Analyzing Sustainable Product Development processes in Fuzzy Front End Stage

Course Title:	Front end management for New product development
Course Number:	ETM 543/643
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Term :	Fall
Year:	2015
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ETM OFFICE USE ONLY
Report No.:
Type: Student Project
Note:

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Abstract

This is a study on the importance of including sustainability at the fuzzy front end (FFE) stage in new product development process. Sustainable design is a design philosophy that seeks to minimize or eliminate negative impact to the natural environment through skillful and sensitive design. The importance of including sustainability at the fuzzy front end includes but is not limited to early tackling of barriers, enabling doing the right things versus doing things right and providing a platform to tackle sustainability problems at a higher system level.

This study also analyzed tools for implementing sustainability at the fuzzy front end. They include, decision matrix, Eco compass, strategy list, cost analysis, creativity techniques, rules of thumb, expert rules etc. A survey was carried out to understand how organizations' perceive sustainability; if these organizations include sustainability in their new product development process and most importantly if this implementation is done at the fuzzy front end. The survey results suggests that organizations are aware of the importance of including sustainability in the new product development process; however, implementing sustainability at the fuzzy front end is moderate. A framework was developed based on the literature review and survey to implement sustainability at the fuzzy front end.

1.Introduction

In our current world with growing population and limited resources to fulfill everybody's needs, sustainability will play a big challenge in the future. The concept of sustainability is not just about going green and saving our environment; it's about attaining a dynamic equilibrium between human and the resource utilization not compromising on the quality of life. In order to achieve this, companies, manufacturers, engineers, designers, who play a major role in product development, must hold their hands together, to move our society towards a sustainable and smarter society having better quality of life.

The starting point of a product innovation process prior to product development phase is termed as front-end innovation, in which idea genesis, opportunity validation, and concept development takes place and crucial decisions about a new product are taken. The literature shows that these initial phases in product design process has huge impact on the final outcome of the project. The point here is, in order to bring sustainability into product development, right measures has to be taken in these initial phases of product design process. Though front end and sustainability are two hot research topics, we could find that very less research is done on integrating them together. Also, we could find this practice is flawed and not many companies are thinking too early in incorporating sustainability in their front-end [6].

The proposed study aims at analyzing the sustainable product development process & tools in the fuzzy front end stage of stage of new product development, aiming at the following objectives.

1. To understand the effectiveness of sustainable product development tools in the front end stage.
2. At which stage do the companies in manufacturing sector incorporate sustainability considerations?

In order to achieve it, we have done literature review and case studies on key work published in the sustainable product development domain related to the front end processes. The case studies helped us to know the effectiveness of each techniques in product development. Finally a survey was designed and sent out to product development managers and senior leaders in the automobile, semiconductor, apparel, energy sector in the US to understand the influence of the sustainable processes and its role in the front end of their company. The questions in the survey are provided in the Appendix A. The whole of our approach used in research can be pictorially represented as below.

Figure 1: Methodology used for research

The remainder of this paper is structured as follows. We begin by giving some background study on the researches related to our topic in Section 2. We then describe the survey results in section 3. Analysis of our literature study and results obtained based on the survey conducted is described in section 4. Section 5 has conclusions on our key findings from conducting this research. And finally in section 6, we have mentioned the limitations and future research plans.

2. Literature Review

The early stages of literature review focused on understanding SPD (Sustainable product design) principles, significance and the importance to incorporate this concept into the front end. After understanding the background of this concept further literature review was conducted by reviewing the journal papers and case studies related to the following 3 areas in SPD as shown in fig. 2:

- Organization strategy/Business opportunity identification
- Framework
- Tools

This was done to help identify the key process and tools that could be used in the front end stage.

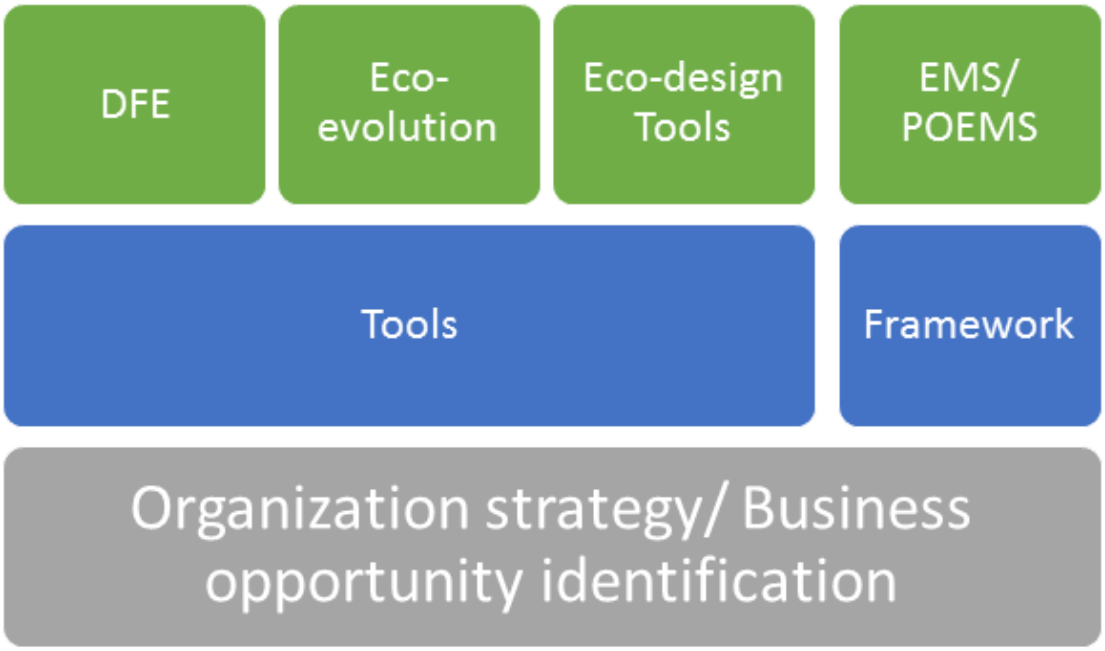

Figure 2: Literature review areas for SPD process/tools

2.1 Sustainable Product Design

Sustainable product design concept has emerged as a guiding paradigm for designing environment friendly products and processes. McLennan [1] defines Sustainable Design as a design philosophy that seeks to minimize or eliminate negative impact to the natural environment through skillful and sensitive design. The three pillars of sustainability are people, planet and profit. This concept is also known as the triple bottom line shown in Figure 3. Sustainable product design concisely aims to address all these pillars in a balanced way to improve not only the environmental aspects but also the social and

economic impacts of products, systems and services. [2]. It is not necessarily about new technologies but about ‘rethinking’ on how to meet the need for growth while reducing negative environmental and social impact. [3]

Figure 3: Triple bottom line

The basic objectives of sustainable product design is to reduce consumption of non-renewable resources, minimize waste and create healthy/productive environments. The scope of the design is far-reaching and not limited to a specific profession or discipline; for e.g. construction, consumer electronics, industrial products, manufacturing and industrial processes etc.

2.2 Significance of Sustainable product design

The explosion in global population is perhaps one of the greatest reasons why sustainable development is so important. As the world population rapidly grows, it has become more apparent that natural resources are limited and need to be used in a viable manner. Sustainability is, therefore, no more a luxury but a need.

Sustainable design addresses surrounding environmental parameters when devising plans, programs, policies, buildings or products. In addition to the environmental benefits, other factors for initiating sustainability is that it improves the image of the company and its products, which can result in better sales. Secondly it pays, because reducing material and energy consumption, as well as waste and contaminants, saves money. In addition, it is an investment in the future because it improves innovation capabilities and long-term success strategies [4]. Consumer awareness of suitability issues drive the demand for sustainability. The requirements of the designer to consider the three pillars in the design process has resulted in ‘sustainability’ as a standard in product design.

2.3 Importance of sustainable product design in the Front End Stage

In order to develop an efficient and successful product, high-quality up-front analysis is crucial. In view of sustainable product innovation, most front end literatures doesn't explain quite well on how to integrate sustainability in early stages of product development. But actually in practice, it is flawed. There are several tools available to guide designers, engineers and managers in the design process when the product specifications are set, but none occupy any link to sustainability design. Listed below are the key points supporting why integrating sustainability in the front end is vital [5, 6].

Tackling sustainability problems at higher system levels: According to Brezet's model of 'eco-design innovation' [5] outlines 4 types of environmental innovation, categorized by product improvement, product redesign, function innovation and system level innovation, which agrees to the environmental impact reduction or eco-efficiency that can be achieved. The first two stages: product improvement & product redesign focuses on lower system levels and delivers small to moderate improvements in environmental sustainability. The next stages: function innovation & system level innovation focuses on function and system innovation and deliver significantly greater system improvements in environmental performance. In order to tackle problems at higher system levels, the problem needs to be already integrated in the Front End, as the resources are allocated and design space is very limited[6].

Greening the design brief: A design brief is a written description of a project that needs some form of design. It can be an agreement, or contract between the parties involved in the project or a point of transfer between different professionals, where the project is handed over from marketing to design, or from a product manager to an in-house design team or external design agency. It acts a project tracking tool which defines the next steps to be followed [7, 8]. Its primary role is to provide a base to the whole design process and also a report or summary of the examinations and the decisions taken in the front end [6].

Commitment and allocation of resources: Decisions taken at front end have a major influence on all subsequent phases of the innovation process as resources are allocated mainly during the front end phase. The final approval at the end of the front end is usually a formal go/no-go decision, which determines whether the organization will invest on a project and how much they will invest, also allocation of other resources like people, time etc. It is also a vital point to incorporate sustainable design opportunities, as its success majorly depend on the previously allocated resources. Otherwise, the overall sustainability is doomed to fail with insufficient resources [6].

Early tackling of barriers: Several external and internal drivers and barriers play a major role in sustainable design, which have their roots in the front end process and so right actions in the FE can tackle such barriers. For instance, executing an early financial and environmental analysis helps in making the benefits clear, another barrier is lack of understanding of sustainability and sustainable design tools, which can be tackled by providing proper education, relevant and reliable information to various stakeholders involved in the process [6].

Front-loading: In the front-end stage, the degrees of freedom and influences on the project outcome is very high with little information available and low cost of changes. Gradually, more information is available towards later stages in the process with increasing cost of change. And it is under these circumstances, fuzzy front-end team have to make their decisions. Due to these factors, dealing with sustainability in the front-end of a product innovation process is often called 'wicked'; or multidimensional with a complex interdependency. In order to deal with this wicked aspects, they have introduced the method 'front-loading'. It is a strategy that seeks to improve development performance by shifting the identification and solving of problems to earlier phases of a product development process" [9]. In other words, one would spent more time and energy in the front phase for environmental analysis and strategic design to get more information so that influence is high and the cost of change is low [6].

Doing the right thing vs. doing things right: To make sustainable design successful, it requires both strategic (front-end) and operational (new product development) activities [10]. This is why sustainability aspects are incorporated already into the front-end activities of the innovation process in order to be considered at a strategic level [11]. The operational level focuses on eco-efficiency or doing the things right, on the other hand, the strategic level focuses on eco-efficiency or doing the right thing [6].

2.4 Sustainable Product Design Principles

Sustainable companies reflect a balance of economic, social and environmental responsibilities. The companies determined to factor in the sustainable design into long-term product innovation strategies strive to alleviate the negative environmental, social, and economic impacts along a product's supply chain and through its life cycle, as endorsed by cradle-to-cradle approach. [2]. It is a process involving collective efforts of designers, suppliers, manufacturers, sales and service professionals, and consumers to integrate 'sustainability' into the life cycle of product including design, manufacturing, marketing, distribution, consumption and disposal. The common principle of sustainability [3, 2] are explained in the section below.

1. **Renewability:** Renewability is a key principle of sustainability in a product process integration, and it describes the special technology properties. It should also be a useful and helpful guide to the design team to ensure that nothing goes to "waste and harm" during the product's design and development.

2. **Low Impact Materials:** This principle drives the need to use materials that are nontoxic, produced in sustainable fashion or recycled, and require little energy to process. For example, in earlier days, a writing pen would be made of plastic but these days, sustainability is driving companies to manufacture these pens using recycled paper.

3. **Energy Efficiency:** Manufacturing processes, equipment, tools, and facilities, which require less energy. Designers should pay more attention to this principle as global population increases is pushing the envelope of the need a design to be 'energy-efficient' more towards a requirement.

4. **Reuse and Recycling:** Performance in a commercial 'afterlife' should be designed into products, processes, services, and systems. When products reach the end of their life cycle, it should be possible to recycle or reuse them.

5. **Durable design:** This involves increasing the durability of relationships between people and products, through design in order to reducing consumption and waste of resources.

2.5 Organization Strategy & Business Opportunity Identification

2.5.1 Corporate Vision

The need to design for the environment cannot be overemphasized. In fact, green design is now the driving force within many firms. For example a concept known as the design for disassembly (the technique by which products can be taken apart after use for separate recycling of metal, glass and plastic parts.) is being employed by major car manufacturers. The gap between good intentions and execution is the predicament that managers who want to do the right thing environmentally but are under pressure to make profits face (especially when the economy is weak). There is therefore a need for strong support from top management. A case study of Philips Sights and sounds [17] gives a detail of how they

have incorporated environmental concerns in their new product development. The key highlights from this initiative made in this firm are:

- Philips [17] have started developing a methodology for innovative, more eco-efficient product design strategies.
- The experience gained shows that this methodology highlights the need to integrate environmental issues in the product planning process as early as possible. Where else is as early as possible than at the fuzzy end?
- Steps taken include incremental environmental improvements of existing working products and services at the operational level.

The driving Forces include:

- Formulation of corporate environmental policy by the CEO of Philips
- Growing public pressure to find socially responsible ways of disposing of used consumer electronics goods
- Regulations concerning the use of certain chemical substances

Philips also designed a development manual and it included the below key points:

- Material Use: The primary objective is weight reduction and a reduction in the amount of end of life [17] waste
- Hazardous substances: Classify hazardous substances using the EACEM(European Association of Consumer Electronics Manufacturers) standard
- Industrial Processes: Consciously reduce the use or completely eliminate the use of known harmful substances like CFC(Chlorofluorocarbons)
- End of Life: Make rules for disassembly friendly construction; plastic compatibility rules.
- Energy-use: provide information and directives about energy use in both operational and standby modes
- Environmental design evaluation: Evaluation design is based on environmental weight, end of life costs and environmental release criteria to be used.

In order to move towards sustainability, firms and other stakeholders need to rethink the way they operate and the function of their products and services [17]. There is a need to move through the four step model in order to achieve significant resource and energy reductions and generate breakthroughs.

- Re-Think the way they operate and function of products and services e.g. creative problem solving and opportunity seeking.
- Re-Design existing product to incorporate environmental factors
- Re-Fine eco-efficiency by reducing resource conservation whilst adding value and reducing costs.
- Re-Pair by dealing with end of pipe solutions. Most companies are at this stage.

A key requirements for companies to achieve sustainability is to rethink the way they operate. In addition, companies need to re-evaluate the way they consume for example substitute products for services (e-book instead of hard copy books). Green product innovation refers to either new product design or delivery that reduces negative impacts on the environment.

The environment has been on the public consciousness more than ever before and many companies are seeking solutions on their own [17] to incorporate "green" concerns into their activities. The increasing attention on the environment can be attributed to the media and the U.S Environmental Protection Agency which has established a detailed climate policy. Developing environmental friendly products is gaining importance and firms that have ignored the environment for so long are now forced to develop policy on its inclusion [18]. Public policy debate on new products as it relates to environmental concerns and needs is on the increase. A new product is said to hurt the environment if the following occurs:

1. Scarce raw materials
2. Manufacturing or design causes pollution or excess power usage
3. Usage causes pollution
4. If any disposal problem cannot be handled by recycling.

In conclusion, "firms are seeking to act in a socially responsible manner by including "green" concerns in their product development activities. Consumers and Stakeholders demand it and increasingly the government measures are requiring it" [18].

2.5.2 Environmental Strategies

A case study on the European electrical and electronics industry was looked into to understand the strategies used in the **eco-design** process [12]. The key element of the eco-design is the incorporation of the life cycle thinking and tradeoff considerations throughout the life cycle of the product. The process also helps in integrating the environmental issues during early design process in addition to the product development and continuous improvement cycles of product design. This is done by integrating tools such as life cycle assessment, other assessment tools, and integrated software tools.

This methodology of eco-design has embedded in it the following key Eco design strategies:

- Selection of low impact material
- Reduction in materials usage
- Optimization of production techniques

- Optimization of logistic techniques
- Reduction of impact during use
- Optimization of the initial life stages – design for upgrade and reuse
- Optimization of end of life systems
- New concept development
- Combination of strategies

One of the other research that has been done for strategies to be used in the sustainable product development area was by O.J. Hanssen [13]. He stresses on the below key points to be incorporated into the strategy to help achieve sustainability with respect to product development:

- Eco-effectiveness (sustainable) as a measure for environmental improvement of product systems as an alternate to eco-efficiency.
- End of pipe solutions in industrial processes to preventive solutions, through cleaner production.
- A change from process oriented environmental actions towards more product-oriented approaches.
- A change from an open life cycle approach(cradle to grave) to an approach with closed material and energy cycles (cradle to cradle)

Hanssen [13] has developed a systematic structure for improvements in environmental and resource efficiency with four main strategies for improvements:
- Reformulating user requirements, to find new innovative solutions beyond the scope of today's product systems.
- Improvement in the performance of the product systems, in relation to user requirements
- Substitution of the whole product system, or substitution/elimination of parts of the system (subassemblies, components, materials or suppliers)
- Optimization of the processes and operation of each system unit(raw material acquisition, raw material refining and processing, manufacture, use and maintenance of products, all types of transport, energy production, waste treatment) or in the interaction between system units(transport, recover rates of materials)

From the organizational infrastructure standpoint companies adopt different strategies to initiate the sustainability and make it a way of day-to-day execution. Jennifer R. DuBose [14] presents a case of company Interface Inc. that made strategic commitment to sustainability and integrated it with the incentive bonus plan. Other factor that contributed in giving concert direction to company's sustainability mission were top involvement, recommendations and leadership, input from outside expert consultant in the field of sustainability, Training the staff and financial scrutiny.

2.5.3 Green Product Portfolio

The green product portfolio is helping with identifying sustainable product development functions instead of only improving the products with respect to eco-design principles. With the help of green product portfolio a firm can develop products that meet sustainability principles and thus maintain a competitive position in the market. Green product portfolio management deals with lot of factors ranging from market trends to capacity utilization of machinery, and also help incorporate sustainability concepts [30]

Incorporating classical Eco-design methodology into Green Product Portfolio management help bring out additional options for sustainable innovations. Identifying options for such innovations takes place in the fuzzy front end of the new product development process. The paper brings out three important observations [30]:

- Previous research has largely neglected developing methodology for developing products with a sustainable function;
- Previous research does not address the problem of how companies should determine which product development strategies are most appropriate to their existing needs and wishes to profile themselves as companies active in sustainable product development.
- These 2 key concepts are currently missing from product development courses.

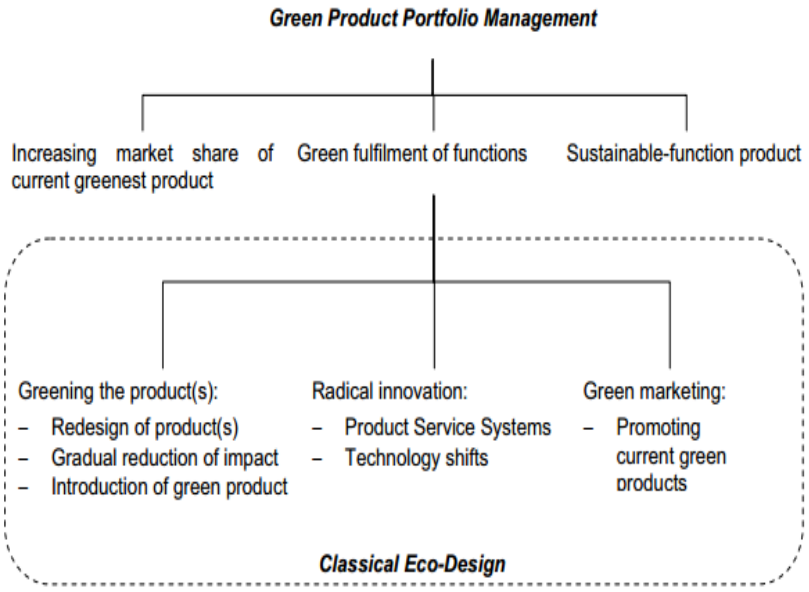

Figure 4: Topologies of strategies open to companies wanting to green their product portfolio [30]

2.6 Framework

This section discusses various sustainable product development frameworks available and popular in industry. The most efficient one is the Environmental management systems, which is a set of processes and practices that helps an organization to decrease its environmental impacts as well as to increase its operating efficiency, through continuous review, assessment and enhancement of its environmental performance.

2.6.1 Environmental Management Systems (EMS)

- The implementation of ISO 14000 [19] series may provide a good framework for environmental product improvement.
- The ISO standard on environmental management may influence the behavior of companies as regards the environment.
- ISO doesn't intend to set an absolute standard; but hopes that companies will strive to include environmental improvements in their products in order to increase market share.

The ISO series can be a good vehicle for increasing the environmental awareness within companies. They can enhance continual environmental improvements of both processes and products.

ISO 14001 standards and EMS requirements

The standard is used to track and control environmental aspects that are influenced by the organization. It does not specify environmental performance criteria but how to deploy an EMS system. Worldwide adoption of the standard as of 2008 and the top countries adopting these standards is provided below:

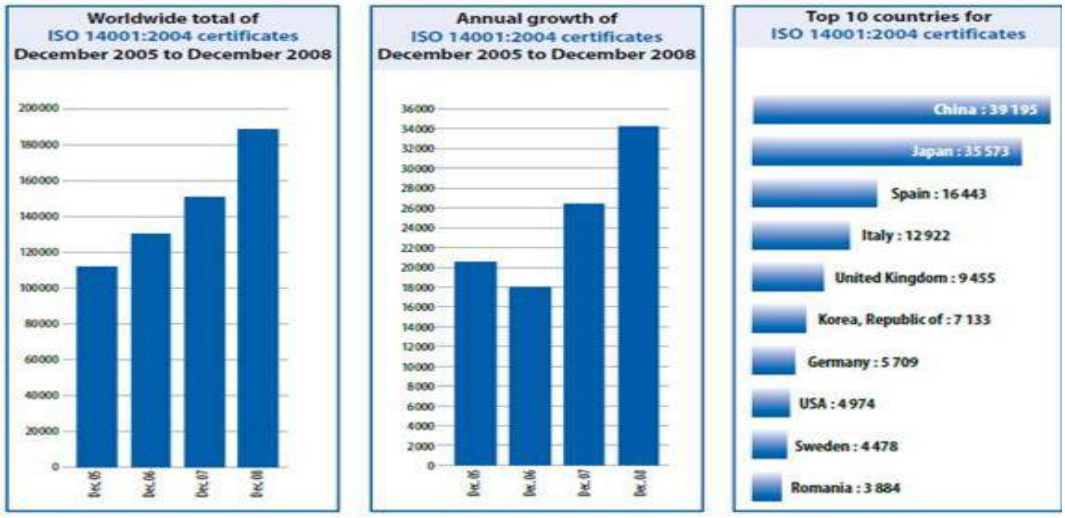

Figure 5: The ISO 2008 survey results for the ISO 14001 standard. [23]

The standard differs from the IS0 14000 standard as the ISO 14000 standard provides information on the environment management series but the ISO 14001 has more details on the Environment management system requirements. The details on the ISO 14000 standards for environmental management systems are:

- ISO 14000 refers to the environmental management standards series.
- ISO 14001 environmental management system standard should be used along with ISO 14004. ISO 14004 provides further guidelines for the elements of an environmental management system and its implementation.
- An ISO 14001 environmental management system (EMS) is a structured system designed to help organizations manage their environmental impacts and improve environmental performance caused by their products, services and activities. An environmental management system provides structure to environmental management and covers areas such as training, record management, inspections, objectives and policies.

The EMS process helps with continuous improvement of the system and the environmental performance as provided below:

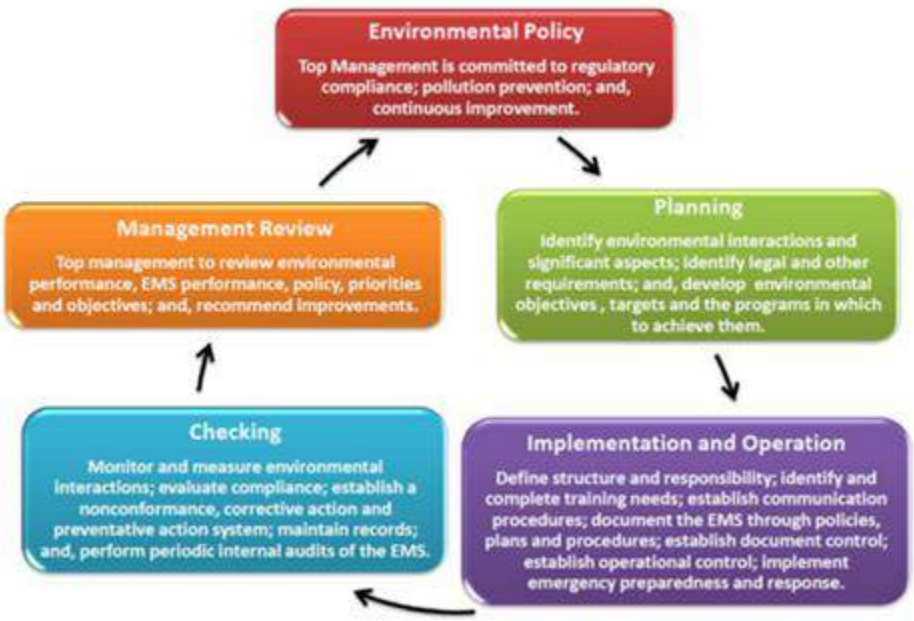

Figure 6: Environmental management system: continuous improvement cycle [23]

Some of the key tasks that needs to be done prior to implementing the EMS system is to:

- Identify an individual to help coordinate the different task,

- Organization should have an environmental policy that reflects its commitments,
- Understand the interaction between the organization and the environment,
- Identify the environmental impact and a review of the system and the environmental performance. [23]

Product Oriented EMS [24]

The concept of having product oriented EMS systems is to incorporate the management of environmental effects of products into the EMS structure as for manufacturing firms the flows of materials and energy related to products are the most important. Combining DFE (Design for Environment) and EMS principles help incorporate this as it allows to:

- Brings in a life cycle perspective. This will also help complement the mainly facility oriented legal requirements and authority control
- Incorporating the DFE principles into the EMS will make it more of a continuous improvement rather than a pilot project character
- It can help in successful cooperation both internal and external to the organization.

Model for POEMS:

- The below process is described in a method targeting the first implementation of the system in an organization. It can be implemented in organizations with or without an existing EMS.

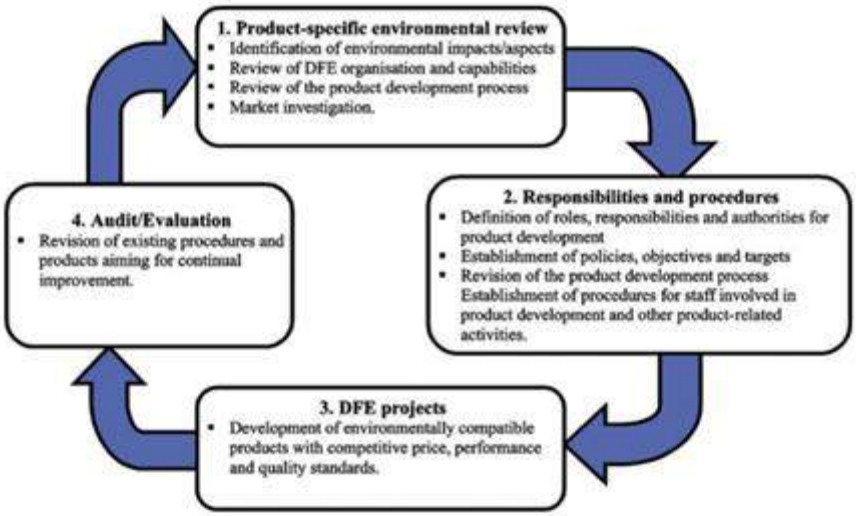

Figure 7: Product oriented EMS [24]

Steps 1: Product related environmental aspects are reviewed. This review involves the product life cycle and helps to include key stakeholders from the supply chain, which is not done in a normal EMS. In this stage the organizational aspects of DFE should also be

done to help understand the capabilities and weakness of the organization and include a further investigation and understanding of the product development process. A key outcome of this stage that can help further steps is if both the above analysis help reveal information of existing and future markets.

Step 2: Resources for the product development, incorporating the environment design parameters should be done at the beginning of the design process and handled as any other design parameter. Senior management support should be obtained so that the corporate visions, strategies and policies are in line with the intentions of the environmentally adapted product development process.

Step 3: Is the operational level. The projects should use the guidelines developed in stages 1 and 3 while executing product development. This step can include many parallel projects contradictory to traditional EMS which generally focused on single product development.

Step 4: Is a critical step to make sure that the audit procedures and methods should help with continually improve the product-related environmental performance.
As the results on POEMS are scarce. But the limited study that has been done shows that there are four levels of important factors influencing to what extent the EMS and DFE activities are integrated.

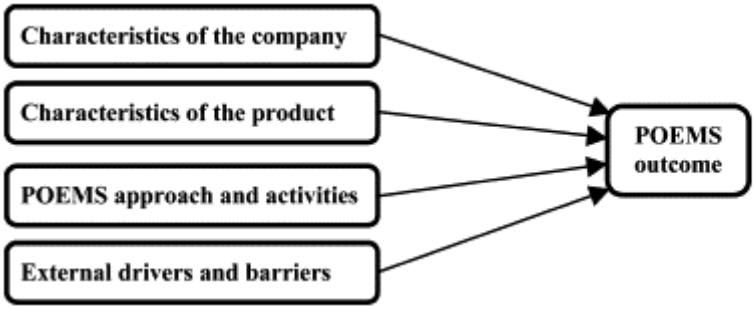

Figure 8: Product oriented EMS [24]

The details on each of the above factors are:

Characteristics of the company: The key influencing elements in this category are related to company structures, systems, cultures and attitudes, human and economical resources and the amount and quality of available information.

Characteristics of the product: Understanding of the products influence on the environment is very critical and different products have different influence on the

environment. With respect to their influence the range of alternatives also differs. A study by Hubka and Eder [25] has classified the properties into different classes and similar understanding of the developed product can help make the right decisions towards sustainable product development.

POEMS approach and activities: This related to the characteristic of the company and mainly deals with at which stage the environmental issues are considered, what reviews, checkpoints, environmental milestone questions are introduced.

External drivers and barriers: This is the most critical factor and includes the external environment in which the company operates. The main factors that can influence the effectiveness of this system are: business market and the societal environment. In addition to the stakeholders in the supply chain, factors such as auditors, authorities, banks, competitors, insurance companies, media, politicians, shareholders can have a critical influence.

2.7 Tools

2.7.1 Tools for Eco-design and Sustainability

Eco-design and sustainability tools and techniques are required to implement sustainable development in a company. Several eco-design tools have been proposed and developed, ISO-TR 14062 suggests the use of 30 various tools [16] that differ in several ways: 1) they have been developed for different purposes, and 2) they are structured in different ways. The structurally categorized tools are further classified into three categories: tools based on checklists, tools based on Life Cycle Assessment (LCA), and tools based on Quality Function Deployment QFD [16]. The purpose-based tools are intended for [4]:

- Analysis of environmental strengths and weaknesses.
- Priority setting and selection of the most important potential improvement.
- Provision of assistance for idea generation (brainstorming), design and draft.
- Co-ordinate with other important criteria like CBA, etc.

Since, in this paper, we are focusing on tools for fuzzy front-end development, we will discuss tools that provide assistance for idea generation, design and draft in more details. These tools help include appropriate environmental aspects in the product design and development.

o **Decision matrix**: This tool provides a way for the team to specify the most important improvement option/idea by asking the team for environmental improvements, technical feasibility, cost and customer benefits[4].

o **Strategy list:** This tool is used to improve or compare the environmental performance of a product concept(s). The tool consists of a list of suggestions for each phase (product manufacture, product use, product recycling, and product disposal, distribution) of the life cycle to improve the environmental performance [15]. The suggestions are based on the criteria such as optimization of material input, energy usage, reduction in amount of land usage, increase in service potential, reduction in pollutants, waste, emissions and health and environmental risks.

o **Spider web diagrams**: It is used for an estimation to decide between concept designs alternatives. The tool relies on a set of user-defined criteria for the estimation. For each solution, the tool makes a qualitative evaluation of the criteria and provides an environmental profile for each solution [4.15].

o **Eco Compass**: The e-compass technique is a comparative tool to evaluate one existing product with another or to compare a current product with new development options. The eco-compass has six dimensions: Resource Conservation, Health & Environment Risk, Revalorization, Service Extension, Energy Intensity and Mass Intensity intended to encompass all significant environmental issues. This technique is similar to e concept spider web. [15, 4]

o **Expert Rules and Rule of Thumb:** Expert rules and rule of thumb provide help to keep in mind general environmental criteria requirements[4] for design while generating ideas.

o **Creativity Techniques:** Creativity stimulating tools as Brainstorming helps the idea generation process by generating diversity of ideas[4]. Another technique, Morphological box, wherein an existing solution is broken down into elements/sub systems, e.g. product parts. For each element, different proposals are described and alternative solutions for the product are created by combining the proposals for each element [4, 16].

o **Cost benefit analysis: c**ost analysis tool is used to determine the costs that a product will incur during its development and production phase or the entire cycle and the associated profitability[4, 16]. Since there are a lot of uncertainties associated with FFE stages of product development. Outcome of such analysis is often a rough estimation of the profitability of eco-improvement measures by keeping account of the associated costs.

2.7.2 Environmental Benchmarking Tools

Product benchmarking is carried out in industry as a means of comparing products with those of competing companies and also as a means of gauging improvements in new designs [27]. There are several tools such as design decision support tools which can used to generate comparative data for benchmarking purposes. But the availability of strategies and analysis tools like eco design, Design for Environment (DFE), Eco-evolution enables environmental and disassembly measures to be incorporated in the product benchmarking studies.

In the paper [19], they have discussed experiences in moving the companies towards more sustainability through eco-design. According to Brezet, Cramer and Stevels [28], eco-design process involves four stages/levels: The first level involves incremental involvement of products, the second level is redesign of existing product concepts, and the third is the alternative fulfillment of functionality and new concepts or ideas, while the fourth deals with complete goals to move towards sustainable society. So when developing eco-design projects in organizations, it is very crucial to know the level of eco-design the company or business unit is aiming for. The paper discusses the experience of a division of a Philips and demonstrated how eco-design can be successfully integrated into current business operations of a company. Their research concludes several facts like: incremental improvement of environmental product attributes is an ongoing process on areas where eco-design can be linked to cost reductions, radical product re-design troubled due to lack of appropriate validation methods, intensive stakeholder dialogue essential for finding product alternatives and for its successful market launch, setting up of common goals essential to move society towards sustainability [19].

In the paper [27], application of a specific DFE tool to benchmarking is discussed and its effectiveness on several products are demonstrated. Design for Environmental tools enables organizations to include environmental metrics which includes disassembly and end-of-life disposition to the benchmarking metrics already in use. This would lead to identify best in class solutions for such environmental factors that are getting popular to companies in developing competitive products.

In the paper [29], the authors discusses and analyze the potential role of evolutionary theories in environmental innovation emphasizing sustainability. It also focuses on driving factors that adapts products to their changing environments. As a result a new strategy known as Eco-evolution strategy has evolved, which is based upon incremental innovation through re-examination of existent knowledge and technological trajectories. It attempts to identify the lock-in of non-optimal technologies and sustainable alternatives in order to plan sustainable design and organizational horizons. The paper concludes that eco evolution is an efficient strategy when non-optimal technological trajectories and sustainable innovation options are identified on existing knowledge base.

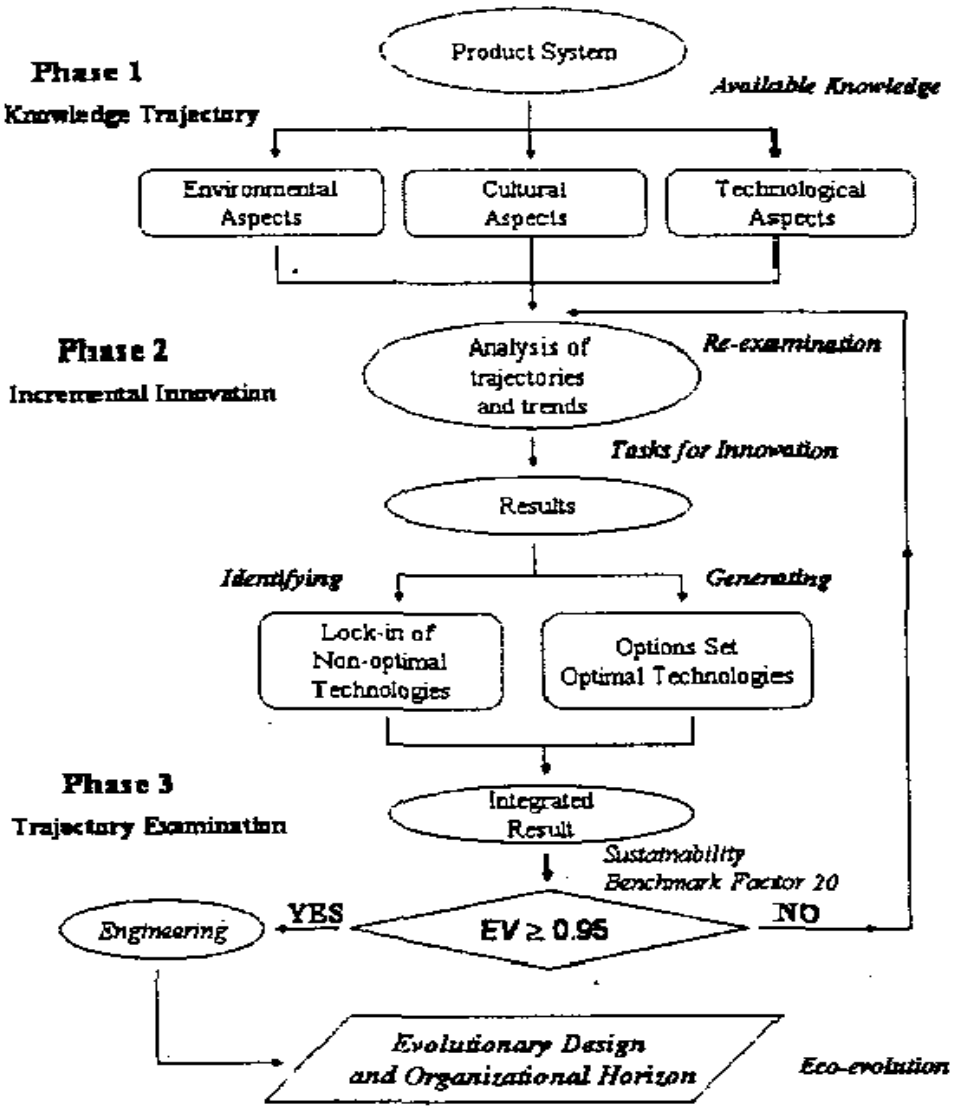

Figure 9: Eco-evolution strategy [29]

Eco-evolution [29] is an iterative process or strategy involving three phases or steps as shown in Figure 9. The first phase, knowledge trajectory, aims at compilation and analysis of information about a) technical b) cultural c) environmental aspects related to current product and system. The technical aspects include the product profile, the product life cycle, design evolution, technological development and life cycle cost. While the cultural aspects includes the regulatory framework, the market and, trends on consumer's preferences and requirements. And the environmental aspects include life cycle assessment and future analysis. Then the resultant knowledge trajectory is translated into a set of tasks for efficient delivery of function in line with dematerialization. In the second phase, incremental innovation, these set of tasks is analyzed in order to identify lock-in of non-

optimal technologies and to generate innovation options. The proposal for innovation establishes a potential horizon for the design evolution. Such a result is said to be incremental innovation. In the third phase, trajectory examination, *the* incremental innovation is evaluated against the sustainability benchmark to verify the potential level of improvement *or* Eco-evolution. To perform the analysis, a single indicator EV (Eco-evolution) is proposed. Its value varies between 0 and 1. For instance, EV=1 means that environmental impact categories identified during the initial life cycle assessment are *reduced* by 100% in the proposed innovation strategy. But, the theoretical level of sustainability in accordance with factor 20 implies that the total system impact is reduced by *95% [29]*. Therefore, *EV =0.95* agrees to a sustainable level of innovation if chosen impact categories are representative of the overall system's impact. If EV's value does not satisfy the benchmark, more analysis at the *second phase* of the strategy will be needed. If the assessment results are acceptable, a final engineering process aiming at managerial matters such as cost control and product marketing will be piloted prior to final execution [29].

Thus the literature review was done across the 3 main areas of SPD:

- Organizational strategy/business opportunity identification,
- Framework
- Tools

which can be correlated to the front end development process in the below manner:

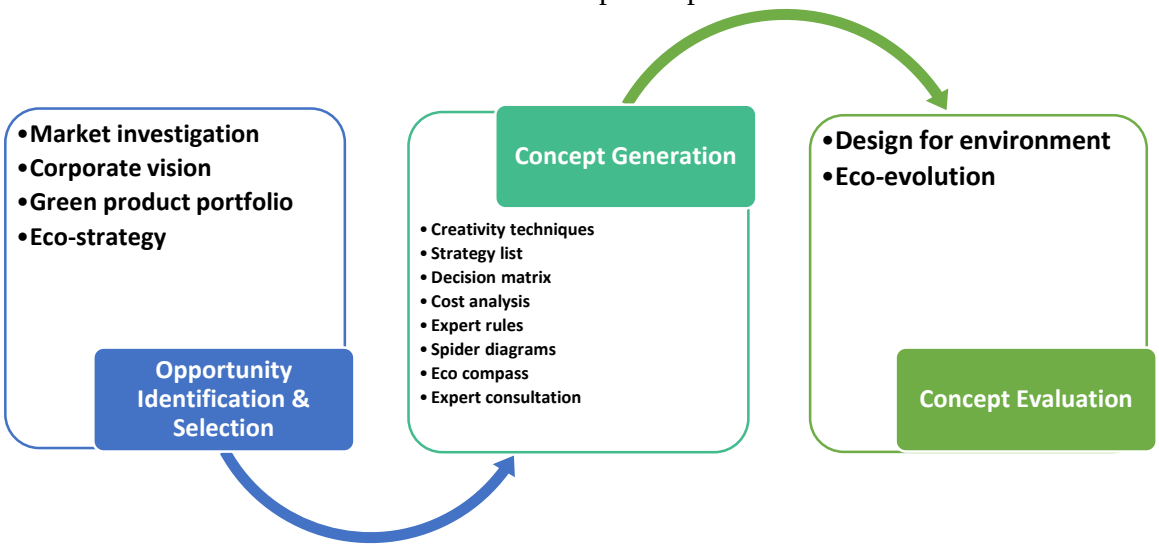

Figure 10: Literature review outcome

Using the above framework can help companies incorporate sustainable product principles in the front end stage of development. At the **opportunity identification and selection stage**, which involves different methods like - market investigation, to understand the future product development areas; corporate vision, to incorporate sustainability concepts

into the product development stages; green product portfolio, to develop sustainable product solutions. These methods will not only improve the eco-efficiency of a given product but also support the framework to cherry pick the best ideas for product development. Incorporating Eco-design as strategy will also help the company understand the requirements for the new product development in the context of reducing impact to the environment.

Based on the opportunities that are identified **concept generation tools** like creativity techniques, eco compass and expert consultation can help develop new concepts for product development. The new concepts will be developed in a more holistic way and will have the concept of sustainability also incorporated in the idea generation.

Once the idea generation phase is done techniques like eco-evolution and design for environment can help **evaluate** the ideas with respect to sustainability. This analysis can also be one of the inputs that is provided to the overall concept evaluation team to choose the product idea that can be funded for product development.

3. Survey Results

Product managers, Product owners and senior engineers from the field of manufacturing industry, particularly, semiconductor & consumer electronics, automobile and energy sectors participated in this survey. Some questions had fewer responses than others did because participants could chose to skip questions. 32 people responded to the survey. 88% percent people belonged to the target sectors while 22% percent respondents belong to other industries e.g. industrial electronics, healthcare manufacturing etc.

The below graph show the survey results across the target industries:

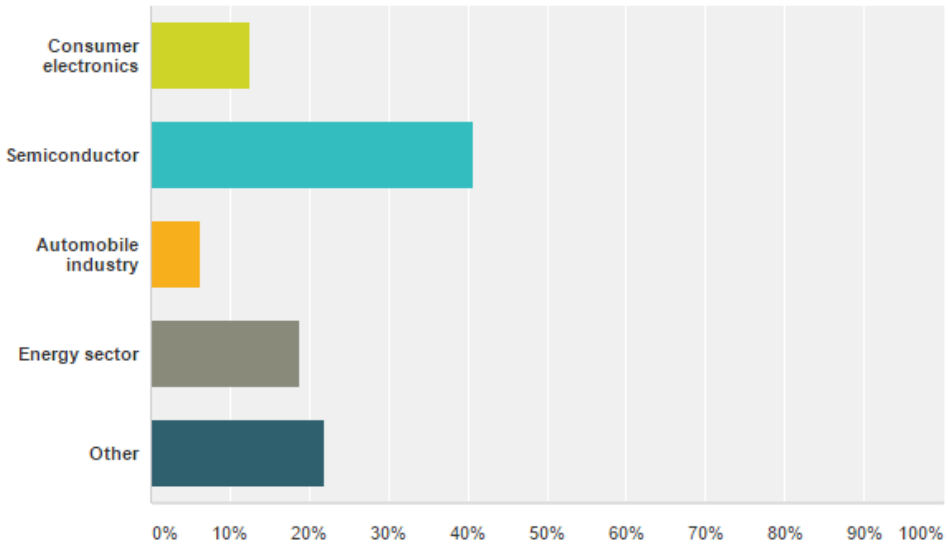

Figure 11: Survey results - Target industry

When asked if their company integrated sustainability at the vision/strategic level for influencing the process of product concept generation, 77.4% responded yes which shows that sustainability is part of the overall organizational strategy and an important consideration for product concept generation. Furthermore, 46% (13 out of 28) asserted the use of EMS environmental management systems. However, respondents choose not to name the current systems in use in their respective organizations. 68% percent (21 out of 32) participants voted that their organization followed ISO related standards to manage their environmental responsibilities. It is evident from results that companies are adopting the industry processes and standard in order to manage their environmental responsibilities.

The survey results highlighted that companies use many tools in different stages of product development lifecycle. It can be inferred from the response that brainstorming, Eco-compass, Cost analysis are the only tools used which can help FFE stage, whereas checklists(42%), LCA(32%), LEDS(32%), Lifecycle cost analysis(42%) etc. are used

widely which help in the later stages of product development. Literature advocates use of Spider web in FFE stages [4], however, it is not used by many companies.

A survey question aimed at collecting information about the stage in which companies are with respect to the four-step model (rethink, refine, redesign and repair), approx. 38% (11 out of 29 respondents) participants selected ‘rethink’ stage which is an initial stage in product idea generation where companies focus on the way they operate on product and services. 21% opted the refine, which is overlap between the early concept generation and design. The remaining 41 % participants chose redesign and repair stages that signifies later stages in product development.

In order to assess the stage at which companies integrate sustainability principles for product development, survey responses 50% selected ‘early product idea generation’ phase whereas the other 50% chose ‘development and operations’ phase. These survey results indicate even though many companies integrate sustainability in their business strategy the rate of integration of sustainability in the FFE stage of product development appear moderate.

Survey results also indicate that top management leadership is most critical for the successfully integrating sustainability in the organization followed by employee training and engaging expert consultant.

4. Analysis

The analysis was done for each stage of the fuzzy front end to correlate the results from the survey to the literature review that was done.

In the **opportunity identification and selection** stage the literature stresses the importance of having sustainability concepts incorporated into the vision and policies[17] followed by a company and the survey results indicate that nearly 77.4% of the respondents indicated that this was the case in their company. There is however moderate adoption of sustainable product principles in the front end stage. This was inferred from the response that only 50% of the companies incorporate SPD principles in the front end. This indicates that there is a gap between the policies and the vision the company has and the product development process with respect to incorporating sustainable product development principles. This also ties into the literature findings [30] which say that the current product development process does not have the sustainability concepts incorporated into the product portfolio used by the companies. Thus sustainable product functions ideas and sustainable product innovations are being lost in the product development process. By sustainable product functions ideas [30] literature refers to products that are sustainable because they solve or reduce an external environmental problem and not just improve the environmental impacts of an existing product. This can only be achieved if sustainability concepts are incorporated in existing tools and methods of the fuzzy front end.

Literature refers to ISO environment standards and use of the environment management systems [19]. But these are not absolute standards that needs to be followed and as reflected in the survey results not all companies follow these standards. The results showed that only 67% of respondents agreed that ISO standards with respect to managing environmental responsibilities was followed in their company. From the literature review it was identified that there are variants to the EMS framework called the POEMS [24] that can help with providing a framework for product development to help manage the environmental impacts of products. But the results from the survey indicated that 46% of respondents agreed that EMS framework was used in their company and none talked about product oriented EMS. Incorporating POEMS will help companies have a guideline in place for the planning stage with respect to incorporating the management of environmental effects of products into the EMS structure as for manufacturing firms the flows of materials and energy related to products are the most important.

From the lack of response indicating the usage of POEMS in the companies it can be inferred that the EMS system in place is used for helping with the operation of the firm and not with the product development process. The results of the survey also indicated that there was lack of awareness about types of EMS frameworks

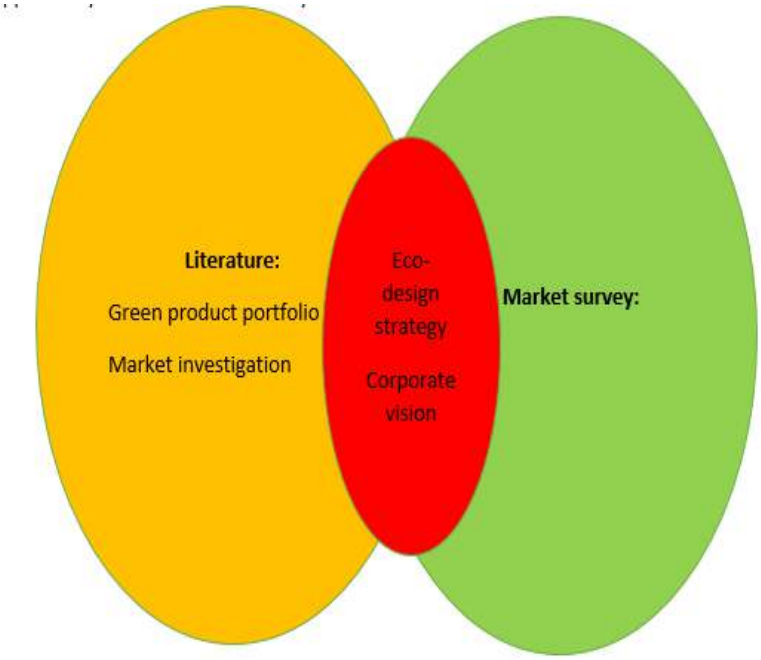

Figure 12: Opportunity identification & analysis phase - Venn diagram

In the **concept generation** phase it was understood that there were too many tools from literature which are used across many phases of the product development[16] and no clear recommendations of which tools are effective in which phases, especially during front end is found in literature. The tools in the literature are also mainly targeting environmental concepts [16]. The team was also not able to identify a tool in literature that helped users to develop sustainable ideas to solve issues in the market. Literature advocates use of Spider web in FFE stages, however, it is not used by many companies [4]**.** Literature studies also recommends small and medium sized companies that they start with simple tools such as checklists, decision matrices, and spider-web diagrams and increase their environmental awareness systematically through training of staff, hiring external experts and through pilot projects[4]. Companies that use a selection of the tools and adapt them to their own needs are able to achieve very good results [4]**.**

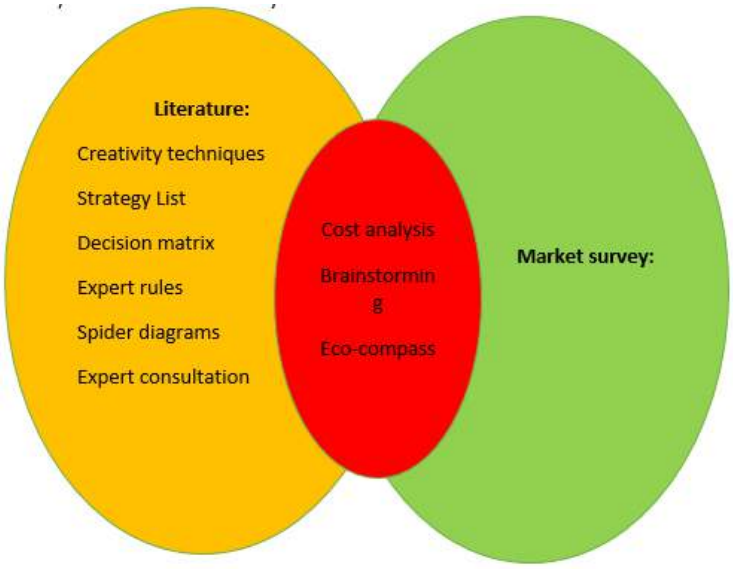

Figure 13: Idea generation & selection phase - Venn diagram

In the **concept evaluation** phase there is very little literature providing techniques to evaluate the quality of a new product idea against the sustainability principles. However some of the benchmarking tools like eco-evolution and design for environment can serve as a guideline to evaluate the quality of a new product idea with respect to environmental considerations

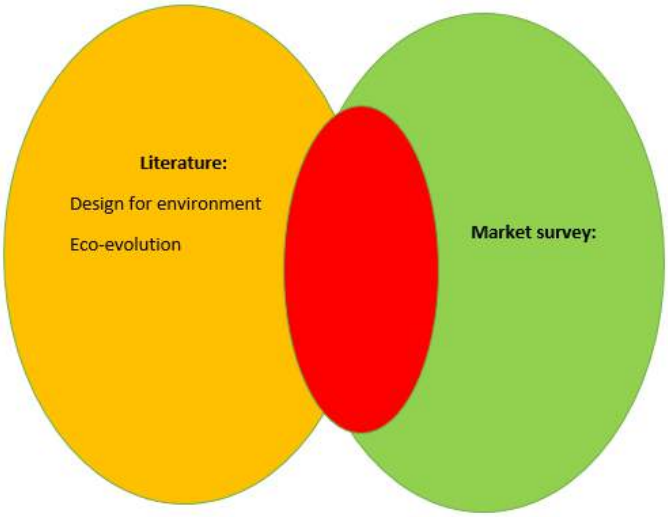

Figure 14: Concept evaluation phase - Venn diagram

5. Conclusion

This empirical study looked into analyzing the tools and process used in the fuzzy front-end stage. The emphasis was given on identifying the key processes and tools and an industry survey was conducted to understand the effectiveness of the different process and tools. This was accomplished through literature reviews coupled with survey in manufacturing industry conducted in two phases. The first phase included literature review and case study discussions to narrow down on the key processes used in the front end for sustainable product development. Based on the literature review that was done across the three concepts of organizational strategy/business opportunity identification, framework and tools the team put together a framework correlating to the fuzzy front end stages provided in [Fig. 10] to help companies incorporate sustainable product principles in the fuzzy front end stage of product development. The second phase was the survey and the analysis of the results to correlate the findings to the literature review results. Analyzing the literature and survey result, the following key conclusions were made:

- Literature points out that eco-efficiency adoption is more than eco effectiveness [30]
- There is lack of research on guidelines on how to effectively incorporate sustainability principles the FFE.
- There are over 30 tools in literature for integrating sustainability at various stages of product development. However, most of the tools targeting environmental aspects of sustainability.
- There is no single tool that targets all the concepts of sustainability.
- The study shows that there is no clear recommendation on tools and process for effective incorporation of sustainability concepts in the FFE.
- The survey of sample size (32), shows that companies are adopting the industry processes and standard in order to manage their environmental responsibilities.
- Survey highlights that most organizations (approx. 78%) have sustainability as a part of the overall organizational strategy. However, adoption of sustainability in FFE stages is moderate i.e. about 50%.
- Other critical factors for successful integration of sustainability were top management leadership, employee trainings and expert consultant inputs.

6. Limitations & Future Research

The focus of this study was to know at what stage organizations include sustainability in their new product development process. This was done using survey and literature review. Although this study has achieved its aim, there were some unavoidable limitations. First, while a diverse industry professional were invited to take part in the survey, we acknowledge that the responses were skewed towards the semiconductor industry and is not a complete representation of the manufacturing population. Second, as with most surveys, some survey responses may have personal influence and bias.

There is a need to do further research to understand if a common framework can be used across the manufacturing industry. This framework will facilitate the implementation of the sustainability at the fuzzy front end. As at the time of this study, there was no common framework in use across board.

Another interesting field of further research is to identify the issues that cause low adoption of sustainability at the fuzzy front end. This is because our survey results shows that the adoption of sustainability at the fuzzy front end is moderate and the benefits of sustainability are better felt at the FFE than at any other stage in the new product development process.

Lastly, it would be very interesting to analyze and evaluate the effectiveness of the various tools used at the fuzzy front end. There are currently some tools that are used across various stages of the NPD process while others are strictly for one stage or the other. Some of those in use at the FFE stage are used at other stages while others are used strictly at the FFE stage.

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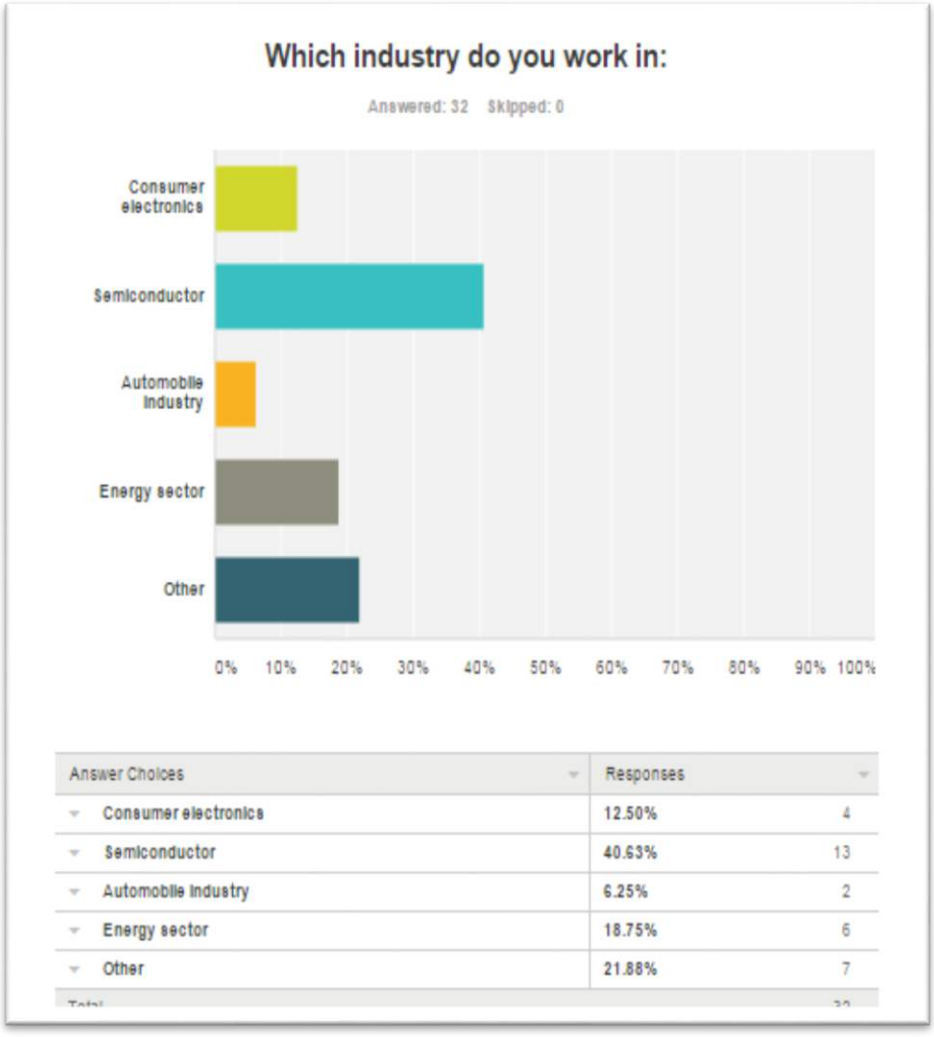
Appendix

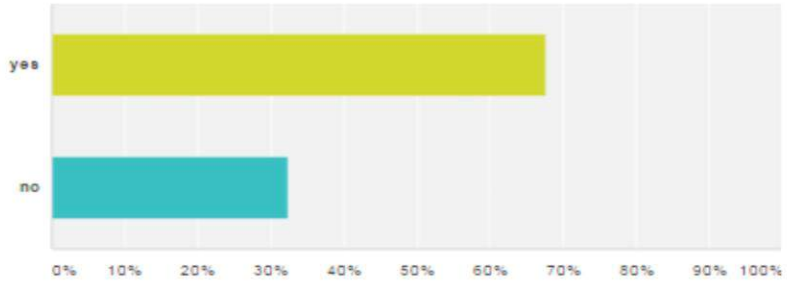
A. Survey Results:



Answer Choices	Responses	
Consumer electronics	12.50%	4
Semiconductor	40.63%	13
Automobile industry	6.25%	2
Energy sector	18.75%	6
Other	21.88%	7

Does your company follow any ISO related standards for the product development process related to environment (The ISO 14000 family of standards provides practical tools for companies and organizations of all kinds looking to manage their environmental responsibilities)

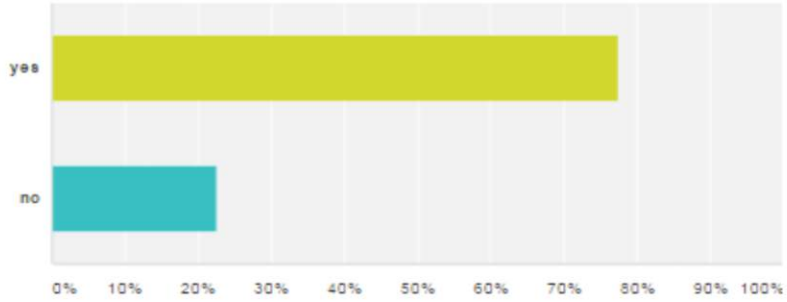
Answered: 31 Skipped: 1



Answer Choices	Responses	
yes	67.74%	21
no	32.26%	10
Total		31

Does your company have the concept of sustainability integrated to the corporate vision/strategy for influencing product concept generation?

Answered: 31 Skipped: 1



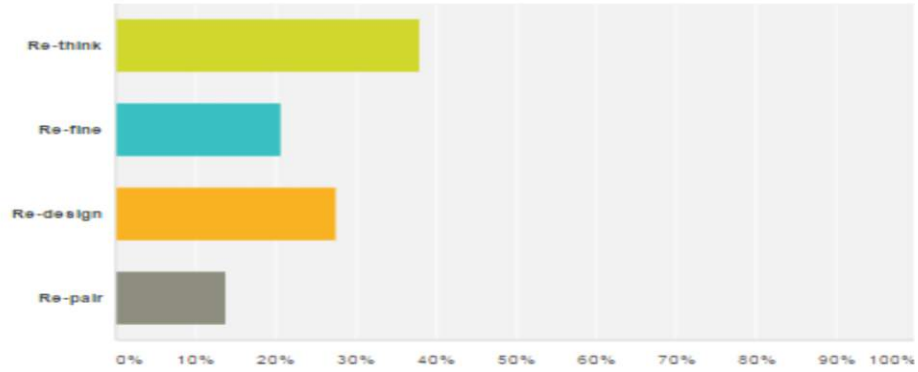
Answer Choices	Responses	
yes	77.42%	24
no	22.58%	7
Total		31

Q4

Customize Export

The four step model in achieving significant resource, energy reductions and generating breakthroughs are Re-Think(initial product idea generation), Re-Fine, Re-Design, Re-Pair(end of product development). What stage is your company at?

Answered: 29 Skipped: 3



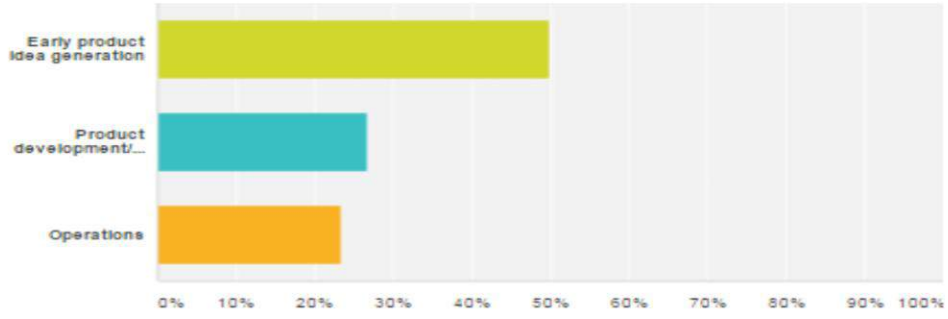
Answer Choices	Responses	
Re-think	37.93%	11
Re-fine	20.69%	6
Re-design	27.59%	8
Re-pair	13.79%	4
Total		29

Q5

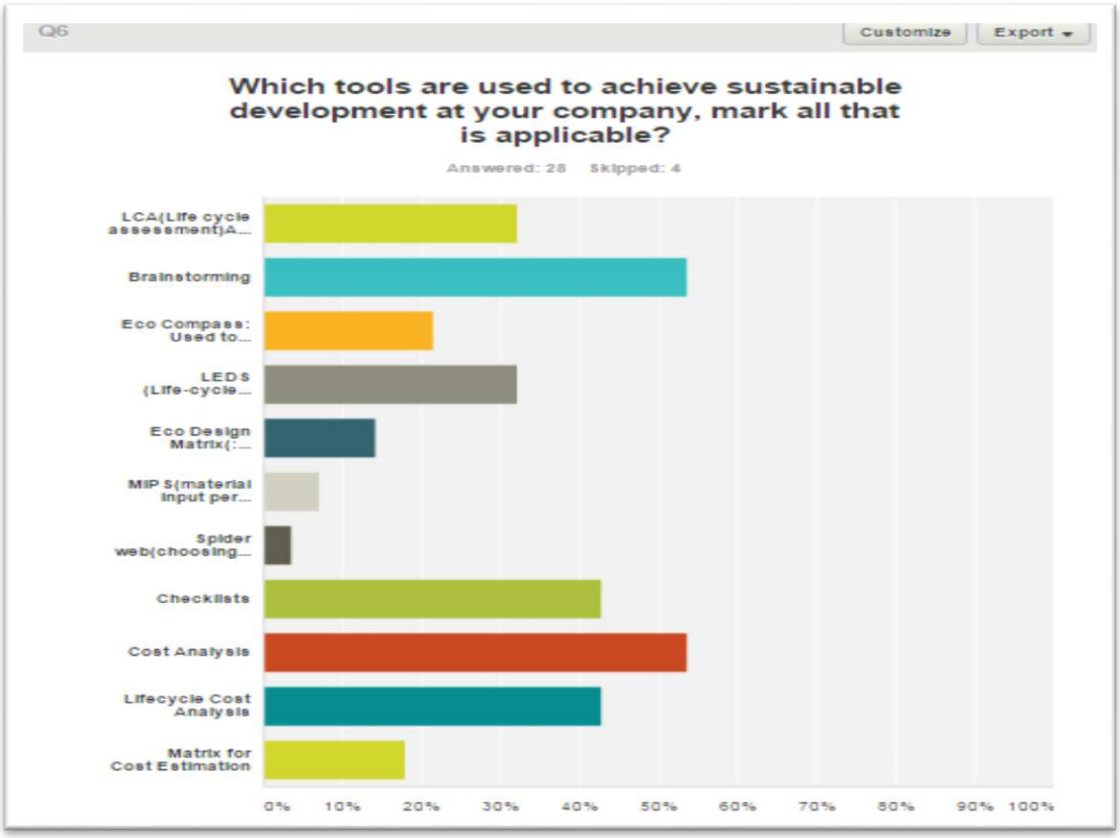
Customize Export

At which stage of product development does your company integrate sustainability principles for product development:

Answered: 30 Skipped: 2



Answer Choices	Responses	
Early product idea generation	50.00%	15
Product development/Engineering	26.67%	8
Operations	23.33%	7
Total		30



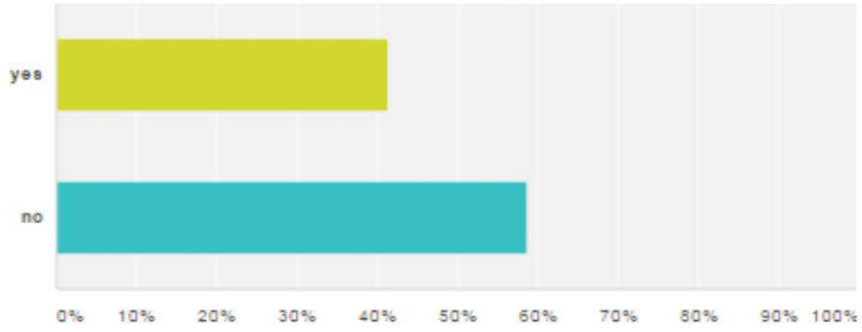
Answer Choices	Responses	
LCA(Life cycle assessment)A technique for assessing the potential environmental aspects and potential aspects associated with a product	32.14%	9
Brainstorming	53.57%	15
Eco Compass: Used to evaluate the product against the older version to uncover areas where the product could become more sustainable or environmentally friendly	21.43%	6
LEDS (Life-cycle Design Strategy)Wheels: Used to determine a range of approaches designers can use to improve environmental performance of products	32.14%	9
Eco Design Matrix(: Decision matrices, such as ABC analysis, in which one lists the most important criteria for evaluation and asks the user to evaluate each single criterion)	14.29%	4
MIP S(material input per service unit: Used for Quantitative determination of the material and energy input required for a product across its entire life-cycle	7.14%	2
Spider web(choosing the best option)	3.57%	1
Checklists	42.86%	12
Cost Analysis	53.57%	15
Lifecycle Cost Analysis	42.86%	12
Matrix for Cost Estimation	17.86%	5
Total Respondents: 28		

Q7

Customize Export

Does your company use tools to facilitate the social or ethical considerations of sustainable design ? if yes please specify

Answered: 29 Skipped: 3



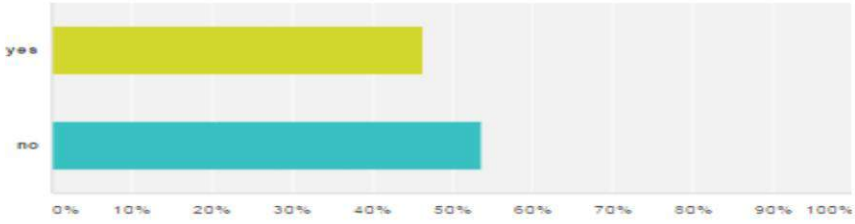
Answer Choices	Responses	
yes	41.38%	12
no	58.62%	17
Total		29

Q8

Customize Export

Does your company follow or deploy a version of the environment management systems, if yes which one.(Environmental management systems (EMS) is an effective way to organise, plan, make decisions and evaluate progress in order to decrease a company's negative impact on the environment).

Answered: 28 Skipped: 4



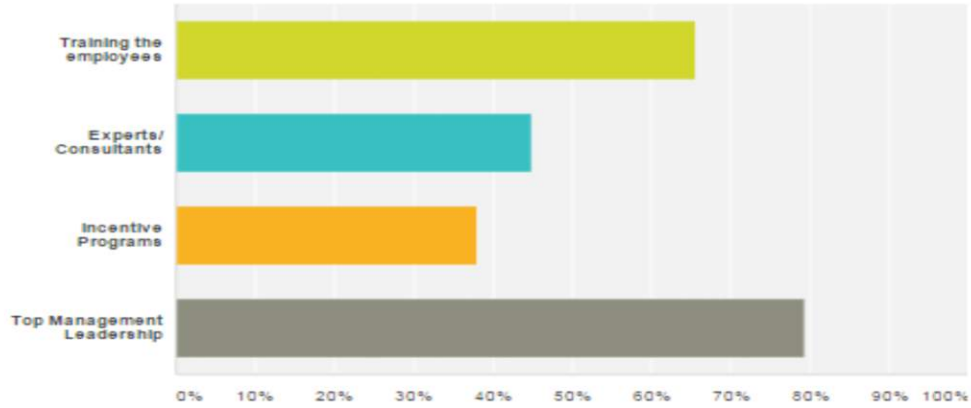
Answer Choices	Responses	
yes	46.43%	13
no	53.57%	15
Total		28

Q9

Customize Export

What are the key factors (at organizational level) that contribute for implementation of Sustainability at your company?

Answered: 29 Skipped: 3



Answer Choices	Responses	
Training the employees	65.52%	19
Experts/ Consultants	44.83%	13
Incentive Programs	37.93%	11
Top Management Leadership	79.31%	23

Total Respondents: 29