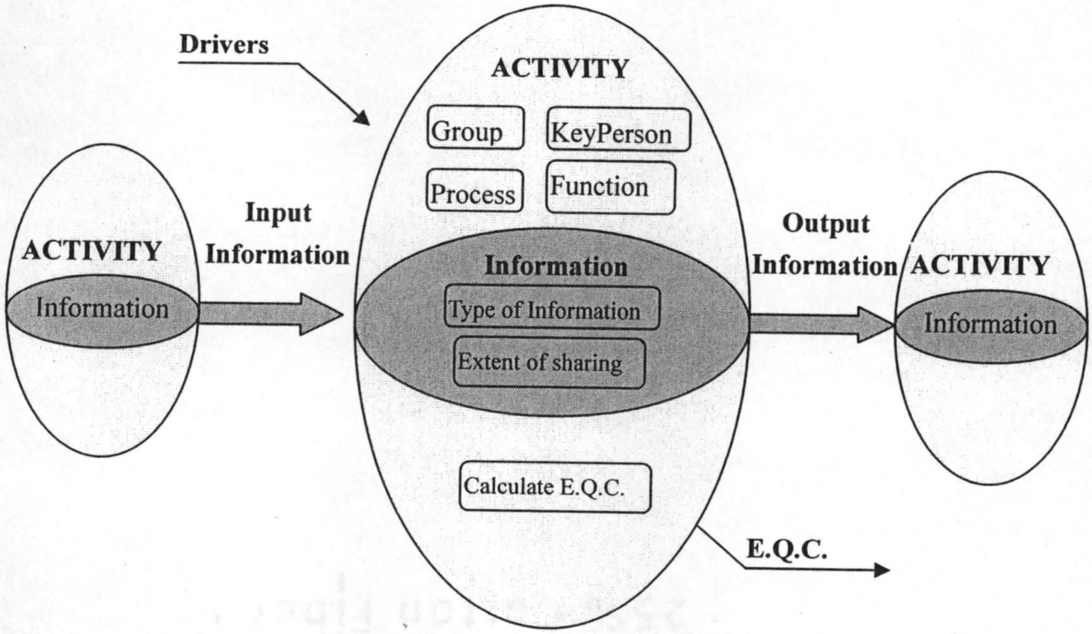

Figure 4.7 Activity Entity and Structure

The class encompasses:

- The properties of the activity, includes which group this activity belongs to, what function this activity works for, which process the activity is involved and who is the key person to take charge of the activity.
- Information objects, encompass the information which the activity needs. The properties of the information can be retrieved from the objects, includes the type of information, content of information, extent of sharing.
- The methods to calculate E.Q.C. (environmental impact, quality and cost) through the drivers.

The activity has two inputs (E.Q.C. Drivers and input information) and two outputs (E.Q.C. and output information). The information from other activity is passed to the activity. The activity can access the information as his own properties to calculate the E.Q.C. or generate the E.Q.C. information for the other activities. In the single group, the activities are linked by the information.

Class Activity	
Properties	The properties of the activity class
m_activityName: string	The meaningful name of the activity, e.g. "activitySelectCaseBoxMaterial"
m_activityID:int	The unique number for the activity
m_activityDescription: string	The detail description of this activity
m_cost: Cost	The cost change by the activity
m_quality: Quality	The quality change by the activity
m_envImpact: EnvImpact	The environmental impact change by the activity.
m_activityGroup: Group	The group which the activity belongs to
m_activityProcess: Process	The process which the activity is involved
m_activityFunction:Function	The function which the activity works for
m_activityKeyPerson: Person	The key person who take charge of this activity
m_nextActivityID:int	The ID of the downstream activity
m_lastActivityID:int	The ID of the upstream activity
m_inputInformation: InformationList	The information which is involved in this activity, because one activity may not have only one kind of information. I use the Information list type to save them. (InforamtionList::List, this class is inherited from List Class)
m_outputInformation:InformationList	The information which is generated by this activity.
Methods	The utility functions of the activity
getActivityID():int	Retrieve the activity ID, I set a unique integer number as ID for each activity to manipulate the activities easier.
setActivityID(int id):void	Assign the activity ID during the Activity object initialization
getActivityName (): string	Retrieve the activity name, m_activityName
setActivityName (string actName): void	Assign the activity name during the Activity object initialization
getActivityDescription (): string	Retrieve the activity description, m_activityDescription

Table 4.12 Activity Class O-O Definition

setActivityDescription(string actDescription): void	Assign the activity detail description during the Activity object initialization
GetCost() : Cost	Retrieve the cost change of this activity
SetCost(Cost cost): void	Assign the activity cost change by modifying the member variable m_cost
getQuality():Quality	Retrieve the quality change of this activity
setQuality(Quality quality):void	Assign the activity quality change by modifying the member variable m_quality
getEnvImpact():EnvImpact	Retrieve the environmental impact change of this activity
setEnvImpact(EnvImpact impact): void	Assign the activity environmental impact change by modifying the member variable m_envImpact
getActivityProcess():Process	Retrieve the process which this activity belongs to
setActivityProcess(Process process):void	Assign which process this activity belongs to during the activity object initialization, m_activityProcess
getActivityKeyPerson():Person	Retrieve the key person who takes charge of this activity
setActivityKeyPerson(Person keyperson):void	Assign key person during the activity object initialization, m_activityKeyPerson
GetLastActivityID(int id):void	Retrieve the id of the upstream activity
setInputInformationList(InformationList informationlist):void	Assign the input information list of this activity to m_informationList during the initialization
getInputInformationList():InformationList	Retrieve the input information list of this activity, m_inputInforamtion.
addOutputInformationList(Information outputinformation): void	Add the information object that is generated by this activity into the output information list, m_outputInformationList.
caculateEQC(Driver driverE, Driver driverQ, Driver driverC): (EnvImpact impact, Quality qulity, Cost cost)	Calculate the E.Q.C output through the input drivers

Table 4.9 Activity Class O-O Definition (Continued)

To combine the information with the activity structure, the information list object is added into the activity structure. This information list is the set of different information, because an activity may have the multiple input information. I select the List datatype to record the information. Every member of the input information list is the information object. They may from the different groups on the different issues.

With the consideration and contribution of the input information, the activity generates the information (e.g. design decision) to share or exchange with other groups as the output of the activity. I record this kind of information in output information list.

Class InformationList	
Methods	
InformationList()::List	The InformationList initialize function, InformationList is inherited from the List Class directly. It allows the objects in the list to be added, deleted, searched or retrieved.
Add(Information info):void	add information object into the informationList object
Delete(Information info): void	Delete the information object into the informationList object

Table 4.13 InformationList Class O-O Definition

To describe the special features of information, I use the independent class – Information Class. In this class definition, the detail information is filled into, which group this information belongs to? What issues this information relates with (E.Q.C.)? What is the information overlap for this information among the groups, how much it is shared fully, partially or none? How this information communicate with the suppliers?

Class Information	
Properties	
m_infoDescription: string	the detail description or the data presentation of this Information, e.g. the plastic case box recycle percentage
m_infoGroup: Group	which group this information belongs to
m_relateCost:Boolean	This information relates the cost issue or not
m_relateQuliaty:Boolean	This information relates the quality issue or not
m_relateEvnImpact:Boolean	This information relates the environmental impact issue or not
m_overlapGroup: string[]	The information may overlap with more than one group, I select the string array to save the groups' names.
m_directRelateSuppliers:Boolean	The information communicates with the suppliers directly or not
Methods	
setDescription(string description): void	Assign the information detail description to m_infoDescription, include the data
getDescription(): string	Retrieve the information description
setInformationGroup(Group group): void	Assign the group which information belongs to during the Information initialization
getInformationGroup(): Group	Retrieve the group which the information belongs to
SetInformationType(Boolean bCost, Boolean bQuality, Boolean bImpact):void	Assign what issues the information relates with e.g. if the information relates to the environmental impact, then set m_relateEnvImpact=1.
SetOverlapGroup(Group group1,int g1,Group group2,int g2):void	In my research, I just discuss about Stewardship, Design and SCM groups, so overlap with the other two groups is maximum. In this method, the groups names are assigned to string array m_overlapGroup and the integer parameters to describe the extent of sharing, 0 as none, 1 as partially, 2 as fully.

Table 4. 14 Information Class O-O Definition

Class Group	
Properties	
m_groupName:string	The name of the group. In my research, the name is "Stewardship","Design"or"SCM".
Methods	
setGroupName(string name):void	Assign the name of the group
getGroupName():string	Return the name of the group, m_groupName

Table 4.15 Group Class O-O Definition

CHAPTER 5
Evaluation Of The Effectiveness Of Interaction Strategies

5.1 Case Description

As we known, more and more environmental concerns are emphasized in IT industry in this decade [Williams, 2004][Lee, 2004].

In this work, to verify my methodology to solve the real problem, I select a computer system as an example. Because the concurrent famous computer system developers like DELL and IBM, they purchase the components from the part suppliers who have the more advanced technologies than themselves, e.g. motherboard, video card and audio card.

Marketing collect the customers' needs. Designer translate them into the customer requirements (CR), the customers need the computer system has the following features:

CR1: Small size and good multimedia presentation ability, including video and audio.

CR2: Low Price for purchasing the product

CR3: Less environmental impact during the computer manufacturing and recycle process.

The designer will generate the design solutions to fit the customer requirements.

1. To decrease the computer size (CR1), the determinant factor which affects the computer size is the dimension of the motherboard, the biggest component of the system. So the design problem is selecting the size of the motherboard.
2. To fit the multimedia presentation ability (CR2), the designer needs to select the appropriate audio and video cards. Here are some decisions need to be traded off, they may select powerful video and audio cards with the large size, or normal cards with small size, or ask the motherboard supplier to integrate them into the motherboard.
3. To consider the environmental impact of the product (CR3), we know most of the components of the computer system are made of printed circuit board, whatever motherboard, audio card or video card. The environmental impact occurs during the computer manufacturing should not be ignored, especially the process of manufacturing the Printed Circuit Board (PCB). [Lee, 2004]

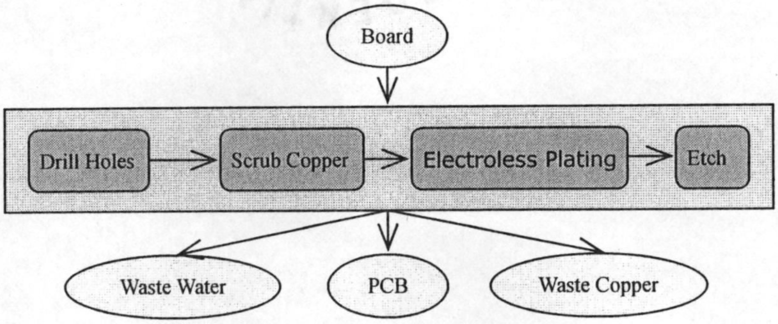

Figure 5.1 PCB Manufacturing Process

Within the manufacturing process of PCB, as Figure 5.1, the board begins with the plating and selective etching of copper coil on a nonconductive sheet of plastic. The automated drilling machine makes the holes on the board for mounting the electronic components. To remove the copper particles after drilling, the board is scrubbed and the dissolved copper is the solid waste in this step. After being scrubbed, the board is cleaned to promote good adhesion. Since the holes still need be conductive, the electroless copper plating is employed to provide a conductive layer over the surface of the board also through the holes. At the end, the exposed copper is removed by etching to reveal the circuit pattern. In above steps, water waste and waste copper generated, our environmental target is set for monitor the hazard substance in the waste water and the waste copper generation. [Kirsch, 1991]

To make the interaction strategies comparison more specific, I pick the waste substances to analyze along the PCB manufacturing process as listed in Table 5.1. The amount of the waste is calculated by the area of the PCB need to be manufactured (cm^2).

Table 5.2 is the components information from the suppliers, I select the motherboard, video card and audio card from different suppliers (product data is from the official web pages of Intel, bfgTech and Creative):

Category	***Substance***	***g/cm²***
Acids Bases	Phosphoric acid H_3PO_4	2.41
	Hydrofluoric acid	3.42
	Nitric acid	1.19
	Sulfuric acid	7.85
	Ammonia	1.062
Photolithographic Chemicals	Hydrogen peroxide	4.43
	Tetraethyl ammonium hydroxide	4.31
	Acetone	0.554
	subtotal	25.226
Category	***Substance***	***g/cm²***
Solid Waste	Copper Containing Sludge	0.34
	subtotal	0.34

Table 5.1 PCB Manufacturing Waste Data

Category	Supplier Name	Product Model	Tech Add-In value	Specification: area, stereo output and fill rate
Motherboard	Intel	D925XEBC2	$87	243.84mm*243.84mm stereo output 100 db(assumed)
Motherboard	Intel	D875PBZ	$115	244.61mm*243.84mm 1.2 *Billion texels/sec* stereo output 100db (assumed)
Motherboard	Intel	D845GVSR	$72	233.69mm*208.28mm
Video Card	BFG	Geforce6800	$95	80.22mm*53.69mm *5.6 Billion texels/sec.*
Video Card	BFG	GeforceFX5600	$66	77.25mm*52.20mm 4 *Billion texels/sec*
Audio Card	Creative	Audigy 4	$35	79.02mm*51.11mm Stereo Output 108db
Audio Card	Creative	Audigy 2 ZS	$28	75.76mm*48.33mm Stereo Output 106db

Table 5.2 Suppliers Product Specification

The information which the supplier provides is the product model No., technical specification and the Tech add-in value of the components. The Tech Add-In Value is the pre-investment which is used to develop the components technology besides the cost of components manufacturing. It is also the profit of the suppliers. I select two important functional parameters for audio card (Stereo output) and video card (Graphics processing rendering speed).

The cost of manufacturing PCB is estimated as $0.0086/cm^2 from the curve of [Murphy, 1996]. I sum the manufacturing cost and the Tech

Add-In Value to get the total price of the components as the Table 5.3 (product data is from the official web pages of Intel, bfgTech and Creative).

Product Model	***PCB Manufacturing Cost($)***	***Tech Add-In value($)***	***Total Component Cost($)***
D925XEBC2	5.113	87	92.113
D875PBZ	5.129	115	120.129
D845GVSR	4.185	72	76.185
Geforce6800	0.370	95	95.370
GeforceFX5600	0.346	66	66.345
Audigy 4	0.347	35	35.347
Audigy 2 ZS	0.314	28	28.314

Table 5.3 Product Detail Quotation from Suppliers

	Location	**Distance (mile)**
Assembly Place	Corvallis,OR	0
D925XEBC2	Portland,OR	100
D875PBZ	Seattle,WA	256
D845GVSR	San Francisco,CA	560
Geforce6800	Beaverton,OR	109
GeforceFX5600	San Jose,CA	605
Audigy 4	Boston,MA	3100
Audigy 2 ZS	Boston,MA	3100

Table 5.4 Manufacturer Location Data

However, the location of the component manufacturer is another factor. The distance from the component manufacturer to the assembly center will influences the whole system delivery time and the working process schedule of Supply Chain Management Group. In my case, I assume the involved components manufacturer information as Table 5.4.

5.2 Evaluation Methodology

To evaluate the effectiveness of different interaction strategies, a method is needed to calculate the E.Q.C. along the product development process and make the evaluation for the different strategies. The main steps of the evaluation methodology are presented as Figure 5.2.

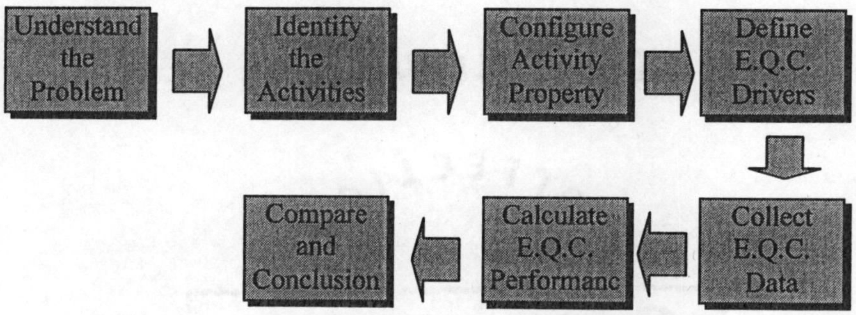

Figure 5.2 Evaluation Methodology Diagram

5.2.1 Figure out the Activity E.Q.C. property

After the activities are identified, the E.Q.C. properties of an activity need to be clarified. As I mentioned in Activity Class Definition, an activity may affect the product's Quality, Environmental Impact or Cost.

An activity may relate one or more issues. To apply the E.Q.C. drivers on the correct activities, the designer should work out the activity's E.Q.C. property at first. Also the E.Q.C. properties make the activity definition more structured, and easier to save activity data into the database. In this case study, I made the green mark for **E**nvironmental Impact Activity, blue for **Q**uality Activity and yellow for **C**ost Activity on the activities.

5.2.2 Define E.Q.C. Drivers

As I mentioned in the previous chapter, E.Q.C. drivers are the triggers to make the E.Q.C. performance quantitative. Once the clear activity road map and the properties of the activities are identified, the drivers need to be identified to be used on the activities. Then, along the activities roadmap, monitering the change of E.Q.C. performance is possible.

For the single consideration (E., Q. or C.), multi-drivers may affect it. e.g., the PCB area and the operator error behavior maybe the drivers of environmental impact consideration simultaneously.

In my case study, the cost and environmental impact has the linear relationship with the area of PCB based on Table 5.1, so I select the environmental driver as the area of PCB. And, I take the video Fill rate as quality driver.

5.2.3 Calculate E.Q.C. along the product development process

Cost: The total system manufacturing cost is the summation of PCBs manufacturing cost and components technology add-in value.

$$Cost = \sum ActiviyCost_{PCBManufacturing} + \sum TechAddinValue$$

The cost driver times the PCB area of components is the PCBs manufacturing cost:

$$Cost = \sum (AreaPCB * \Delta \cos t / cm^2) + \sum TechAddinValue$$

However, the Technology add-in value is provided by suppliers.

Environmental Impact: the total system manufacturing environmental impact is from PCBs' manufacturing.

$$Environmental \operatorname{Im} pact = \sum ActiviyEnv._{PCBManufacturing}$$

The environmental impact driver times the PCB area of components is the environmental impact released from PCB manufacturing:

$$Environmental \operatorname{Im} pact = \sum (AreaPCB * \Delta Env. / cm^2)$$

Quality : Fill rate is the important rending speed performance of video card. There are the bunch of factors influence it. To simplify this application, I only consider about one of the factors - video card memory capability. From the products specification from the suppliers, I plot the video memory capability and fill rate as Figure 5.3. The relationship will be expressed as :

$$FillRate = \sum (2.5247 * Ln(\Delta memAdd / activity) - 8.5)$$

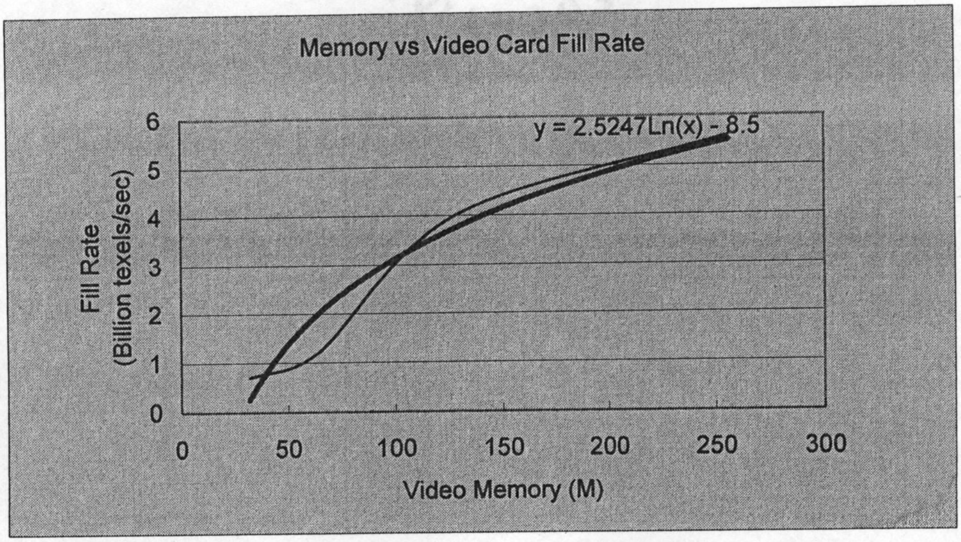

Figure 5.3 The relationship of Video Memory capability and Fill Rate

5.3 Interaction Strategies

5.3.1 Description Of Interaction Strategy And Major Activities Roadmap

As described in the last chapter, different industrial companies have their own interaction strategies to handle the communication between the suppliers and the design group. The environment, quality and monetary consideration affect the design decisions diversely. I enumerate four different interaction strategies to generate the design solutions for supplier selection and purchasing components selection.

Figure 5.4 shows the major activities along the product development process in the product developer companies. Every interaction strategy follows the similar product development process. The information sharing activity and the actor would be different by the interaction strategies. The interaction strategies will not change every activity. From the major activities, A_1 and A_2 always are the function of Marketing Group and Design Group. But A_3 maybe operated by Stewardship group, SCM or both. Although only this activity changes the actor, the information which is generated/collected by this activity maybe changed. The different information from the pervious activities may change the decision of A_4 (components / supplier selection). Obviously, this change will influence the final product design greatly.

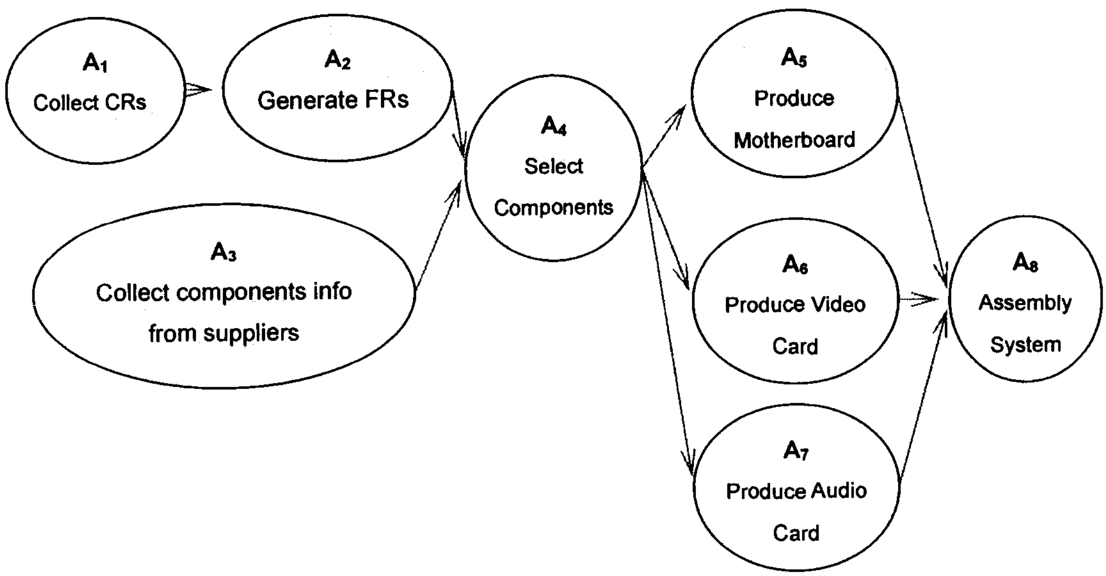

Figure 5.4 Major Activities Roadmap of System manufacturing

5.3.2 Selected interaction strategies and detail activity roadmaps

Interaction Strategy I. (Figure 4.3)

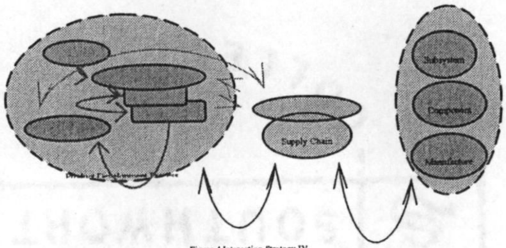

Figure 4 Interaction Strategy IV

Stewardship Group shares the information with SCM and SCM communicates with suppliers directly. After the design group receives the customer requirements, the design group will generate the technical purchasing criterions which fit the CRs. Then, design group will request the supplier's information from SCM or Stewardship Group. Because only SCM could communicate with the suppliers directly in this strategy, SCM pay more attention to their attitudes. In this case, they return the D925XEBC2 information to design group, because Intel has three manufacturers in different place (Portland, Seattle, San Francisco) to manufacture the different motherboard models. The manufacturer in Portland is the closest one from assembly center. Then, the Stewardship Group and Design group validate the selected components on both functional consideration and environment benign consideration. If this component satisfies Stewardship and Design Group, this component could be the final selection. For the same reason, the video card manufacturer of Geforce6800 is much closer than the others manufacturer. Geforce6800 is selected as the Video Card of the system.

ABM Process Modeling of *Interaction Strategy I*

Once we know what happen in this interaction strategy, I adopt ABM (Activity Based Model) to simulate the product development process. Then, the E.Q.C. data is collected along the process.

The suppliers' information are filtered and selected in the transformation among the groups. The different interaction strategy emphasizes on the different information of suppliers, for examples, the SCM emphasizes on the delivery time and supply chain efficiency, the Stewardship Group emphasizes on how much environmental impact will be released when this component is manufactured and the Design Group will put more attention on how good this component will fit the customer needs on product functional performance. The different priorities of the groups make the component selection different.

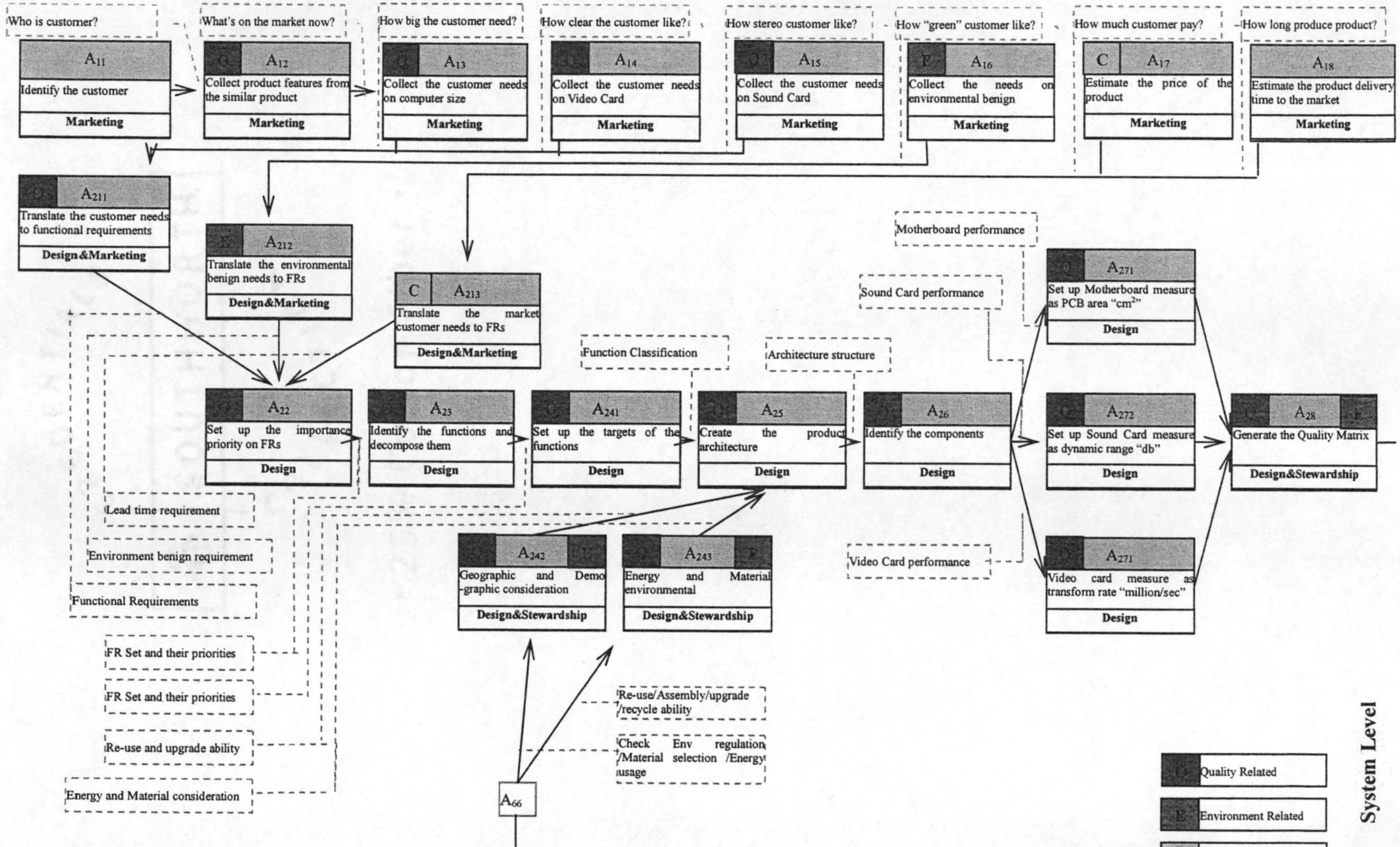

Figure 5.5 Activity Roadmap of Interaction Strategy I

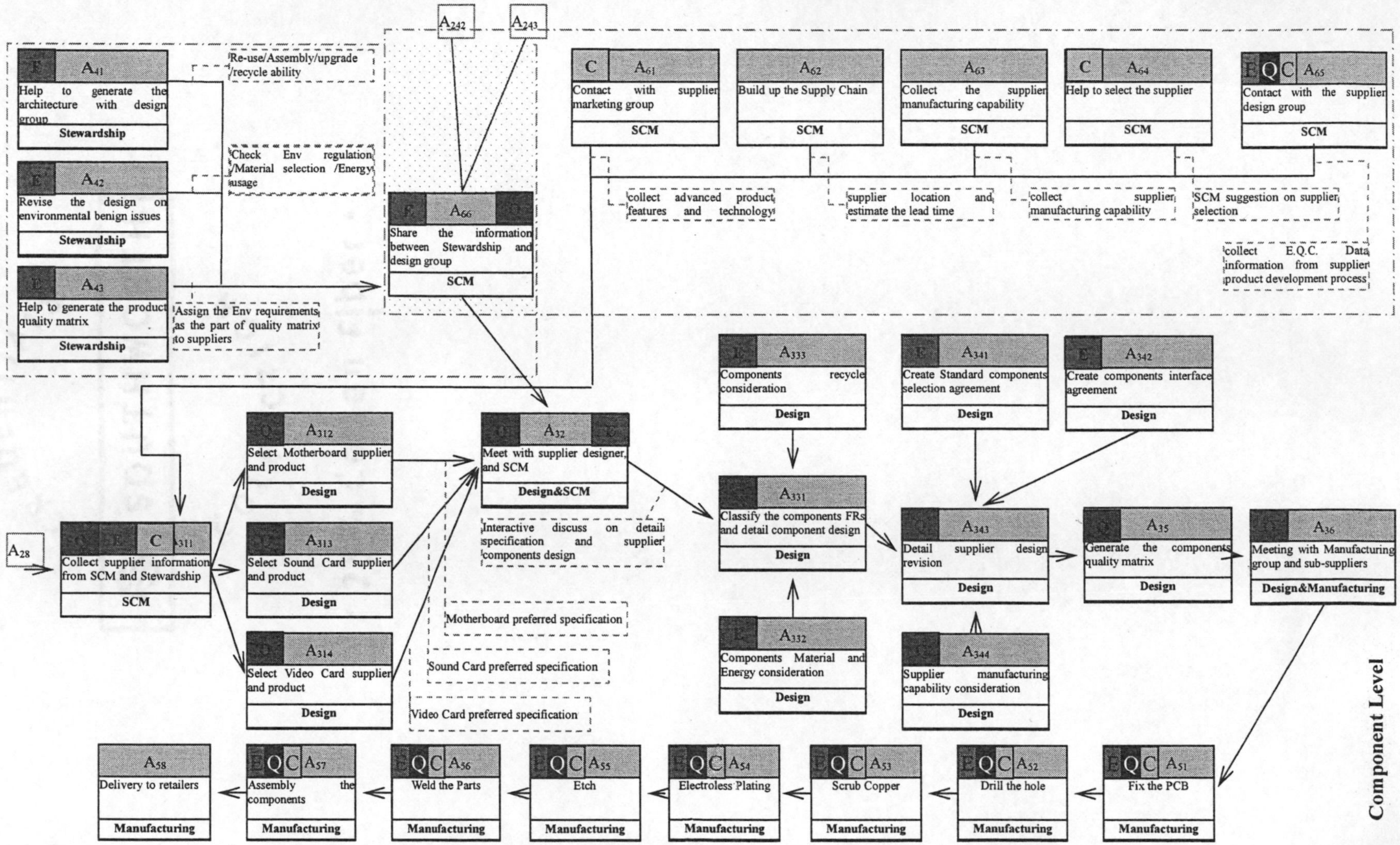

Figure 5.5 Activity Roadmap of Interaction Strategy I (Continued)

Interaction Strategy II. *(Figure 4.4)*

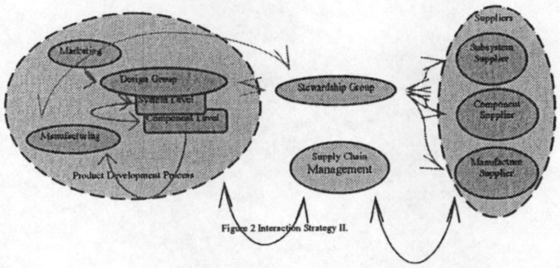

Figure 2 Interaction Strategy II.

In this interaction strategy, Stewardship Group is independent, and without any information sharing with other groups.

Similar with the Interaction Strategy II, along the product design process, the Stewardship group helps the design group to communicate with suppliers. Because of the priority of environmental consideration in Stewardship Group, they will recommend to select D845GVSR, Audigy 2 ZS and GeforceFX5600 as the motherboard, sound card and video card. Although the quality performances of these parts are not the best, the specifications from the suppliers show these parts will cause less negative effect to the environment when the parts are produced.

ABM Process Modeling of *Interaction Strategy II*

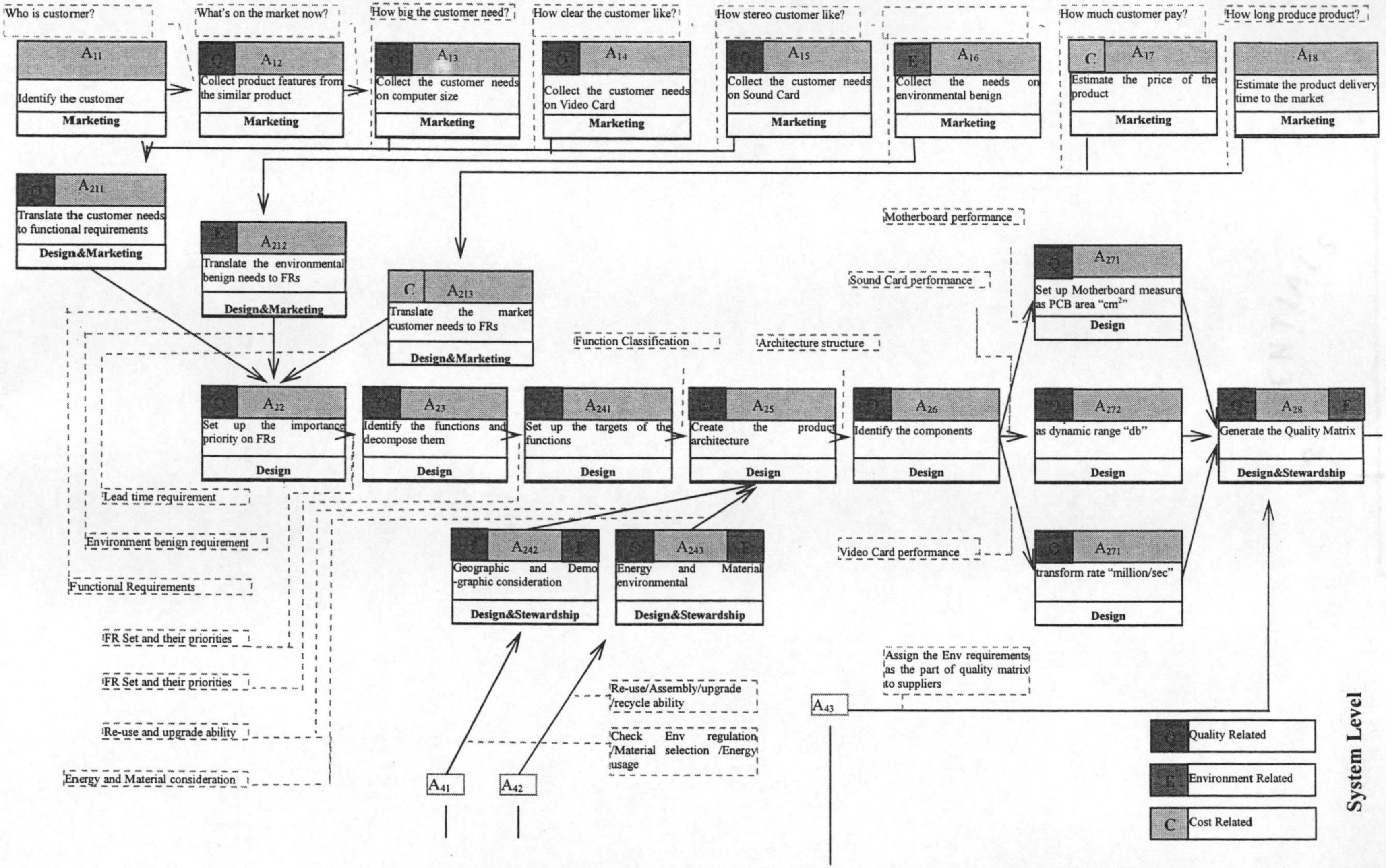

Figure 5.6 Activity Roadmap of Interaction Strategy II

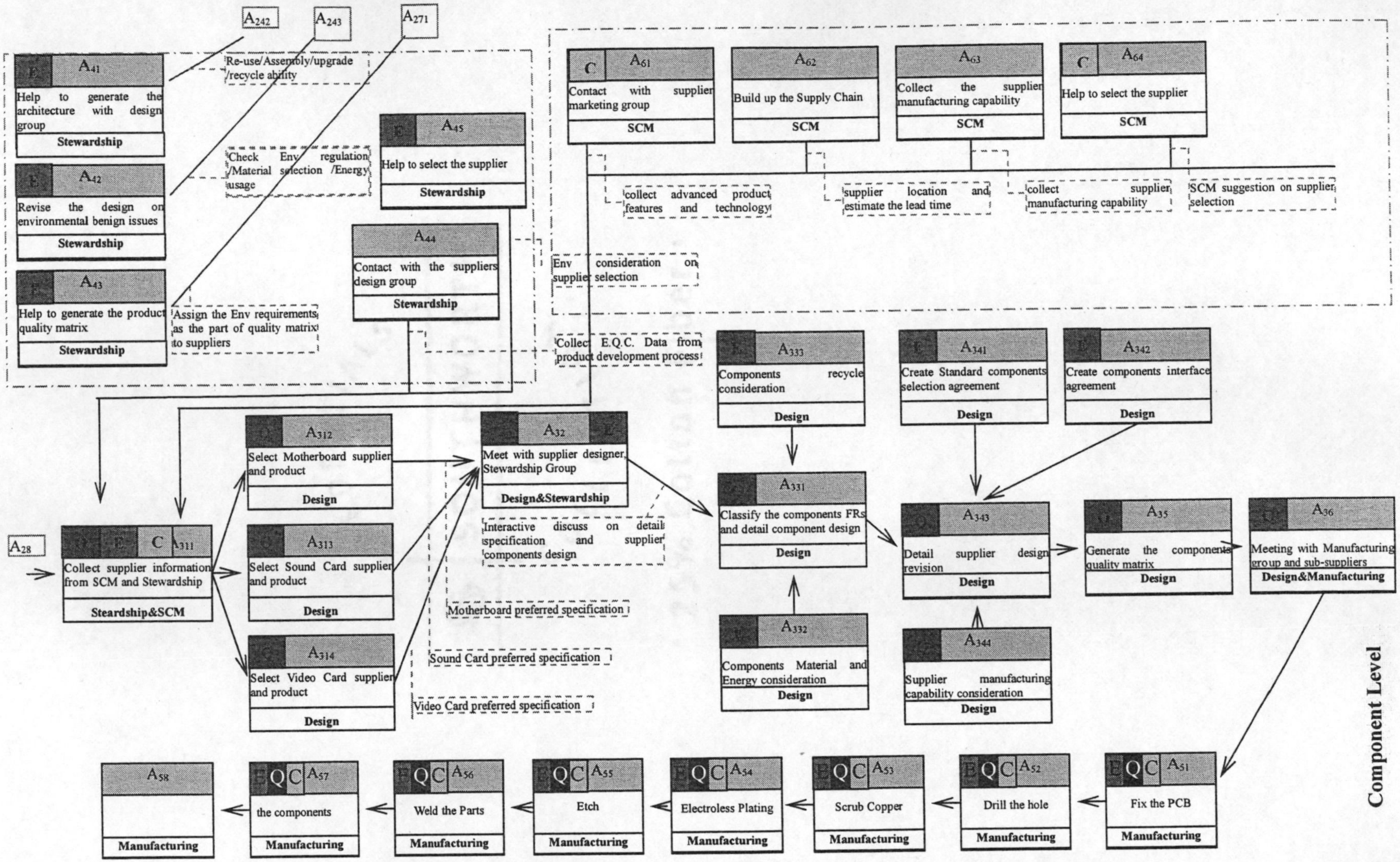

Figure 5.6 Activity Roadmap of Interaction Strategy II (Continued)

Interaction Strategy III. *(Figure 4.5)*

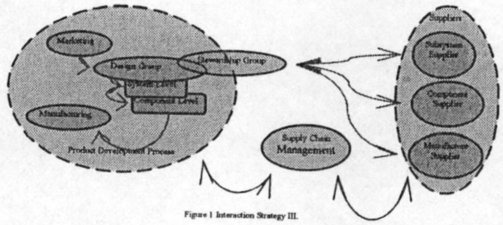

Figure 1 Interaction Strategy III.

The Stewardship Group shares the information with Design Group in this scenario. The attention of Design Group focuses on the quality of components. Obviously, the quality is the most important for design group on supplier selection. In this point of view, the D845GVSR, Audigy 4 and Geforce6800 are purchased from the different suppliers, because they have the best quality performance. Stewardship will check the Design Group's final parts selection to check the parts exceed the environmental benign regulation of the government or not and help the Design Group collect the suppliers parts information.

ABM Process Modeling of *Interaction Strategy III*

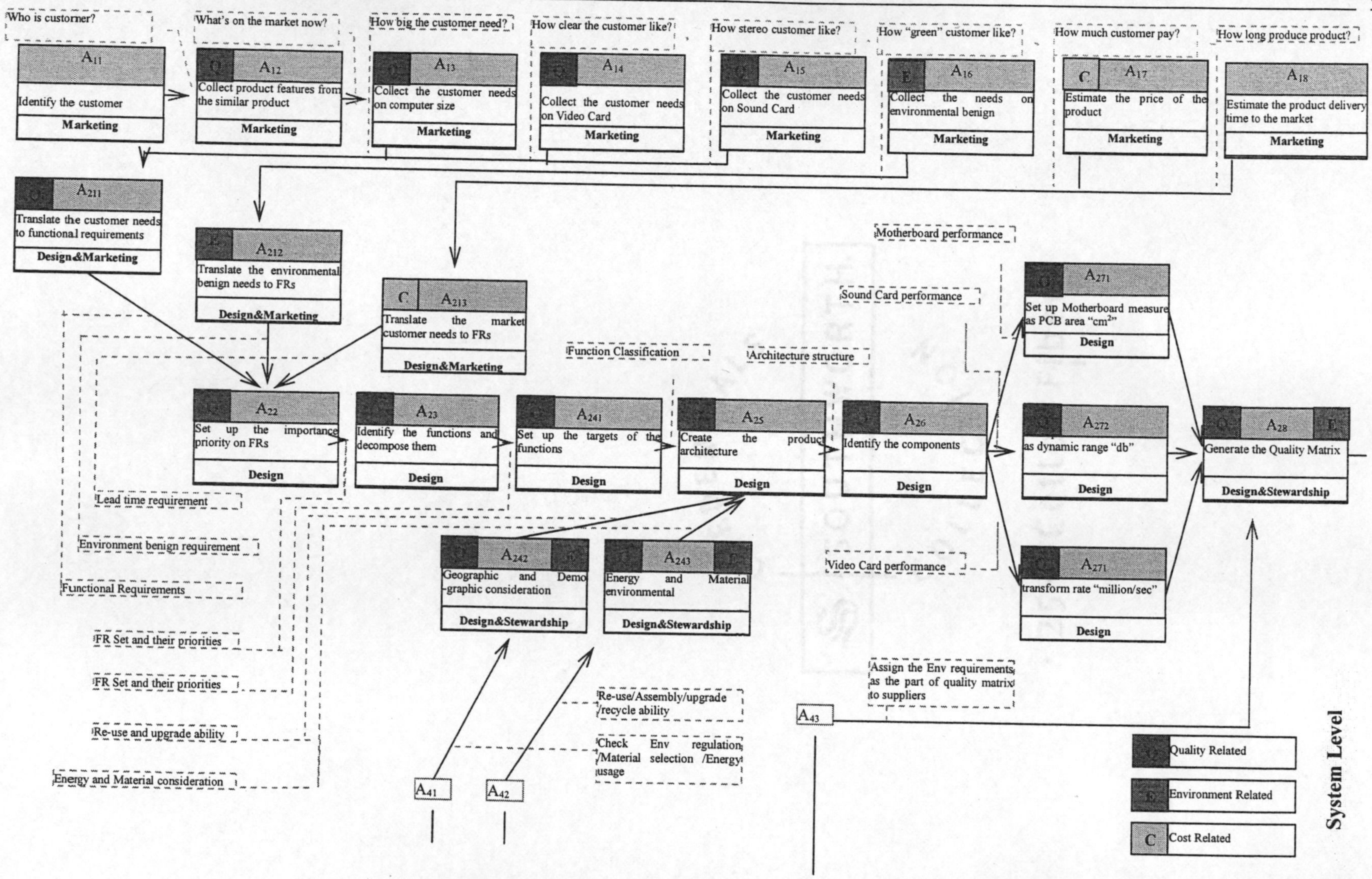

Figure 5.7 Activity Roadmap of Interaction Strategy III

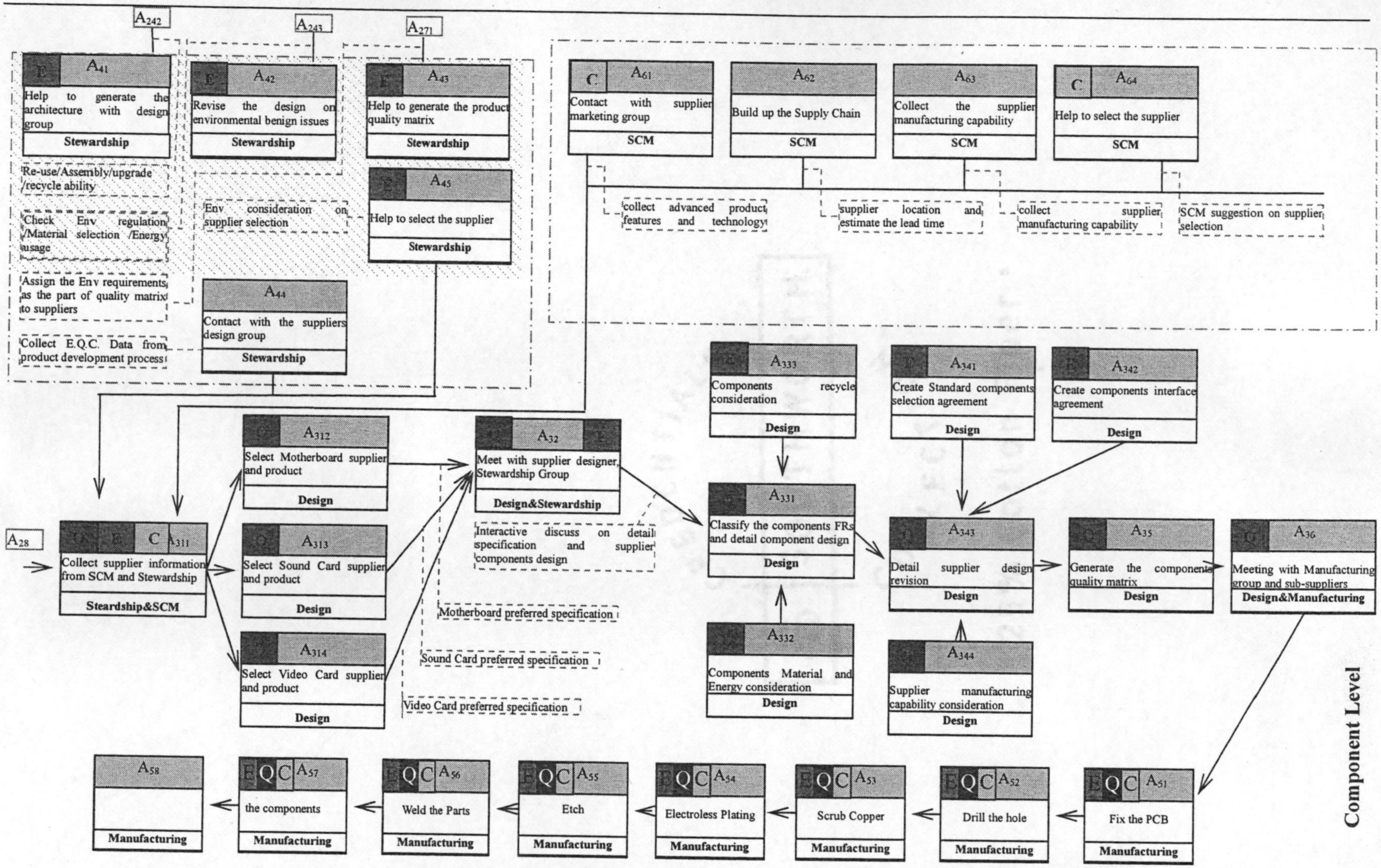

Figure 5.7 Activity Roadmap of Interaction Strategy III (Continued)

Interaction Strategy IV. *(Figure 4.6)*

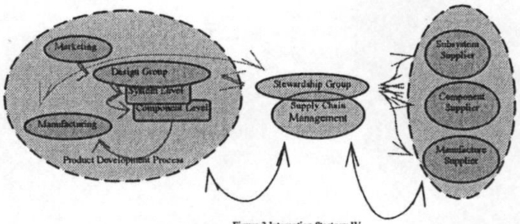

Figure 3 Interaction Strategy IV.

In this scenario, the Stewardship Group shares the information with SCM. Unlike Interaction Strategy I, the Stewardship Group may communicate with the supplier directly. The supplier information would be filtered by the Stewardship Group and SCM together. That means the parts need to satisfy both environmental benign and distance close to the assembly center in the meantime. Under this situation, motherboard D875PBZ is the compromise. The video card and audio card is integrated into the board. This solution may reduce the environmental impact greatly also decrease the distance from the assembly area and the video, audio quality is acceptable for SCM and Design Group.

ABM Process Modeling of *Interaction Strategy IV*

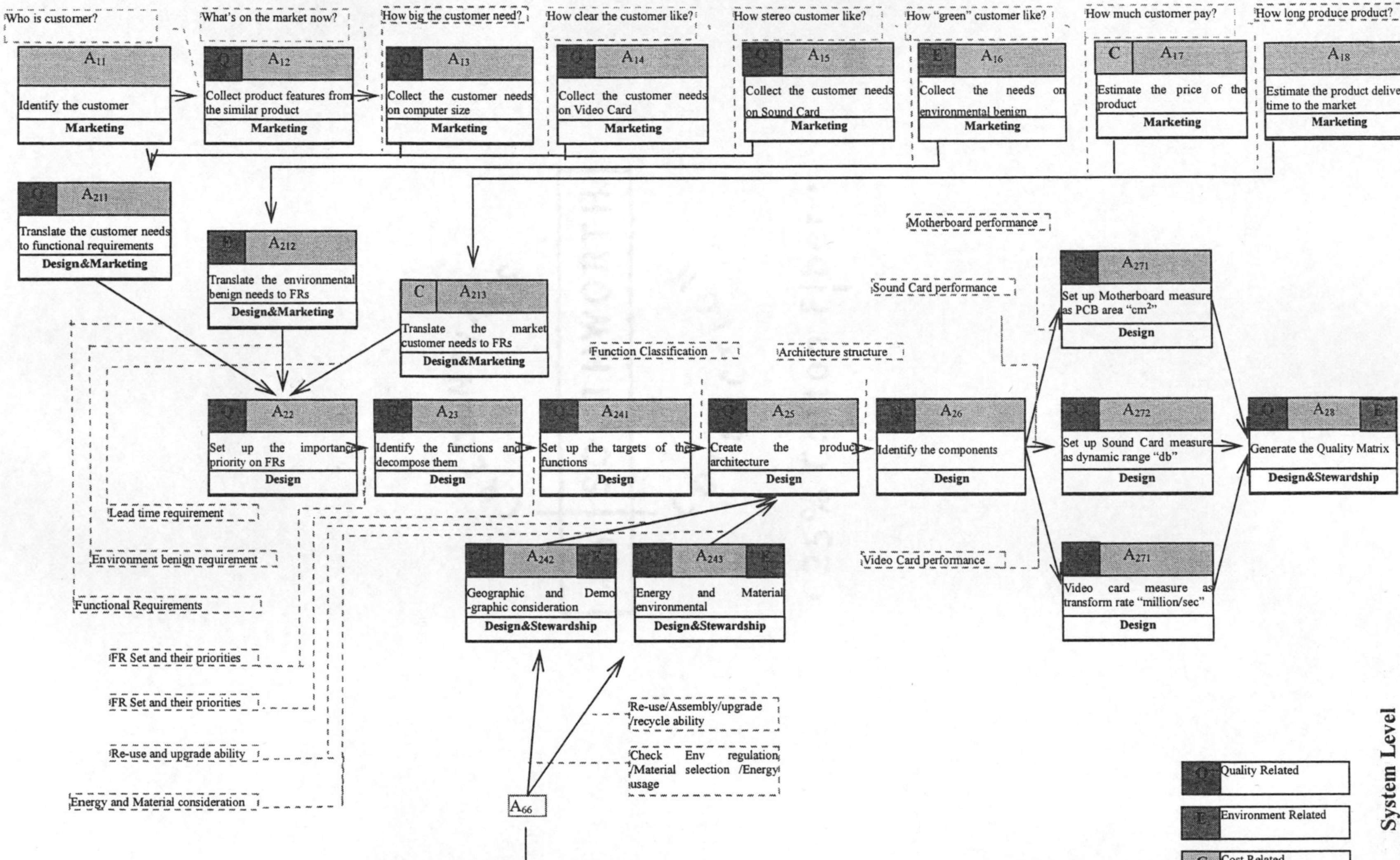

Figure 5.8 Activity Roadmap of Interaction Strategy IV

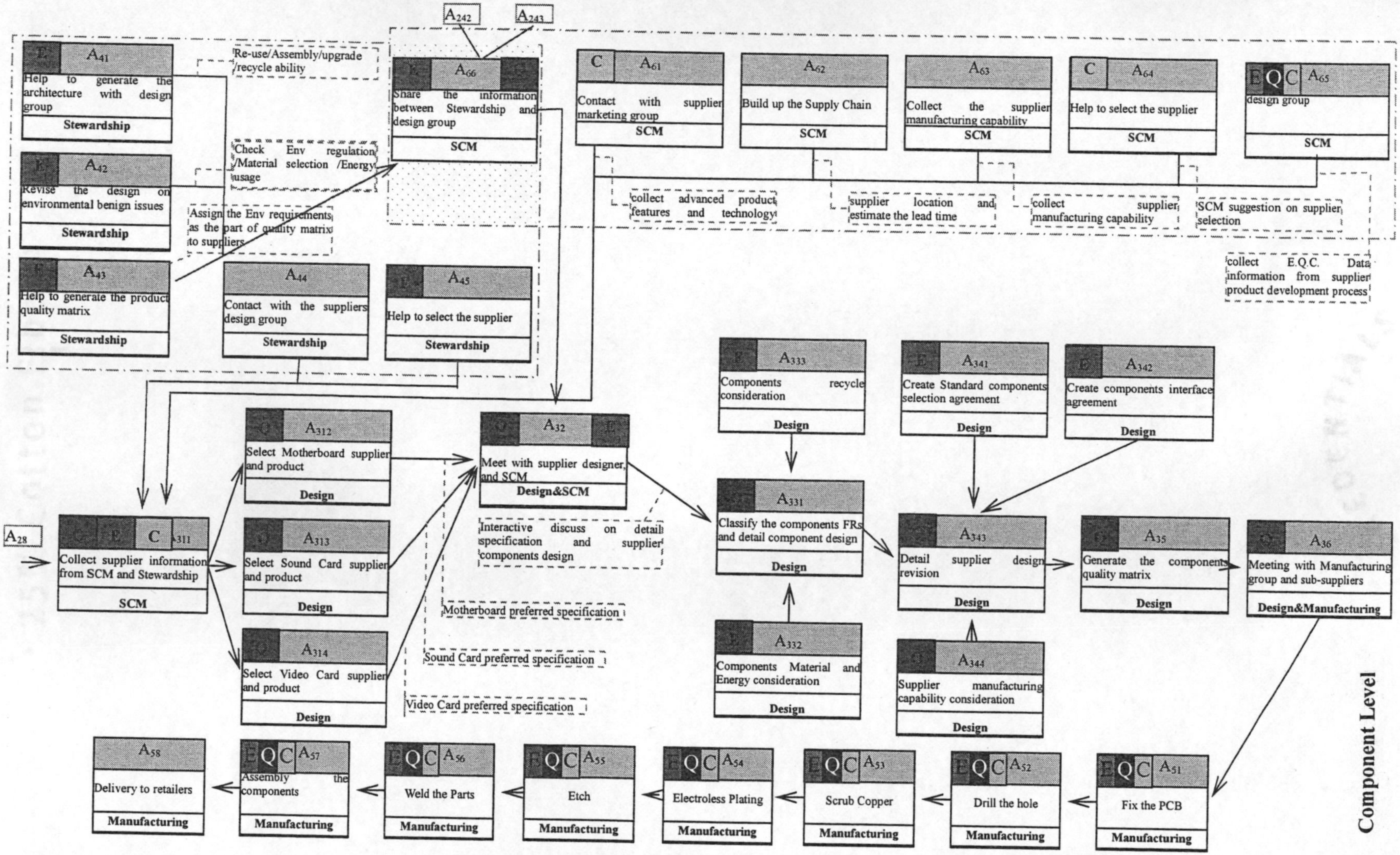

Figure 5.8 Activity Roadmap of Interaction Strategy IV (Continued)

5.4 Collect Data

The detail data can be collected from the activities of components manufacturing process as the following tables:

Interaction Strategy I.

Component	*Model*	*PCB Area (cm^2)*	*Waste Water (g)*	*Waste Copper (g)*	*Cost ($)*	*Quality db/Billion texels/sec*
Motherboard	D925XE BC2	594.58	14998.86	202.16	92.11	100/5.6
Video Card	Geforce6 800	43.07	1086.49	14.64	95.37	
Subtotal		637.65	16085.35	216.80	187.48	

Table 5.5 Calculation E.Q.C. Performance of Interaction Strategy I

Interaction Strategy II.

Stewardship Group is independent for information sharing with other groups.

Component	*Model*	*PCB Area (cm^2)*	*Waste Water (g)*	*Waste Copper (g)*	*Cost ($)*	*Quality db/ Billion texels/sec*
Motherboard	D845G VSR	486.73	12278.24	165.49	76.19	106/4
Audio Card	Audigy 2 ZS	36.61	923.65	12.45	28.31	
Video Card	GeforceFX5600	40.32	1017.23	13.71	66.35	
Subtotal		563.67	14219.11	191.65	170.84	

Table 5.6 Calculation E.Q.C. Performance of Interaction Strategy II

Interaction Strategy III.

Stewardship Group shares the information with SCM and communicates with suppliers directly

Component	*Model*	*PCB Area (cm^2)*	*Waste Water (g)*	*Waste Copper (g)*	*Cost ($)*	*Quality db/ Billion texels/sec*
Motherboard	D845G VSR	486.73	12278.24	165.49	76.19	108/5.6
Audio Card	Audigy 4	40.39	1018.81	13.73	35.35	
Video Card	Geforc e6800	43.07	1086.49	14.64	95.37	
Subtotal		570.19	14383.53	193.86	206.90	

Table 5.7 E.Q.C data for Interaction Strategy III selection

Interaction Strategy IV.

Stewardship Group shares the information with SCM and communicates with suppliers indirectly.

Component	*Model*	*PCB Area (cm^2)*	*Waste Water (g)*	*Waste Copper (g)*	*Cost ($)*	*Quality db/ Billion texels/sec*
Motherboard	D875P BZ	596.46	15046.22	202.79	120.13	100/1.2

Table 5.8 E.Q.C data for Interaction Strategy IV selection

5.5 Comparison of the Performance Evaluation Results

To compare the four interaction strategies, I show the difference by Environmental Impact, Cost and Quality Chart.

Some assumptions are made:

1. In the computer manufacturing process, many substances will bring the damage to the environment. In my case study, I assume the waste water and waste copper is more harmful than the other hazard substances. Only the water waste and waste copper are analyzed during the PCB manufacturing process as the environmental impact.
2. I didn't assign the water waste and waste copper to the different priority levels. I assume the priority levels of the waste substances are all the same, so I could sum them together to calculate the environmental impact in the quantitative number.
3. The components from the supplier maybe not the best alternative. I just randomly select the suppliers and the product to show how my method and theory work in the case study.

From Figure 5.9-5.11, I plot the interation strategies data on the figures.

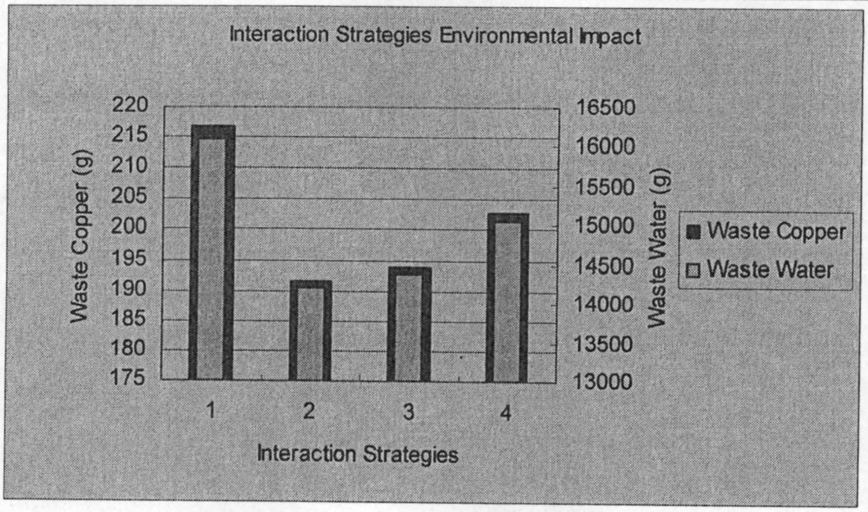

Figure 5.9 Environmental Impact Result Data Chart

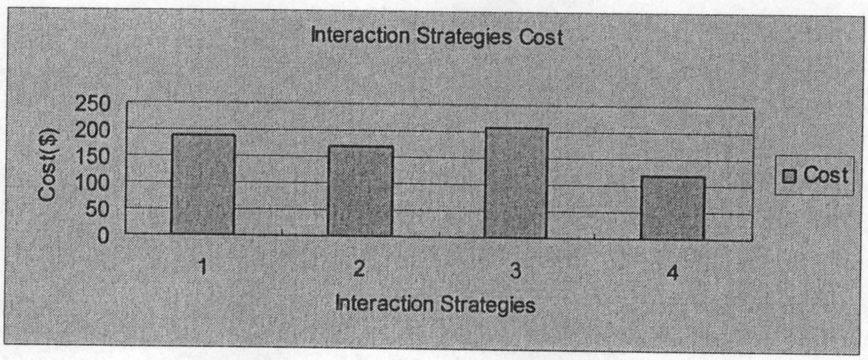

Figure 5.10 Cost Result Data Chart

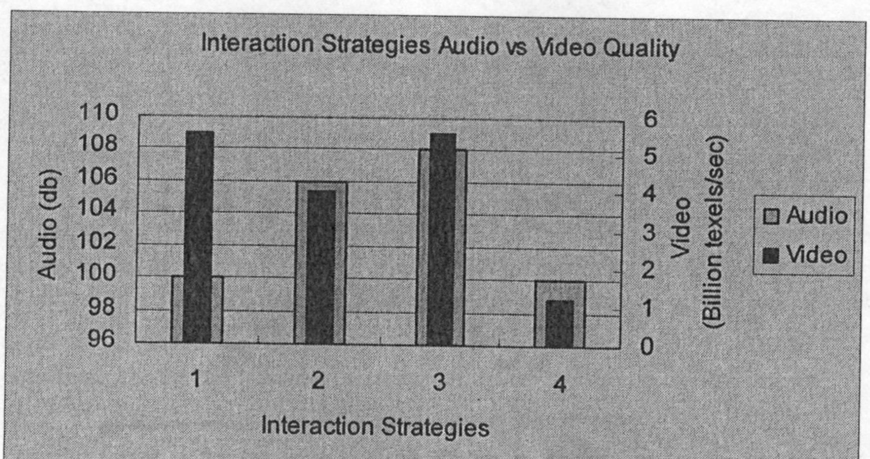

Figure 5.11 Quality Result Data Chart

To select the best solution of the components integration on E.Q.C. consideration, I generate the selection matrix for the comparison. In the matrix, the design solutions from the interaction strategies are assigned the ranking number for E.Q.C. performance. The ranking number from 1 to 4 means the best to the worst. Based on the above E.Q.C. Chart of different interaction strategies, Table 5.9 is the interaction strategies selection matrix.

	Environmental Impact	Cost	Quality	Overall
Interaction Strategy I	4	3	3	10
Interaction Strategy II	1	2	2	5
Interaction Strategy III	2	4	1	7
Interaction Strategy IV	3	1	4	8

Table 5.9 Interaction Strategies Selection Matrix on E.Q.C.

From the last column of Table 5.9, the ranking of interaction strategy II has the lowest ranking results. That means this solution has the best overall evaluation value on E.Q.C. performance. This solution reaches the optimal point among the alternatives in this problem decision space. In the matrix table, the optimal interaction strategy is highlighted.

CHAPTER 6

Conclusion and Future Work

With the growing consideration on environmental issues, the concurrent industrial developer companies are seeking a better solution to achieve the environmental benign requirements of the society and customers. Many design and management tools are developed for this purpose, why are the product developers still not satisfied? The key point is the monetary benefit and the quality of the product can not be ignored, or belittled. This calls for the model which can present the E.Q.C. consideration simultaneously in the product development process. Based on the Activity-Based model of Bras, I used the quality and quality driver to make the model more powerful- Three View Activity Based Model. The integration of quality and quality driver are the core parts of this new model. The quality driver makes the quality quantitative and makes the evaluation of E.Q.C. possible. This fulfills the business companies' real needs.

After the activity and the property of the activity are identified, the activities will be organized as the network, they are linked to each other as a roadmap. Then the information overlap and interaction strategy are introduced. That is the problem most developer companies are facing. They realize the difference of the interaction strategies makes the final E.Q.C. performance different. But they don't know a clear reason and how E.Q.C. performances are influenced by the interaction strategy. To solve this problem, the new three-view activity based model is presented and the evaluations among the different strategies are made.

Through the E.Q.C. drivers, the E.Q.C. data are collected from the product development process and suppliers to make the final evaluation.

From the above case: study evaluation process, the E.Q.C. three view activity based model and the evaluation methodology demonstrates their value.

In the future, to make this research go further, I should put my attention on the following aspects:

1. In my thesis, I just pointed out that overlap may cause the different interaction strategies, and the different interaction strategies make E.Q.C. performance quit different. In other words, because different information is passed on in different interaction strategies, the designers make different design decision. But how much the E.Q.C. performance will be changed by the specific information is altered by the different interaction strategy? If we can realize this point, we may put my research on information level instead of the combination of information – interaction strategy level.
2. So far, I can't find a good industrial partner to apply my model

and method in the detail product development process. In my case study, I can't find the detail manufacturing and design phase data. Some imagination exists.

3. To simplify the case study to allow the reader to follow the problem solving process easily, I didn't identify and take all of the E.Q.C. drivers. If we want to make the application more realistic, we could select all the E.Q.C.

CHAPTER 7

Contribution

In my thesis, I try to identify the problems from a industrial developer company when they try to improve the efficiency of their environment special program, like Stewardship. In my investigation, the difference of information overlap between the groups makes the interaction strategies. First of all, I collect the possible information on E.Q.C. in every group. To carry on the information, I define the Activity as the carrier. Then the Three View Activity Based Model is developed, quality consideration and quality driver are involved. The problem is presented by the activities and the model. Under the help of the model, I use a computer developer case study to show how my model and evaluation method works. The model and method I developed is not very mature, but I am trying to present my new idea and progress, and I hope this idea will bring more inspiration on this topic.

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