Improving environmental performance of industrial products through product service systems

Doctoral dissertation
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This dissertation deals with the unintended sideeffects of utilizing resources and causing environmental load.

The intention of this report is to contribute to a leap improvement in enviornmental performance of industrial products. The results of the dissertation are directed towards companies that want to eliminate, or at best reduce the unintended side effects of their activities and industrial products. The main result of this dissertation is a strategy containing principles and methods for reducing the unintended side effects of a product system which arise during all meetings between the product and the product life systems.

This research has been carried out at the insitute of Machine Design and Materials Technology (IMM) at the Norwegian University of Science and Technology (NTNU).

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ABSTRACT

This dissertation deals with the unintended sideeffects of utilizing resources and causing environmental load.

The intention of this report is to contribute to a leap improvement in enviornmental performance of industrial products. The results of the dissertation are directed towards companies that want to eliminate, or at best reduce the unintended side effects of their activities and industrial products.

The results are directed to the research community as a contribution to research on the effect of a shift from product-based to function-based economic system, and the potential improvement in environmental performance this may imply.

The main contribution of this dissertation is a strategy for developing product service combinations and thereby closing material loops of industrial products. The result is based upon product development models, creative tools and performance measurement combined with the resolution of the basic physical contradiction into a four step strategy for a long term shift of a business model based on product service combinations instead of products only. The fourstep strategy involves traditional product development models with focus on holistic lifespan thinking. Furthermore, emphasize is made to the need to include the creative tools to conquer psychological inertia and barriers for leap improvements in environmental performance.

The strategy is mainly based upon logical resoning and thought experiments and combined with observations in industry. It is difficult to give a final proof of the usefulness of the strategy, due to the time needed to perform such a strategic shift in the core activities of a business.

This research has furthermore contributed to

- a clarification of the source of environmental load during the meetings between product and product life system where any action to reduce the original load will result in load of its own which means that the fundamental cause of load is still not resolved. Any attempt to remove the fundamental cause of side-effect is a true physical contradiction which violates the second law of thermodynamics.
- a clearer understanding of the need not only to integrate the different disciplines across a company's operations, but also integrate along the value chain to capture the valuable information which arise during meetings between product and product life systems.
- a deeper understanding of the need to include creative techniques into the early phases of product development proejcts where dispositions for subsequent project phases and subsequent product life phases are disposed and locked against subsequent major modifications. Creative

techniques contribute to the break out of existing mind patterns and contribute to the creation of solutions which reduce the business-as-usual pattern which acts as a barrier to leap improvement in environmental performance

- a clarification of the need to identify and develop the company's environmental perspective. The need to develop strategies for improving environmental performance of company internal processes, product systems and systemic networks of actors along the value chain is vital to achieve leap improvements in environemntal performance.
- a deeper understanding of the barriers to overcome to transform products-based business to service-based business.

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CHAPTER 1

INTRODUCTION

1.1 Environmental problems and their background

A significant amount of the environmental problems the world face at present, and the speed at which they occur, cannot be derived from natural variations, but seems to be the cause of human industrial activity.

In spite of heavy investments to address environmental problems over the last three decades, unsustainable patterns in consumption and production persist. As a consequence of industrial activity, a substantial contribution to the environmental impact is created:

- Non-renewable resources vanish by extraction in industrial production without subsequent reuse
- Pollution and accumulation of waste leads to extermination of species of the animal and vegetable kingdom, acute and chronic injuries of animals along with destruction of natural values
- Energy production based on fossil fuel leads to regional and global climate changes which again leads to changes in the biosphere.

If future development follows the same path as until present time, a risk that our following generations may experience scarcities which may inhibit or make it difficult to maintain a society and a standard of living as we know in the industrialized world today.

Public concern have during the past couple of decades become the driving factors with increasing pressure, for forcing industry to improve environmental performance of their products and activities.

Acceptable pressures on the environment will be exceeded in the next half century by a factor of between 5 and 50 (Speth, 1989, Weterings and Opschoor, 1992) depending on assumptions, their uncertainties and looking upon specific environmental factors in particular situations and countries. Schmidt-Bleek (1994) arrive at similar conclusions.

Our Common Future warned that if pollution control were not intensified, property and ecosystems would be threatened, and existence would become unpleasant and even harmful to human health.

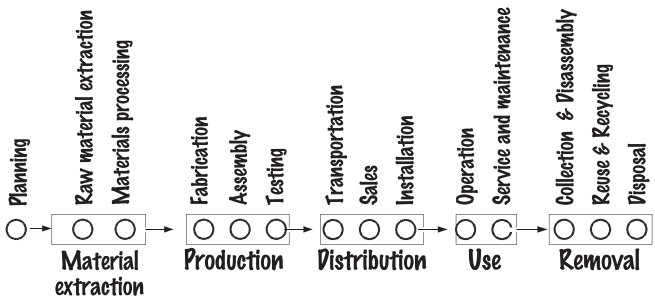
1.2 Environmentally friendly industrial products

The most common way to identify and map the environmental load of a product is to study the key industrial activities related to the specific product through the product's total lifetime:

- Raw material extraction
- Material processing
- Manufacturing
- Distribution
- Utilization
- End-of-life scenario: Reuse, material recycling or final disposal

This is illustrated in Figure 1.1.

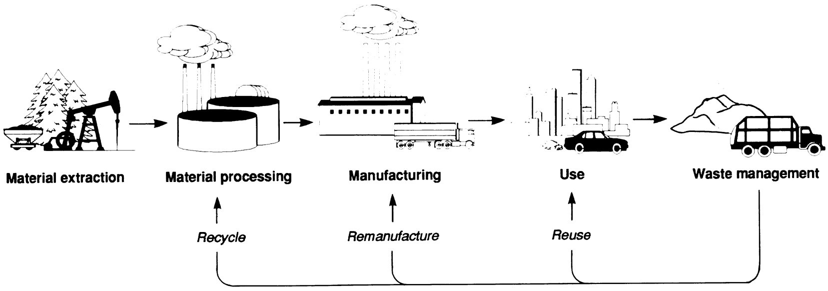
Figure 1.1 A schematic product life



Increasing price tag on waste disposal has led companies to develop strategies for reducing the volume of toxic and waste products going to landfill (Xerox, 1999, Gotlieb, 1995). The recovery of materials through end treatments, both at each production stage and at final end of life, has offered companies an economic benefit by closing material loops and recycling reusable components into the manufacturing process (Ottman, 1997, Xerox, 1999). This is illustrated in Figure 1.2. In Figure 1.2 reuse, remanufacture and recycle represent the most common waste management strategies in order to close material loops.

Figure 1.3 shows six approaches for improving environmental performance in industry and society as a whole. The origin of environmental work in industry today is mainly the "end-of-pipe" strategy with focus on cleansing technology for removal of already created pollution. This approach was mainly used until a decade mid 80's. Environmental work have since changed focus from preventing pollution to occur, and further changing product- and process design to a holistic view on product and process systems.

Figure 1.2 Stages of the product life cycle (U.S. Congress (1992))



The six approaches in Figure 1.3 are:

1 "End of pipe" thinking; environmental effort focused on already created pollution at the emitting point

2 Preventing pollution and focusing on removing pollution from existing products and processes

3 Design for Environment (DFE); Information concerning the total product life is used in the product design phase for optimizing environmental performance as a design target within each product life phase

4 Life Cycle Design. A design approach with focus on Cradle-to-Grave to ensure that potential environmental impacts are identified and eliminated or reduced.

5 Industrial Ecology aims at identifying and stimulating the interdependencies between the value chains of different products over time. Focus on designing product systems with a Cradle-to-Cradle approach

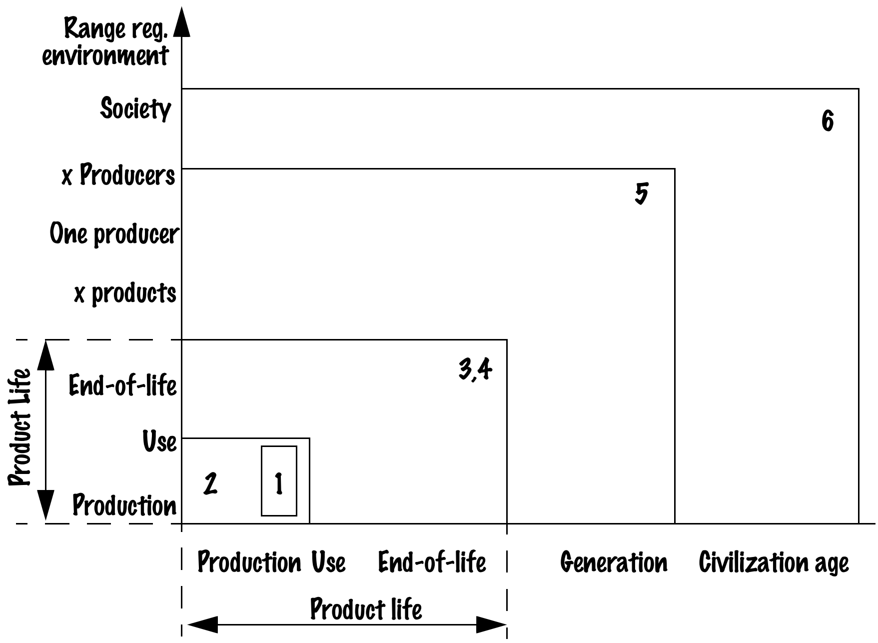
6 Sustainable society, -technology and -economy. Economic development in harmony with the environment. Affects all human activity.

Today, more and more companies both in Norway, as well as in other industrialized countries, are recognizing their responsibility for reducing the environmental load due to their activities. They solve the issue pro actively identifying environmental goals which favors change in both technological solutions and employee behavior through changing products and processes, shifting towards cleaner technologies, reuse and recycling in contradiction to the traditional reactive approach where all approaches are implemented due to governmental regulation and regulatory law.

Programs for reuse, remanufacture and recycling seeks to prevent waste generated at the product end-of-life situation and preventing this waste from being emitted into the surrounding environment by redirecting waste streams or product components and materials back into the value chain for production of new product. This is either true reuse of components/parts into the identical product from where it is collected, or down cycling where materials from a high level product is down cycled into a low-level product.

These programs have shown significant reduction in waste release to air, water and landfill, but also shown to be economically advantageous for the producer. The Xerox Corp.-example illustrates this issue.

Figure 1.3 Illustrating the evolution of environmental work in industry.



According to Xerox Corp. Environment, Health and Safety (EH&S) policy, Xerox Corp. shall (Xerox, 1999):

> *Xerox Corporation is committed to the protection of the environment and the health and safety of its employees, customers, and neighbors. This commitment is applied worldwide. The following principles shall govern all business practices in the design, manufacture, procurement, marketing, distribution, maintenance, reuse/recycling and disposal of products and related services:- Xerox operations must be conducted in a manner that safeguards health, protects the environment, conserves valuable materials and resources, and minimizes risk of asset losses.*

- *Xerox is committed to designing, manufacturing, distributing and marketing products and processes to optimize resource utilization and minimize environmental impact.*
- *All Xerox operations and products are, at a minimum, in full compliance with applicable governmental requirements and Xerox standards.*
- *Xerox is dedicated to continuous improvement of its performance in Environment, Health and Safety.*

Xerox Corp. has developed a system for their copying machines that enables used parts to be reconditioned for use in new machines. Component parts are standardized for easy replacement. These includes electric motors, power supplies, photoreceptors and aluminium drums. Xerox recycled in 1991 about 1 million parts by both replacing components and using parts in new equipment. This process saves Xerox $200 million annually (U.S. Congress, 1992).

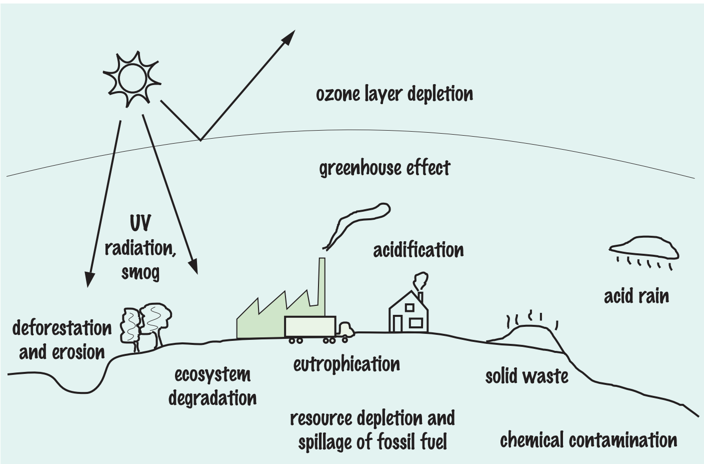
Another example is the 3M Pollution Prevention Pays (3P) program. This is an approach to prevent pollution at the source – in products and manufacturing processes – rather than removes it after it has been created. While the idea itself was not new when 3P was started in 1975, the concept of applying pollution prevention on a company wide basis and documenting the results made 3M to one of the pioneers in this approach. Since 1975, 3P has prevented 771,000 tons of pollutants and saved $750 million.

1.3 Drivers for environmental responsibility

1.3.1 Significant environmental problems

It is useful to be able to visualize the kinds of environmental problem a product can cause during its life span. Some of the links with environmental problems are direct and obvious, others are unexpected and remote. Figure 1.4 presents an overview of global environmental problems (Brezet and Van Hemel, 1997).

Figure 1.4 Overview of global environmental problems (Brezet and Van Hemel, 1997)



Another way to classify the different types of environmental problem is to break them down into geographical scale levels. The higher the scale level, the more sources that contribute towards these problems and the longer it takes for the improvement to become perceptible. When tackling local environmental problems one often has to contend with a number of different parties. Global problems, such as depletion of the ozone layer, make it essential that agreements on the best solutions are reached at the global level. Table 1.1 shows sortie examples of environmental problems and their geographical scale (Brezet and Van Hemel, 1997).

Table 1.1 Environmental problems and their geographical scale (Brezet and Van Hemel, 1997)

Geographical scale	Type of environmental problem	
local	• noise • smell	• air pollution • soil and water pollution
regional	• soil and water over-fertilization and pollution	• drought • waste disposal • air pollution
fluvial	• pollution of rivers	• regional waters and watersheds
continental	• ozone levels • acidification	• winter smog • heavy metals
global	• climatic change • sea level rise	• impact on the ozone layer

1.3.2 The business perspective

From a business point of view, it is important for an enterprise to be able to anticipate environment-related social trends. Ecodesign has become part of the business agenda in many industrialized countries and increasingly in developing countries.

Motivation to implement ecodesign on the grounds of business economics can come from two different directions: from within the business itself (internal drivers) or from the immediate surroundings (external drivers).

Environmental requirements can be seen as a threat by one company and as an opportunity by another; one will focus on preventing a backlog, whereas the other will wish to take the lead. Those companies that view ecodesign as an opportunity will anticipate environment-related social trends and be aware of how to convert them into internal drivers for ecodesign in the form of entrepreneurial benefits (Brezet and Van Hemel, 1997).

Internal drivers

- **Managers' sense of responsibility.** Awareness of the importance of sustainable development among managers and product developers is often due to a moral sense of responsibility for conserving the environment and nature.
- **The need for increased product quality.** A high level of environmental quality will raise the quality of the product in terms of factors such as functionality, reliability in operation, durability and repairability.
- **The need to improve the image of the product and the company.** Communicating the environmental quality of a product to the market through an environmental 'seal of quality', a good report in consumer tests or by general marketing will improve the company's image.
- **The need to reduce costs.** An immediate financial benefit is achieved if a business is able to purchase fewer materials and consume less energy

during manufacture of each of its products. A financial benefit can also be achieved in time by generating less waste and by reducing the friction of hazardous waste. This implies a saving on (future) waste disposal costs.

- **The need for innovative power.** Ecodesign can lead to radical changes at the product system level-that is, in the combination of product, market and technology. New markets can sometimes be penetrated whereas the old product concept did not succeed.
- **The need to increase employee motivation.** Personnel are motivated to a greater extent if they themselves are able to help reduce the environmental impact of the company's products and processes. This is partly due to the pressure felt from their own surroundings. Moreover, ecodesign can help improve occupational health and safety (OH&S), which affects the company's employees directly.

External drivers

The two main factors that encourage environmental improvement in the surroundings of any company are the government (legislation and regulation) and market demand (from industrial customers and end-users) (Brezet and Van Hemel, 1997).

- **Government.** Product-oriented environment policy is developing rapidly in industrialized countries. The focus of this legislation is shifting from the prohibition of certain materials and regulations for waste transport to regulations concerning “extended producer responsibility” or a “take-back obligation” like current Norwegian legislation on waste from electric and electronic equipment and the forthcoming WEEE-directive within EU.
- **Market demand.** Environmental demands made by industrial customers and end-users are evidently powerful drivers for the environmental improvement of the company approach and its products. Large companies increasingly require environmental safeguarding declarations from their suppliers and require documentation on environmental related issues like material content and energy use. In general, an industrial customer is able to influence a company more than an end-user.
- **Social environment.** Much of the pressure exerted by the social environment is via the market: consumers make demands about products and production processes. Through their social contacts, managers and employees are also asked about safety at their place of work and the responsibility that the company takes for nature and the environment. The ‘environment' in the sense of the well-being of nature also has a direct influence on personnel. Perceptible damage to the immediate environment acts as an incentive for improvement.
- **Competitors.** Activities undertaken by competitors can also lead to environmental improvements in a company. It is, for instance, important to know how competitive products score on environmental aspects in consumer tests.
- **Trade organizations.** Trade or industrial organizations in some branches of industry-such as packaging, and car manufacturing- encourage

companies to take environmental action and potentially impose penalties on companies that do not take the required action.

- **Suppliers.** Suppliers influence company behavior, for example by introducing new materials and processes. Research and development in general, and environmental technology in particular, result in the marketing of innovations which bring both environmental and financial benefits.

1.3.3 Influences on external drivers

Important and widely-recognized changes in society will increasingly influence some of the main external drivers. A company beginning to implement ecodesign needs to be aware of these changes (Brezet and Van Hemel, 1997).

1. **Increasing supply chain pressure.** A growing number of industrial customers now expect their suppliers to give documentation of environmental aspects of the goods they supply. Suppliers are being required to sign environmental policy statements and to supply environmental information along with commodities. If a company is largely dependent on a limited number of customers, it has no option but to comply with these demands.
2. **Public opinion.** There is no reason to assume that public opinion will become any less critical as far as the environment is concerned. Pressure groups are becoming more professional in their critical view on industrial activities. It is expected that consumer understanding of these subjects will increase. Superficial claims about environmental performance, made only as a marketing ploy, will be regarded with increasing suspiciousness.
3. **Energy costs.** Influenced by environmental policy, the cost of energy is expected to rise considerably in the coming years. Subsidies for energy-intensive production methods will become a thing of the past and energy charges will have a powerful impact on corporate decisions, and on the choices and behavior of end-users.
4. **Waste charges.** Waste-processing charges (land-fill and incineration costs) will in many countries undergo clan increase in the years to come, following the principle 'the polluter pays'. The prevention of waste and emissions, reuse and recycling will consequently become more economic. End-users will also have increasingly to pay for the environmental costs of their activities.
5. **Take-back obligation.** Legislators will start to make manufacturers liable for the environmental consequences of their products after disposal. Germany is the leading nation in this area and has already introduced a take-back obligation for packaging and goods such as television sets, computers and cars. Norway has introduced legislation on waste from electric and electronic equipment and EU has a forthcoming directive on the same issue (the WEEE-directive).

6 **The obligation to provide information.** In the years to come, more and more companies will have to provide environment-related information on their products and processes, and will have to pursue an active environmental communication policy.

7 **Norms and standards.** Standardization organizations are expanding all existing norms and standards to include environmental issues. The ISO 14 000 series will become the international standard for certifying environmental management systems. It is expected that product-related aspects-such as the obligation to collect and publish environmental data-will be incorporated in this standard.

8 **Ecolabelling schemes.** A number of nations have introduced schemes for ecolabelling products or product groups. There is a steady increase in the number of ecolabelling programmes and they are now gaining more attention.

9 **Subsidies.** In some countries, subsidy programmes are being developed to stimulate industry to take up ecodesign and to carry out research into potential environmental improvements. At the same time subsidies on energy and raw material consumption are ending.

10 **Environmental competition.** 'Responsible care programmes' are becoming more common in many industries. As a result, the number of companies that have gained experience in the field of cleaner production, including ecodesign, is increasing rapidly. Competitors must take care not to allow this lead to become so great that it will be impossible to catch up.

11 **Environmental requirements in consumer tests.** Environmental requirements are being increasingly incorporated in consumer organization product tests. Products failing to get a high score on these requirements no longer qualify for the title of 'best buy' or 'good choice', whatever other excellent features they might have.

12 **Environmental requirements for design awards.** The organizers of several highly-respected design competitions have stipulated that contestants must provide specific environmental information on their products.

13 **Increasing cooperation with suppliers.** There is a growth in international trade and an increase in collaboration with non-local suppliers which operate on the basis of the 'just-in-time' principle and target costing. Companies are starting to contract out much more of their product development and are also collaborating with suppliers to decrease the time-to-market for each new product. These trends increase the need to incorporate environmental concerns into the development process as early as possible and to involve all the different parties in the entire product chain when doing so.

Proactive vs. reactive attitude

All businesses have a choice to make about their attitude to the environment: they can set the trend or they can wait and see. Both attitudes have their benefits and drawbacks. A proactive company will go against current tendencies or define “a new flow” while the market, competitors and legislation fail to go along. A proactive company tries to influence and change markets and benefit from this change. This needs investment and energy. On the other hand, the trend setter is rewarded: image and market potential are improved, a cleaner environmental record is achieved and the feeling of being prepared for what is to come is also apparent. The proactive company sees the environment change from being a threat to becoming an opportunity for innovation, and even the investments made can yield benefits instead of costs.

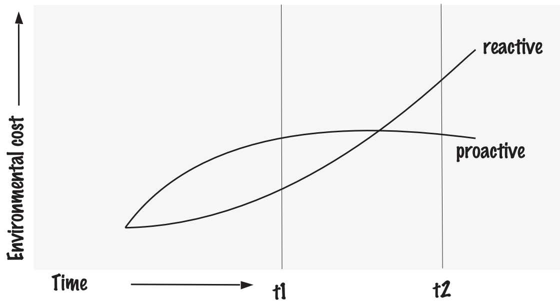
A reactive company adopts a 'me-too attitude' or reacts only when a certain trend is obvious or when legislation requires action. This makes it unnecessary to think in terms of holistic thinking through scenarios and experimentation. The follower does not regard environmental aspects as an opportunity but a threat (costs) only. After the financial argument, uncertainty about environmental issues and forthcoming legislation is one of the most frequently heard arguments for taking, and staying in, a reactive role (Brezet and Van Hemel, 1997).

Financial considerations

Financial considerations ought to lead many companies to become trend setters. A decision model is shown in Figure 1.5, which illustrates how environmental costs develop for trend setters and for followers. The figure makes a number of points (Brezet and Van Hemel, 1997).

- If the management of a company feels that environmental improvement plays a central role and chooses to adopt a proactive role, the costs in the short term (t1) may be higher than those of the competitors which adopts a a reactive role. Investments in measures to prevent waste and emissions from production processes and products will be required. However, these investments often produce substantial savings and have short payback periods, which results in the win-win situation .
- The preventive investments will pay for themselves because the costs involved for raw materials decreases and/or the costs involved in treatment of waste and emissions are reduced. This applies particularly if the decrease in costs is linked with an increase in productivity resulting from a higher quality of the products and processes. This situation influence by flattening the cost curve for the proactive company while the costs for the reactive company will continue to rise (t2).
- The more steeply the environmental costs per unit rise, or the greater the savings achieved, the shorter will be the timeperiod between bringing the chosen strategy into practice and actually reaching break-even point.

Figure 1.5 How environmental costs develop for proactive and reactive companies (Brezet and Van Hemel, 1997)



Time-frame considerations

Plans for the future are essential for both proactive and reactive companies. All plans should consider both short- and long-term elements.

A pilot project needs to be profitable in the short term. A pilot project may suggest an alternative to raw materials reducing pollution, a reduction in the amount of waste or a reduction in energy consumption. This usually motivates the company to continue the path improving enviornmental performance.

In the long term, however, there need to be conceptual changes which optimizes the product system level instead of the product component level. These changes will require the involvement of many different internal and external stakeholders. Future scenarios and trends play a major role here. If innovative changes complying with these trends are linked to changes in the company's structure, the innovation process result in a continuous improvement process.

1.4 Industrial ecology

It is generally agreed that environmental considerations cover a product's entire life span and that a holistic, system-based view provides the largest capability for reducing environmental impact of both products and associated processes. In Design for environment, life cycle design, environmentally conscious design and manufacturing and green design, the scope of considerations both in terms of time and of the environment, is the life span of one product.

An analytical framework for studying the concept of holistic thinking in industry has been proposed in the new paradigm called industrial ecology. As consumers buy products from different manufacturers, which have multiple suppliers, which again have multiple product lines, limiting the considerations to one product lifesaving may not be enough. Industrial Ecology tries to capture the network of suppliers and consumers considering the interactions within multiple product life spans focusing on creating life cycles where materials are reused and energy use is minimized focusing on the holistic system. Moving towards industrial ecology generally requires

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cooperation between several industries, and which implies a vertical move in Figure 1.3.

The industrial ecology approach seems presently to bring new words on how the ultimate goal should look like, but lacks the notion to bring operational techniques into the research arena which can aid in moving forward towards this scenario. A network of suppliers and consumers rapidly becomes very complicated and complex when analyzing the material and energy streams.

1.5 Traditional design for environment techniques

1.5.1 Ecodesign and similar approaches

A lot of research work has emphasized the design of industrial products, not only the processes behind the products. This activity is often referred to terms such as Ecodesign, Design for Environment, Eco-Redesign, Green Design. Several authors have contributed to the development of methods and tools for managing environment as a product property in the product development process.

Van Weenen presents an overview of 30 different guides and manuals for the inclusion of environment as an issue in product development (Van Weenen, 1997a). One of his observations is that only very few of the published methodologies presents a clear vision on the role of products and how they relate to demands that are embedded in values and convictions. Some guides are aimed at very specific target groups, whereas others aim for a much wider audience such as the EcoDesign Manual (Brezet and Van Hemel, 1997).

Only very few of the guides and manuals discussed in Van Weenen (1997a) were based on a vision on the future, on choices or directions with respect to sustainable development. The needs for sustainable development were hardly addressed. van Weenen claims that issues related to developing countries seemed to have been totally neglected among the methodologies presented in the study (Van Weenen, 1997a). Figure 1.6 illustrates the essential elements of the 30 methodologies of Van Weenen.

The variety of terms related to the so-called life-cycle approach all more or less share the same starting points and captures the same time scale and range for improvement (Brezet and Van Hemel, 1997). Ecodesign strives to integrate design for X strategies (-recycling, - manufacturing, -disassembly) of all life span phases into one. This way it is prevented that a design option which enhances ecoefficiency in one stage, has negative consequences in another. By prioritizing between several possible strategies, a product can be made considerable more ecoefficient throughout its total life span.

The LiDS-wheel (Life cycle Design Strategies) presented by Van Hemel (1995), gives a typology of possible actions that can be applied to realize environmental benefit in the total life-cycle (Van Hemel, 1995). Actions are focused on a component level, product structure level and product system level. An additional strategy provokes companies to reconsider current product concepts and core busienss strategies. Although product system levels are part of ecodesign, its strategies aim at redesigning and optimizing the current product, which serves as a reference. With the focus on optimization of products, ecodesign is a specific design-activity.

The following aspects are found to be characteristic for ecodesign (Van Hemel, 1995):

- ecodesign focuses on integrating all aspects throughout the life span
- ecodesign focuses on the redesign or optimization of current products
- ecodesign is a design-activity: environmental aspects are integrated in the design phase.

In recent years ecodesign has been implemented successfully within a great deal of companies worldwide. Research shows that up to 45%, of 77 SME's studied in the Netherlands, have implemented design options for their specific product (Van Hemel, 1998). Especially cleaner production, prevention of waste of energy/consumables during the use phase and easy maintenance/repair/recycling have proven to be popular strategies and relatively easy to implement. Company drivers were mainly the possibility of reducing costs (Van Hemel, 1998).

1.5.2 What is a sustainable product?

Several authors have developed approaches to develop sustainable industrial product (Hanssen, 1997, Van Weenen, 1997b). A relevant question regarding the environmental load of any product is: *What is a sustainable product?*

Such a *product* cannot exist. The environmental load occurs as a result of an activity where the product is a component of a larger technical system, not as a result of the product itself. The product is always a part of such an activity, and thereby indirectly becomes a part of the source of the environmental load.

A product may be very environmentally friendly regarding materials, energy and toxicity. However, if the product is used in an unsustainable manner, it becomes part of an unsustainable activity which cannot be defended. Improving the product would give only minor contributions to a greener society, as the main contributor, i.e. the activity stays unchanged.

Similarly, an environmentally unfriendly product may be used in a way which is part of a nearly sustainable activity. Improving the environmental load of the product may give a significant contribution towards a sustainable society.

It seems that the word sustainable is only valuable in the context of an activity. An object is never sustainable. However, the object can be utilized in a sustainable manner.

Figure 1.6 Essential elements of different ecodesign methodologies from (Van Weenen, 1997a)

GUIDE/ MANUAL	Objective	Target Groups	Procedure	Tools	Examples	Fig./Tabl./ I Illustr.	Media/ Source	PP.
1. Waste Prev.	Waste Prevention	Science, Ind., Gov.	WP policy design	Life Cycle Model	Ind. W.P. practice	+/ +/ +	Book, DUT	418
2. Practic. Guide	Inform designers	Designers . Consumers	-	Points	Inks, Paper, plastics	-/ +/	Insert, ID-magazine	16
3. Get. at Source	MSW tox. reduction	Decision makers	5-step process	Criteria. Checklists	Batteries	+/ +/	Report, WWF	138
4. Ökol. Quality	Assess ecol. qual.	Companies	Step-wise T.A.	Criteria. Worksheets	–	+/ +/ +	Report. Hessen	185
5. Facility. Guide	Poll. Prev. by SME's	Individuals in SME's	Dev. & Org. of Program	Criteria. Worksheets	–	+/ +/ -	Report, US-EPA	143
6. Design. Green	Awareness	Designers . Engineers	-	Checklist	–	+/ +/	Brochure, Dow	20
7. Method. P. 0.	Environm. Design	Designers , Developers	-	Checklists. Thumb rules	Case studies	+/ +/ -	Report. EDC	128
8. LCD Manual	Reduce env. impact	Designers, Engineers	Developm. activities	Analysis. Assessment	–	+/ +/ -	Report, US-EPA	181
9. Env. Compat.	Guidance . Env. prod.	Groups of SIEMENS	-	Checklists Guide-lines	-	+/ +/	Brochure. SIEMENS	16
10. Teach. E. D.	Prepare engineers	University Engin.	Project managem.	11 proj. sugg., DFD	Paper vs. PS cups	+/ +/	Guide. Gr.-Valley	?
11. Eco-design	Incentives & Ideas	Product developers	Reference product	Environm. screening	9 Examples	+/ +/ +	Report , IÖW	96
12. Design, Mat.	Provide tools	Designers	–	Ethic. rules. Criteria	Several, 12 Cases	+/ +/ +	Report, Borgens	213
13. Intro. E.P.D.	Guidance. Env. prod.	Businesses. developers	Life Cycle Design	Guide-lines. LCA	Several	+/ +/ +	Brochure. EDC	50
14. Env. Aspects	Help stand. writers	Standard writer s	EIA implementation	Env. Imp. Ass. (EIA)	-	-/ +/	Report, CA/IEC	42
15. New Mater.	Provide information	Mat . scien., Designers	Design brief form.	Checklists	Case study	+/ +/	Report. EF, Dublin	105
16. D.F.E.	Provide tools	Industry. Government	Developm. & Implem.	DFE principles	Cases	-/ -/	Brochure. WICE	24
17. Guide Aspect	Reeduce env. effects	Standard writers		-		+/ -/	Brochure, CSA	9
18. Sust. P. D.	Provide method	Comnanies. Nordic proj.	6.steps plan	Syst. eng., QFD, LCA	-	+/ +/ -	Report, ØRF	81
19. Ind. Ecology	Pioneering effort	Academia, Engineers	Implement 5x5 matrix	LCA. Matrix checklists	Some	+/ +	Book, PHI	412
20. Ökodesign	Holistic thinking	Designers. Managers	Ecodesipn procedure	Guide-lines. Checklists	Several	+/ +/ +	Book, VMI	418
21. Sust. Settlem.	Achieve Agenda 2 1	Planners. design.	Planning, Design	Principles , Checklists	-	+/ +/ +	Report, LGMB	260
22. Handbook	Awareness	Designers , Engineers	-	LCA. Checklist	Some	+/ -/ +	Report, IVF	56
23. D.F.E., T.E.	Understand, Env. prod.	Profession. Designers	Iterative process	LCA, DFE Checklists	-	+/ +/	Report, CSA	73
24. Prod. Entw.	Minimise material use	Developers	5 steps procedure	MIPS, Criteria	Several	+/ +/ +	Report, WFI	155
25. DFE	Promote DFE	Executives, Engineers	Procedure	Guide-lines	Several, Case	+/ +/ +	Book, McGraw	464
26. Env. Resour.	Provide information	Architects , Designers	-	LCA, Sheets Matrix	Some projects	+/ +/ +	Guide, Wilev	500+
27. Miljmvurd.	Provide information	Env. Spec., Designers	Cooperate	LCA	Some	+/ +/ +	Book, DTU	335
28. Prod. Dev.	Provide guidance	Managers. Designers	Procedures	LCA	Several	+/ +/ +	Book, Gower	215
29. Eco. promise	Assist businesses	Entrepren., Designers	7 Phases	LC-Appr., Matrices	Several	+/ +/ +	Book, UNEP	348
30. LC Design	Assist SME's	SME's, Designers	Developm., Planning	Criteria lists	Several	+/ +	Book, Springer	180

1.6 Technological lock-in as a barrier to sustainable development

1.6.1 Definition of the phenomenon of technological lock-in

Sustainable development has been part of the research agenda for several years without being able to contribute to a significant reduction of the steadily increasing environmental load on a global scale. Attempts to improve ecoefficiency still face several economy-wide barriers. The best recognized of these are market and intervention failures and inefficiencies, which have been extensively analyzed (OECD, 1992, OECD, 1997). Less understood but equally important is “lock-in” to existing technologies and practices, associated with the investment costs and social inertia that can inhibit change.

The theories of technological lock-in predict that a superior new technology may not be adopted if consumers are locked-in to an older, incompatible technology standard. Lock-in arises with a technology that is valued for its compatibility within a network of users or with older technologies. When the benefits to such compatibility outweigh those generated by an otherwise superior technology, consumers will not switch. However, lock-in may not persist if the value of compatibility declines.

The phenomenon of technological, behavioral and institutional “lock-in“ makes any change look costly, even where changes would bring large economic benefits (Jaeger, 1997). Large changes do occur, but their timing is unpredictable and they are hard to manage.

The gasoline engine is an example of a technology that has so far survived all attempts to replace it (Cowan and Hultén, 1996). Since car manufacturers opted for the Otto-cycle engine at the beginning of this century, a massive infrastructure has been installed for manufacturing engines and supplying fuel. The low cost and high performance resulting from “learning-by-doing” and economies of scale make it extremely hard for any new technology ever to enter the market. Some analysts (e.g. Cowan and Hultén, 1996, Deluchi, 1992, Mackenzie, 1994) claim that electric battery or fuel cell technology can compete with the gasoline engine in the near future, if produced in sufficiently large volumes. However, no firm is yet prepared to take the risk of investing in the necessary production capacity (Cowan and Hultén, 1996). Lovins et al. (1993) believe that an organizational change in the car industry is inevitable: with the current trend towards an increasing diversity of products with lower design and tooling costs, economies of scale will disappear allowing small, new manufacturers with novel technology to enter the market.

Rapid changes already occurring in society may provide opportunities for improving ecoefficiency. The changes include the development of communication and information technology, the emergence of biotechnology and other scientific and commercial breakthroughs. Markets and styles of management and organization are also changing. Collectively, these trends have been described as a move towards a “knowledge-based“ economy.

An economy-wide move towards improved ecoefficiency would probably involve the disappearance of some products and firms, and the emergence of new ones. This is an important part of the cost of change. The fear of losing can lead to a culture that discourages change.

Changing the status quo will involve escaping the market barriers which hinders creative solutions of environmental problems to become innovative products, services and combination of these with successful exploitation of the marketplace.

1.6.2 Escaping technological lock-in

Some initiating events may give a technology an early advantage, but it is the processes that emerge in response that produce the vested interests that lock in the technology.

Users become unwilling to switch technologies because they have invested time and money in the technology that dominates. To escape lock-in, therefore, it is not enough that the competing technology is better. To overcome lock-in, it is necessary that some extraordinary events occur. Cowan and Hultén (1996) present the possible impact of six factors whose existence or strength could help the market escape (or unlock) the lock-in of a technology:

1. **Crisis in the existing technology.** This factor has, in some cases, stopped the use of pesticides in agriculture, where conventional technologies have begun to fail to control damaging pests.
   A crisis in the existing technology may be a situation where the conclusions of the Limits to Growth (Meadows et al., 1991, Meadows et al., 1972) comes true.
2. **Regulation**. This option is currently in use in the case of CFCs in refrigerators, as concerns about the ozone layer prompt regulations aimed at reducing the damage done to it.
   Regulations are beyond the control of companies. Governmental regulation are often meant to guide industry, correct selection of technology and foster innovation to make society and industries become interrelated for the benefit of both. Unfortunately, this often turns out different from the intended objective, both because of unsatisfactory legislation, but also because industries are not able to look beyond the regulations to benefit from it.
3. **Technological breakthrough producing a (real or imagined) cost breakthrough**. The ascendancy of the gasoline car was propelled by the implementation of Taylorism and factory automation by Henry Ford. Light water nuclear reactor power plants gained momentum through the believed future cost breakthrough that was to emerge when the industry matured.
   This situation is what happens in industries today. Industries try to reduce cost due to increased competition. This situation is within control of industry alone.

4 **Changes in taste**. The growing awareness of the environmental effects of some products has created mass markets for environmentally adapted products.
This situation is out of reach of industry. This situation is within the control of the customers. The challenge for industry is rapid feedback on changes in customer taste, e.g. customer needs.

5 **Niche markets.** The growth of emerging technologies is facilitated if there exists a relatively large number of consumers willing to invest in the new technology before low cost production, (internal production economies), and well developed after-sales services, (external consumption externalities) emerge. Early adopters provide the learning and scale economies needed to generate these externalities.

6 **Scientific results.** Science may provide tools to better measure the external effects of an industry or may enable inventors and entrepreneurs to transform basic science into inventions and innovations. Consequently, scientific results can put development pressure on an old technology both by questioning its global efficiency and by providing knowledge about alternative technologies.
This situation is where companies can benefit from inhouse excellence in creating new products through innovative ideas.

Knowledge plays a key role when it comes to reducing the materials intensity (“scale“) of the economy, a goal that Hinterberger and Meyer-Stamer (1997) claim is beyond the reach of conventional environmental policy. Hinterberger and Meyer-Stamer (1997) argue that the knowledge problems of conventional environmental policy cannot be resolved due to the enormous complexity and the inherent dynamism of both ecosystems and economies. At the same time, there are reasons to believe that a reduction in the overall scale of industrial production and consumption are unavoidable in order to assure sustainability. This indicates that old technologies are to be removed and to be replaced by technical systems with improved environmental properties. This requires creative thinking different from the usual mind pattern.

Furthermore, Hinterberger and Meyer-Stamer (1997) argue that due to the complex character of the ecosphere cause-effect relationships, every reaction of the ecosphere to human interference has to be experienced anew and is essentially unpredictable. Knowledge of environmental deterioration is therefore necessarily limited and subject to constant change. Hinterberger and Meyer-Stamer (1997) see a pattern of the history of environmental policy where the identification of the damage caused by a given substance, subsequently moved production and consumption to some substitute. Then the substitute's potential to cause environmental harm is identified, and the cycle started again. This kind of environmental policy is inefficient, and it does nothing to establish a sustainable pattern of development.

Innovation in technology, organization and institutions is the key dynamic in improving ecoefficiency. The innovation process includes not only the development of new technologies, but their successful deployment and diffusion. While some contributing authors express the view that "breakthrough" innovation would be needed to achieve targets such as Factor 10, others emphasized that all types of innovation in technology, behavior and organization will be needed (OECD, 1997).

Apparent obstacles to improving ecoefficiency include (OECD, 1997)

- the first cost of new technologies
- the current system of alliances among stakeholders that tends to preserve the status quo
- the presence of market and intervention failures and inefficiencies
- inefficient communication within and among firms.

The phenomenon of technological, behavioral and institutional "lock-in" makes any change look costly, although large changes may be possible with no cost, or even savings. The challenge is to tunnel through the cost barrier or to avoid it by taking advantage of changes that are occurring anyway. Rapid changes are occurring in society, with the rapid take-off of communication and information technology, the emergence of biotechnology and other scientific/commercial breakthroughs. Markets and styles of management and organization are also changing, while consumer groups are strengthening and beginning consciously to define their own "needs". While these changes will not necessarily lead to a more ecoefficient society, they offer an opportunity to move in that direction (OECD, 1997).

1.7 Scope of research

1.7.1 General

Many of the authors of contributions to conferences seem to struggle with getting hold on the paradigm of sustainable development or the possible translation of sustainability into operational strategies. Causes for (un)sustainability are often hardly addressed, but mainly accepted as a desirable process, and the tradition of thought in which it evolved is not questioned.

Thus, a need to measure environmental performance of a product, and to what extent this product meets the expectations for sustainability in a holistic systems view is needed. Furthermore, design practices presently available within industry and academia, are far more focused on incremental changes than on fundamental leap improvements. Achieving a significant improvement in environmental performance is still only wishful thinking.

1.7.2 Leap improvement in environmental performance

There are several visions on how to break the incremental character of ecodesign and define more fundamental approaches for reaching leap improvements in environmental performance. A number of these approaches are:

1. Four levels of eco-innovation (Brezet, 1997)
2. System innovation (U.S. Congress, 1992)

3 Leapfrog strategies (Manzini, 1997)

4 Sustainable Product Design (Charter, 1997)

5 Sustainable Product Development (Van Weenen, 1997b)

The list gives an impression of current frameworks on industry and academics attempts for achieving sustainability and can be used to get more grip on characteristics of approaches for leap improvements in environmental performance.

Four levels of eco-innovation

Brezet (1997) discerns four types of product-related environmental innovation, based on extensive experience in ecodesign practice. The types are related to two axes: ecoefficiency and time-scale, see Figure 1.7. The transition from type 1 to type 4 requires an increase in innovation freedom, but is expected to achieve higher levels of ecoefficiency, while implementation time is expected to be longer.

The first type of improvement involves the improvement of products from the perspective of pollution prevention and environmental care. Both the product and its production technique will generally stay the same. Examples are the organization of a take-back system for tires and changing the type of coolant used and other types of actions leaving the fundamental properties of the product and its components unchanged.

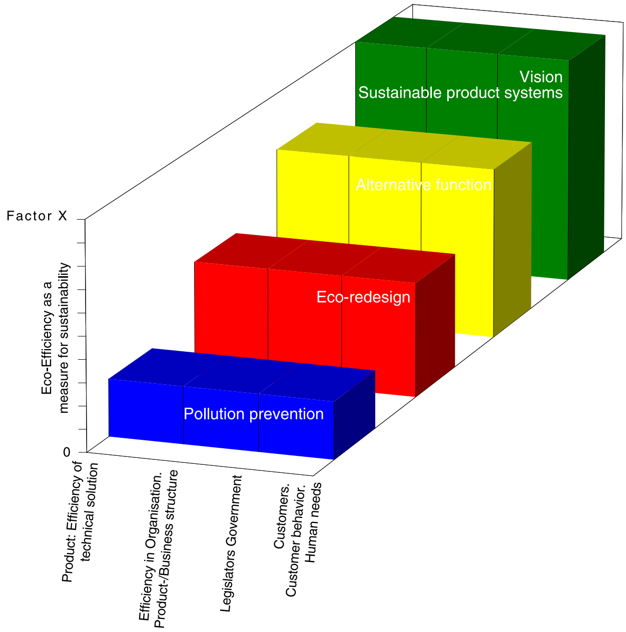
With the second type of improvement, product redesign, the product concept stays the same, but parts of the product are developed further or replaced by others. Examples are the use of other materials, design for recycling and minimizing of energy use during its life span through product and component modifications.

The third type, alternative function, is based on the function of the current product. In the Ecodesign strategy wheel (See Figure 3.16), this is equivalent to strategy 8, alternative function fulfillment. An example is the transition from letters to e-mail, where the function is ‘information transfer’. The environmental profit is mainly through dematerialization.

The fourth type deals with system innovation. Changes in related infrastructure and organization are required in order to develop new products and services on a system level.

Brezet argues that a transition to longer term innovation is required for reaching environmental performance targets. Creating products on the basis of functionality and redefining systems are the most important aspects of this approach. However, no systematic approaches for carrying out this strategy are presently available (Brezet, 1997).

Figure 1.7 Four levels of environmental innovation. Modified from (Brezet, 1997)



Sustainable system-innovation

The need to move beyond product-redesign towards a more system-based innovation is underlined by the OTA (U.S. Congress, 1992). A distinction is made between a product-oriented and system-oriented approach. OTA concludes that not so much the environmental load of an individual product should be tackled, but more the total system-context in which the product functions.

OTA pleads for system-oriented design, although it is acknowledged that this has consequences on business' strategic planning.

Leap frog strategy

When discussing sustainable societies Manzini (1997) calls for system discontinuities. In this light leapfrog strategies refer to the transition from the current mix of products and services to a new and more sustainable one. The service aspect, as a strategy for dematerialization, is an important consideration, as not so much products should be sold, but more the result of the product. A strong relation can be seen with the function innovation, described by Brezet.

Whereas in the above approaches a strong focus was on developing new and more sustainable products or technologies, Manzini emphasizes that social innovation can be an alternative and possibly a more effective strategy for achieving sustainability. An example is the sharing of cars by multiple users, instead of selling cars to all of them. This represents the result-theory, in which not the possession of the car is central (product-oriented), but the possibility of transportation (the result).

Sustainable Product Design

Charter (1997) states that a change will have to occur from redesigning products to rethinking them. The function of the product or the need of the consumer forms the basis. Furthermore it is emphasized that ecological aspects, concerning sustainable product design, will have to be balanced with economical, social and ethical needs.

Finally, the process of sustainable product design is described as a design management activity, in which the need to form stakeholders and partnerships becomes of increasing importance.

Sustainable product development

Like Brezet, Van Weenen (1997b) differentiates four levels of innovation strategies for achieving sustainable product development: end of pipe solutions, lifecycle design for environment, function innovation and sustainable product development. Van Weenen recognizes that theoretically functional innovation (level 3) is an interesting starting point, but that practical examples are scarce.

On the fourth level 'Sustainable product development' (SPD) is defined as a resource-, context- and future-oriented product development, aimed at providing elementary needs, a better quality of life, equity and environmental harmony. Resource -oriented, as it considers the properties and availability of resources and their distribution among countries and generations. Context-oriented, as SPD integrates context-related aspects as natural environment, society, technology and economy. Future-oriented, as SPD addresses future needs and values.

Comparison of the different sustainability approaches

Similarities between the described approaches which differ from the eco-design approach can be brought back to three overall points:

- function / need as a starting point as opposed to product optimization of Eco-design
- the use of an innovation process as opposed to the product design process of Eco-design.
- system level as opposed to the product level of Eco-design

All approaches have in common that the starting point of the development process should not be the product itself, but based on the function or the need. A difference with Eco-design is the shift from optimizing current products to rethinking the function of this product.

Although function and needs are used comparatively, there is an essential difference between the two. Functions are product-related, in the way that they specify the function(s) a current product. Needs are consumer-related, in the way that they give insight in the need(s) of consumers which are served with products (or services). Although these terms are widely used, no descriptions are given how to use them and in what way they are successful for achieving sustainable products.

Whereas Eco-design is integrated in product design activities, it is recognized that sustainable development asks for processes starting at an earlier stage in the development process. Van Nes (1997) states that the goal of higher eco-efficiencies requires the integration of decision making in the product planning process, preceding the actual product design process. Charter emphasizes that this process is not so much led by product designers but is more a design management activity (Charter, 1997).

Many of the described approaches consider a system-innovation as a step for the long term. No precise definitions of this systems-approach and its consequences are given. U.S. Congress (1992) suggest to consider current products in its context in which it functions. Defining the system level on which to focus development is a relatively unknown activity.

Brezet emphasize that system innovations require changes in organization and structure, as they go beyond product-level. The broader the system is defined, the more collaboration between several players seems required in order to have sufficient influence and impact on the total system (Brezet, 1997).

1.7.3 From a consumption economy to a function economy

A possible new paradigm for a futuristic business development is the transition to a function oriented ecological closed loop economy. The goal with a function economy should be to contribute to “continuous higher quality of life with a continuos lower resource consumption” (Bomann-Larsen, 2000).

In a consumption economy which is the dominating direction of the western world economy today, is a linear “cradle to grave” approach. In a consumption economy the natural resources are seen as almost unlimited, and nature is sees as an unlimited sink which can receive unlimited amount of waste. If one resource is totally consumed, there is always a substitute. Natural capital and man-made capital are mainly substitutable, and can replace each other.

A function economy represents a fundamental shift in the relationship between producer and consumer, i.e. an economic change from procuring products to procuring services or functions. Such a service oriented economy can in a better way than a product oriented economy protect natures services on which any economic system totally relies. This will introduce a new understanding of the concept of value: a shift from the acquirement of materialistic products as an indicator for wealth to an economy where a continuos supply of quality, usefulness, efficiency and performance advances well-being.

A fundamental practical difference between a consumption economy and a function economy is where ownership of products is placed when the product is put into operation: on the hand of the customer or the producer/supplier. In a consumption economy one buys and sells products in preference to services. Ownership of products is transferred to buyer at point of sale. The producer is no longer responsible for how the product is being used during the product life; how it is being used, if it is deteriorated by wear or if it is disassembled and recycled at its end-of-life. This means that in the short term, producers will benefit from short product lives and rapid resource extraction to produce products in high volumes to replace products at their end-of-life. Producers will have an economic benefit from selling continuously increasing numbers of their products, and reduced economic benefit of long product lives to keep markets from being saturated (Bomann-Larsen, 2000).

A function economy, on the other hand, offers incentives for a practical transformation of the economy to emphasize conditions and arrangements which can fulfil customer needs more satisfactorily, and which may improve resource efficiency and advances an ecological closed loop economy.

1.7.4 Creating products on the basis of functionality

Michl (1991) discusses in his article “On the rumor of functional perfection“ the issues of an object having perfect functionality.

Michl argues that, what we call “human needs” are a telltale sign that our human existence is basically and fundamentally wanting in perfection, and he claims that the artefacts we surround ourselves with are our attempts to compensate for this fact (Michl, 1991). Furthermore, if human existence was perfect, the need for functional perfection would be absent, as such a state would lack the presence of needs whatsoever, because needs arise only where something is absent. Thus, having no needs, we would have no need for artefacts of any sort, since all our artefacts are there to meet our needs and wants (Michl, 1991).

The accelerating technical development, seems to promise that functional perfection is just around the corner, or at least within our reach. Michl argues that this seems to be the paradoxical reason why the idea of perfect functioning proves to be such an attractive concept, as our knowledge shows us that every product can be improved (Michl, 1991).

Michl makes an important point in that we tend to forget that although our artefacts do alleviate our wants, privations and deficiencies (i.e. our imperfections) they do not in fact make them go away. Not only does the problem remain: the thing devised to alleviate the problem always creates further problems in its own right. What our artefacts in fact do is to treat symptoms: they are patently unable to address the malady itself, the imperfection of our human existence. They are basically substitutes that wear out, break down, go out of fashion, and most often end on a landfill. But if they by chance survive physically, they will sooner or later achieve the status of antiques, where their makeshiftness becomes moderated by their potential for filling a new need regarding ownership (Michl, 1991).

Not only old products but new products as well are substitutes. We are unable to perceive their substitute nature clearly until they have become technologically and aesthetically obsolete. When they first appear on the market they blind us by the brilliance of their newness, amaze us with their improvements and their fashionable exteriors. All this encourages, the illusion that the newly- launched product has come one step closer to the haven of ultimate functional perfection (Michl, 1991).

As all products are characterized by makeshift functionality, their very existence leads unavoidably to the wasting of resources and energy. What we call functionality is not an absolute or objective value, but a relative, or subjective one. When we say that a device is functional we mean by that it is effective with respect to the intended purpose: it can be used to resolve the limited problem it was intended for, plus a certain limited range of other ad hoc ends. The fact that a product is unusable for practically all purposes except its own gives rise to a long line of new problems, which can be solved only with the help of still more resources and energy (Michl, 1991).

In addition to taking up space, many artefacts produce other unwanted results as well which are undesired by-products of the processes of satisfying our needs. This characteristic, and unavoidable, co-existence of intended and unintended effects in all human devices makes them a mixed blessing. The devices become often a nuisance for everybody except the person who owns and uses them, and when they are not in use they become nuisance for the owner as well (Michl, 1991).

The impossibility of separating the unintended effects from the intended ones seems to be at the core of the many environmental problems which have, since the 1970s, increasingly come to the fore in all kinds of contexts. In this time of rapidly growing ecological consciousness it is, however, important not to fall victim to the idle dream that the solution lies in devising a new ”perfect” economic and political order that would produce environmentally problem-free products. Although any product of the western economies can be rightly criticized for failing to be more ”perfect” than it in fact is, we must also realize that no products can ever be ”really” perfect. This fact is linked to the inherent imperfection of all our artefacts; the very notion of functionality simply implies the existence of unintended effects, i.e. of imperfection (Michl, 1991).

The solution to the environmental problems of today, may lie in a much sharper awareness and control of the unintended effects. It is no doubt possible to eliminate or at least subdue any unintended effect of an intended functional solution if we put our mind to it. This is a design problem just like any other one. The catch here is, again, that we cannot eliminate the phenomenon of unintended effects itself: solutions to any problem, including the problem of an unintended effect, bring about unintended effects of their own (Michl, 1991).

Engineers, architects and designers then are to strive for solutions and to control the unwanted side-effects of these solutions - but still bearing with the fact that the fruits of their work will always retain their substitute nature, and that no amount of improvements can ever change this fact (Michl, 1991).

Eekels (1994) arrives at similar conclusions when describing what he calls a law where

$$\text{Identified needs + resources} \rightarrow \text{Intended effects + unintended side-effects}$$

This is illustrated in Figure 1.8. All human activities follows this law. It can be explained using the laws of thermodynamics, where the unintended side-effects can represent the increase in disorder or the fact that the resources used are made unavailable for other purposes. This is always the consequence of using energy and materials, i.e. the steadily increasing entropy due to any activity in the ecosphere. Increasing entropy is a measure of a decrease in availability of resources.

Entropy approaches are usually utilized in energy balances. Such analyses are rare within the product development and manufacturing sphere.

Considering resources in the form of a steel plate, representing the ultimate order prior to a manufacturing process where this resource is utilized. The resource is cut into a number of parts (n), i.e. the intended effect of this manufacturing process. The plate is thus made unavailable as a primary resource. The remainder (m) of the steel plate can represent the unintended side-effect:

$$\text{Identified needs} + (1 \text{ steel plate} + \text{cutting resources}) \rightarrow n(\text{parts}) + m(\text{waste})$$

If the remainder, m can be used as a resource for a secondary process, the entropy is reduced as the secondary resource is utilized instead of a primary resource. If the remainder cannot be utilized, energy is required to transfer the unintended side effect into a resource.

Central issue

This is the central issue in this doctoral dissertation. The unintended side effects are what is causing the environmental problems, and is what this dissertation is all about.

Physical contradiction

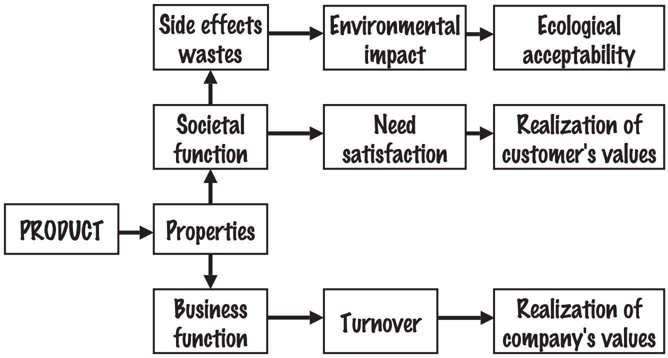
The unintended side-effects are in their nature physical contradictions, which are described later. Although all basic laws of physics naturally must be followed, the contradictions can trigger the creation of new solutions where the environmental performance is significantly increased, and hence the environmental load significantly reduced.

Removing unintended side effects

The author will argue that these unintended side effects can, using the concept of lateral thinking, give rise to a creative approach where the unintended effects apparently may disappear or at lest be significantly reduced. We know that the physical laws prohibit this, but the imagination gives rise to new innovative solutions.

The goal of this dissertation is therefore to present a strategy containing principles and methods for reducing the unintended side effects of a product system which arise through all meetings between the product and the product life systems.

Figure 1.8 The Ecological Track (Eekels (1994))



1.8 Scientific approach

1.8.1 The Procedure followed in the project.

Is design a science?

Leyer (1968) and Aasland (1995) argue that it is wrong to talk of design as a science. Design utilizes science, but in its critical phase it is an art and relies on inspiration and the creative skills of the designer. Furthermore, (Aasland, 1995, Kuhn, 1970) states that the hypothetical deductive method of science does not create new ideas. New ideas is essential when selecting alternative design options, indicating that deductive methods are not applicable in the creative activities of design. However, the research on the methods for designing products can be treated in a scientific manner.

Product development is an object of design science, and research on product development methods lie within the area of design methodology. Design methodology is according to Jakobsen (1995) and Roozenburg and Eekels (1995) the science of methods that are or can be applied in designing products, i.e. research on methods which results are directly applicable on the practical level. According to NOU (1988), applied science is the activity of original character to achieve new knowledge primarily aimed at resulting in practical applicability and goals.

A cross disciplinary field

Product development is a multidisciplinary process, consisting of several cross-disciplinary activities. These cross-disciplinary activities have relations to several research areas where the intention is that cooperation will result in new knowledge. Every area of science has its own language which makes communication difficult. However, research on complex problems may require more than one research viewpoint. Meetings between different research traditions and cultures can result in a deeper understanding and create complementary research results compared to research which is based on single research areas. Multidisciplinary processes and cross-disciplinary activities can result in the "creation" of a new scientific discipline. Jakobsen

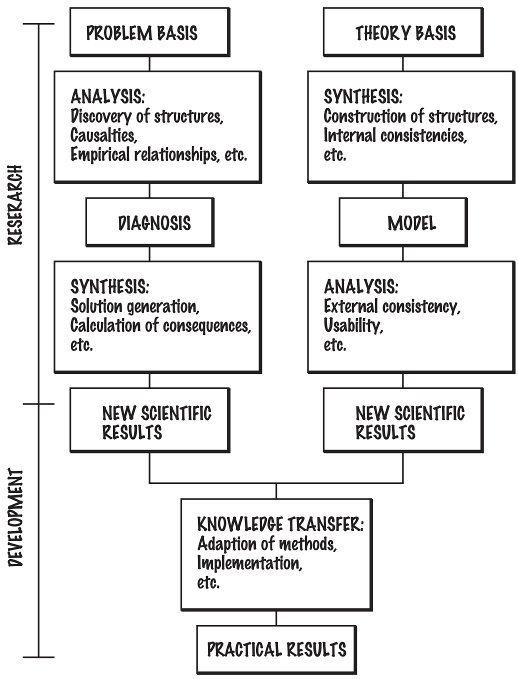
(1995) argue that safety and reliability engineering is such an example, and indicates that science of product development might also fall under this category.

The scientific procedure followed in the project

The process of the research project has been a continuous work within both the theoretical and application area. The approach is illustrated in Figure 1.9 This model was originally applied in the work of Jørgensen (1992). It has later been applied to a number of projects within similar sceintific area and similar research angle as described in this dissertation (Jakobsen, 1995, Keldmann, 1997, Mørup, 1993, Olesen, 1992). The idea behind the model is to improve existing models and methods to provide a better description of empirical reality. During the work, focus of the activities has shifted between the two tracks, through literature studies, logical structuring, empirical observations, thought experiments, etc.

The research has its starting point in a practical problem base where real phenomena in industry and literature are analyzed. The discovered problem areas are analyzed in the theoretical context where new hypothetical statements for leap improvements in environmental performance are formulated. To check their applicability the solutions and hypothesis are applied to product service examples and presented to other researchers within the same research field.

Figure 1.9 A method for applied research h in which attention is focused on the interplay between theory and practice, after Jørgensen (1992)



"breakthrough" innovation would be needed to achieve targets such as Factor 10, others emphasized that all types of innovation in technology, behavior and organization will be needed (OECD, 1997).

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There are several visions on how to break the incremental character of ecodesign and define more fundamental approaches for reaching leap improvements in environmental performance. A number of these approaches are (Van den Hoed, 1997):

1. Four levels of eco-innovation (Brezet, 1997)
2. System innovation (U.S. Congress, 1992)

3 Leapfrog strategies (Manzini, 1997)

4 Sustainable Product Design (Charter, 1997)

5 Sustainable Product Development (Van Weenen, 1997b)

The list gives an impression of current frameworks on industry and academics attempts for achieving sustainability and can be used to get more grip on characteristics of approaches for leap improvements in environmental performance (Van den Hoed, 1997).

Four levels of eco-innovation

Brezet (1997) discerns four types of product-related environmental innovation, based on extensive experience in ecodesign practice. The types are related to two axes: ecoefficiency and time-scale, see Figure 1.7. The transition from type 1 to type 4 requires an increase in innovation freedom, but is expected to achieve higher levels of ecoefficiency, while implementation time is expected to be longer.

The first type of improvement involves the improvement of products from the perspective of pollution prevention and environmental care. Both the product and its production technique will generally stay the same. Examples are the organization of a take-back system for tires and changing the type of coolant used and other types of actions leaving the fundamental properties of the product and its components unchanged.

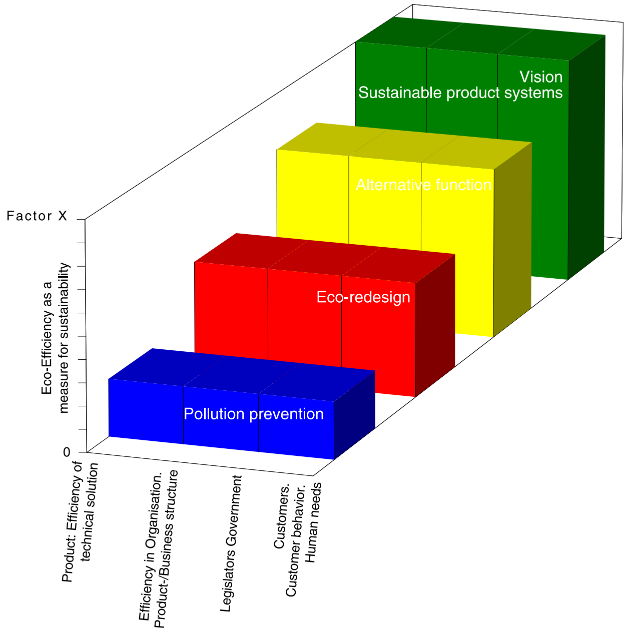
With the second type of improvement, product redesign, the product concept stays the same, but parts of the product are developed further or replaced by others. Examples are the use of other materials, design for recycling and minimizing of energy use during its life span through product and component modifications.

The third type, alternative function, is based on the function of the current product. In the Ecodesign strategy wheel (See Figure 3.16), this is equivalent to strategy 8, alternative function fulfillment. An example is the transition from letters to e-mail, where the function is 'information transfer'. The environmental profit is mainly through dematerialization.

The fourth type deals with system innovation. Changes in related infrastructure and organization are required in order to develop new products and services on a system level.

Brezet argues that a transition to longer term innovation is required for reaching environmental performance targets. Creating products on the basis of functionality and redefining systems are the most important aspects of this approach. However, no systematic approaches for carrying out this strategy are presently available (Van den Hoed, 1997, Brezet, 1997).

Figure 1.7 Four levels of environmental innovation. Modified from (Brezet, 1997)



Sustainable system-innovation

The need to move beyond product-redesign towards a more system-based innovation is underlined by the OTA (U.S. Congress, 1992). A distinction is made between a product-oriented and system-oriented approach. OTA concludes that not so much the environmental load of an individual product should be tackled, but more the total system-context in which the product functions.

OTA pleads for system-oriented design, although it is acknowledged that this has consequences on business' strategic planning (Van den Hoed, 1997).

Leap frog strategy

When discussing sustainable societies Manzini (1997) calls for system discontinuities. In this light leapfrog strategies refer to the transition from the current mix of products and services to a new and more sustainable one. The service aspect, as a strategy for dematerialization, is an important consideration, as not so much products should be sold, but more the result of the product. A strong relation can be seen with the function innovation, described by Brezet.

Whereas in the above approaches a strong focus was on developing new and more sustainable products or technologies, Manzini emphasizes that social innovation can be an alternative and possibly a more effective strategy for achieving sustainability. An example is the sharing of cars by multiple users, instead of selling cars to all of them. This represents the result-theory, in which not the possession of the car is central (product-oriented), but the possibility of transportation (the result) (Van den Hoed, 1997).

Sustainable Product Design

Charter (1997) states that a change will have to occur from redesigning products to rethinking them. The function of the product or the need of the consumer forms the basis. Furthermore it is emphasized that ecological aspects, concerning sustainable product design, will have to be balanced with economical, social and ethical needs.

Finally, the process of sustainable product design is described as a design management activity, in which the need to form stakeholders and partnerships becomes of increasing importance (Van den Hoed, 1997).

Sustainable product development

Like Brezet, Van Weenen (1997b) differentiates four levels of innovation strategies for achieving sustainable product development: end of pipe solutions, lifecycle design for environment, function innovation and sustainable product development. Van Weenen recognizes that theoretically functional innovation (level 3) is an interesting starting point, but that practical examples are scarce.

On the fourth level ‘Sustainable product development’ (SPD) is defined as a resource-, context- and future-oriented product development, aimed at providing elementary needs, a better quality of life, equity and environmental harmony. Resource -oriented, as it considers the properties and availability of resources and their distribution among countries and generations. Context-oriented, as SPD integrates context-related aspects as natural environment, society, technology and economy. Future-oriented, as SPD addresses future needs and values (Van den Hoed, 1997).

Comparison of the different sustainability approaches

Similarities between the described approaches which differ from the eco-design approach can be brought back to three overall points (Van den Hoed, 1997):

- function / need as a starting point as opposed to product optimization of Eco-design
- the use of an innovation process as opposed to the product design process of Eco-design.
- system level as opposed to the product level of Eco-design

All approaches have emphasizes that the starting point of the development process should not be the product itself, but based on the function or the need. A difference with Eco-design is the shift from optimizing current products to rethinking the function of this product (Van den Hoed, 1997).

Functions are product-related, in the way that they specify the function(s) a current product. Needs are consumer-related, in the way that they give insight in the need(s) of consumers which are served with products (or services). Although these terms are widely used, no descriptions are given how to use them and in what way they are successful for achieving sustainable products (Van den Hoed, 1997).

Whereas Eco-design is integrated in product design activities, it is recognized that sustainability requires processes starting at an earlier stage in the development process (Van den Hoed, 1997). Van Nes (1997) states that the goal of higher eco-efficiencies requires the integration of decision making in the product planning process, preceding the actual product design process. Charter emphasizes that this process is not so much led by product designers but is more a design management activity (Charter, 1997).

Many of the described approaches consider a system-innovation as a step for the long term. No precise definitions of this systems-approach and its consequences are given. U.S. Congress (1992) suggest to consider current products in its context in which it functions. Defining the system level on which to focus development is a relatively unknown activity (Van den Hoed, 1997).

Brezet emphasize that system innovations require changes in organization and structure, as they go beyond product-level. The broader the system is defined, the more collaboration between several players seems required in order to have sufficient influence and impact on the total system (Van den Hoed, 1997, Brezet, 1997).

1.7.3 From a consumption economy to a function economy

A possible new paradigm for a futuristic business development is the transition to a function oriented ecological closed loop economy. The goal with a function economy should be to contribute to “continuous higher quality of life with a continuos lower resource consumption” (Bomann-Larsen, 2000).

In a consumption economy which is the dominating direction of the western world economy today, is a linear “cradle to grave” approach. In a consumption economy the natural resources are seen as almost unlimited, and nature is sees as an unlimited sink which can receive unlimited amount of waste. If one resource is totally consumed, there is always a substitute. Natural capital and man-made capital are mainly substitutable, and can replace each other.

A function economy represents a fundamental shift in the relationship between producer and consumer, i.e. an economic change from procuring products to procuring services or functions. Such a service oriented economy can in a better way than a product oriented economy protect natures services on which any economic system totally relies. This will introduce a new understanding of the concept of value: a shift from the acquirement of materialistic products as an indicator for wealth to an economy where a continuos supply of quality, usefulness, efficiency and performance advances well-being.

A fundamental practical difference between a consumption economy and a function economy is where ownership of products is placed when the product is put into operation: on the hand of the customer or the producer/supplier. In a consumption economy one buys and sells products in preference to services. Ownership of products is transferred to buyer at point of sale. The producer is no longer responsible for how the product is being used during the product life; how it is being used, if it is deteriorated by wear or if it is disassembled and recycled at its end-of-life. This means that in the short term, producers will benefit from short product lives and rapid resource extraction to produce products in high volumes to replace products at their end-of-life. Producers will have an economic benefit from selling continuously increasing numbers of their products, and reduced economic benefit of long product lives to keep markets from being saturated (Bomann-Larsen, 2000).

A function economy, on the other hand, offers incentives for a practical transformation of the economy to emphasize conditions and arrangements which can fulfil customer needs more satisfactorily, and which may improve resource efficiency and advances an ecological closed loop economy.

1.7.4 Creating products on the basis of functionality

Michl (1991) discusses in his article "On the rumor of functional perfection" the issues of an object having perfect functionality.

Michl argues that, what we call "human needs" are a telltale sign that our human existence is basically and fundamentally wanting in perfection, and he claims that the artefacts we surround ourselves with are our attempts to compensate for this fact (Michl, 1991). Furthermore, if human existence was perfect, the need for functional perfection would be absent, as such a state would lack the presence of needs whatsoever, because needs arise only where something is absent. Thus, having no needs, we would have no need for artefacts of any sort, since all our artefacts are there to meet our needs and wants (Michl, 1991).

The accelerating technical development, seems to promise that functional perfection is just around the corner, or at least within our reach. Michl argues that this seems to be the paradoxical reason why the idea of perfect functioning proves to be such an attractive concept, as our knowledge shows us that every product can be improved (Michl, 1991).

Michl makes an important point in that we tend to forget that although our artefacts do alleviate our wants, privations and deficiencies (i.e. our imperfections) they do not in fact make them go away. Not only does the problem remain: the thing devised to alleviate the problem always creates further problems in its own right. What our artefacts in fact do is to treat symptoms: they are patently unable to address the malady itself, the imperfection of our human existence. They are basically substitutes that wear out, break down, go out of fashion, and most often end on a landfill. But if they by chance survive physically, they will sooner or later achieve the status of antiques, where their makeshiftness becomes moderated by their potential for filling a new need regarding ownership (Michl, 1991).

Not only old products but new products as well are substitutes. We are unable to perceive their substitute nature clearly until they have become technologically and aesthetically obsolete. When they first appear on the market they blind us by the brilliance of their newness, amaze us with their improvements and their fashionable exteriors. All this encourages, the illusion that the newly- launched product has come one step closer to the haven of ultimate functional perfection (Michl, 1991).

As all products are characterized by makeshift functionality, their very existence leads unavoidably to the wasting of resources and energy. What we call functionality is not an absolute or objective value, but a relative, or subjective one. When we say that a device is functional we mean by that it is effective with respect to the intended purpose: it can be used to resolve the limited problem it was intended for, plus a certain limited range of other ad hoc ends. The fact that a product is unusable for practically all purposes except its own gives rise to a long line of new problems, which can be solved only with the help of still more resources and energy (Michl, 1991).

In addition to taking up space, many artefacts produce other unwanted results as well which are undesired by-products of the processes of satisfying our needs. This characteristic, and unavoidable, co-existence of intended and unintended effects in all human devices makes them a mixed blessing. The devices become often a nuisance for everybody except the person who owns and uses them, and when they are not in use they become nuisance for the owner as well (Michl, 1991).

The impossibility of separating the unintended effects from the intended ones seems to be at the core of the many environmental problems which have, since the 1970s, increasingly come to the fore in all kinds of contexts. In this time of rapidly growing ecological consciousness it is, however, important not to fall victim to the idle dream that the solution lies in devising a new ”perfect” economic and political order that would produce environmentally problem-free products. Although any product of the western economies can be rightly criticized for failing to be more ”perfect” than it in fact is, we must also realize that no products can ever be ”really” perfect. This fact is linked to the inherent imperfection of all our artefacts; the very notion of functionality simply implies the existence of unintended effects, i.e. of imperfection (Michl, 1991).

The solution to the environmental problems of today, may lie in a much sharper awareness and control of the unintended effects. It is no doubt possible to eliminate or at least subdue any unintended effect of an intended functional solution if we put our mind to it. This is a design problem just like any other one. The catch here is, again, that we cannot eliminate the phenomenon of unintended effects itself: solutions to any problem, including the problem of an unintended effect, bring about unintended effects of their own (Michl, 1991).

Engineers, architects and designers then are to strive for solutions and to control the unwanted side-effects of these solutions - but still bearing with the fact that the fruits of their work will always retain their substitute nature, and that no amount of improvements can ever change this fact (Michl, 1991).

Eekels (1994) arrives at similar conclusions when describing what he calls a law where

$$\text{Identified needs} + \text{resources} \rightarrow \text{Intended effects} + \text{unintended side-effects}$$

This is illustrated in Figure 1.8. All human activities follows this law. It can be explained using the laws of thermodynamics, where the unintended side-effects can represent the increase in disorder or the fact that the resources used are made unavailable for other purposes. This is always the consequence of using energy and materials, i.e. the steadily increasing entropy due to any activity in the ecosphere. Increasing entropy is a measure of a decrease in availability of resources.

Entropy approaches are usually utilized in energy balances. Such analyses are rare within the product development and manufacturing sphere.

Considering resources in the form of a steel plate, representing the ultimate order prior to a manufacturing process where this resource is utilized. The resource is cut into a number of parts (n), i.e. the intended effect of this manufacturing process. The plate is thus made unavailable as a primary resource. The remainder (m) of the steel plate can represent the unintended side-effect:

Identified needs + (1 steel plate +cutting resources) → n(parts) + m(waste)

If the remainder, m can be used as a resource for a secondary process, the entropy is reduced as the secondary resource is utilized instead of a primary resource. If the remainder cannot be utilized, energy is required to transfer the unintended side effect into a resource.

This is the central issue in this doctoral dissertation. The unintended side effects are what is causing the environmental problems, and is what this dissertation is all about.

The unintended side-effects are in their nature physical contradictions, which are described later. Although all basic laws of physics naturally must be followed, the contradictions can trigger the creation of new solutions where the environmental performance is significantly increased, and hence the environmental load significantly reduced.

The author will argue that these unintended side effects can, using the concept of lateral thinking, give rise to a creative approach where the unintended effects apparently may disappear or at lest be significantly reduced. We know that the physical laws prohibit this, but the imagination gives rise to new innovative solutions.

The goal of this dissertation is therefore to present a strategy containing principles and methods for reducing the unintended side effects of a product system which arise through all meetings between the product and the product life systems.

CHAPTER 2

MEASURING PROGRESS TOWARDS SUSTAINABILITY

This chapter discusses how to measure sustainable development and environmental performance. Different views of efficiency are discussed. Furthermore, the meaning og leap improvement of environmental performance is discussed. The intention of the chapter is the need to identify the basis for improvement as the starting point for leap improvement of envrionmental performance

2.1 Introduction

The term sustainable product development has emerged in parallel with the discussion on how to achieve a sustainable society. Several authors have tried to define what the concept of development of sustainable products should contain.

Van Weenen (1997) argues that

> *Sustainable Product Development is defined as resource-, context- and future oriented product development, aimed at the fulfillment of elementary needs, better quality of life, equity and environmental harmony.*

Brezet (1997) presents the concept of sustainable product systems as a four step ladder. The four levels have increasing potential to bring about environmental improvements and presents guidelines for thinking for businesses in a longer perspective to be included in their long term strategies.

Charter (1997) describes sustainable product design by three key issues

1. Sustainable Product Design is a design management practice which has, as a key element, the need to ensure that economic, environmental, ethical and social needs are balanced.

2 Sustainable Product Development acknowledges the need to develop innovative product- and service- concepts which minimize environmental, ethical and social impact throughout the life cycle.

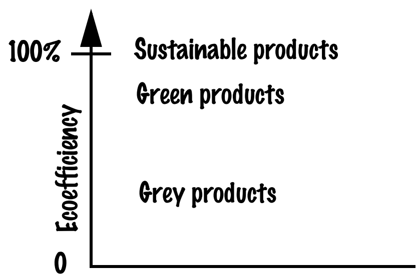
3 Sustainable Product Development is a systems-orientated approach that recognizes the need to form broader stakeholder relationships and partnerships. The aim is to produce zero emissions.

The author disagrees in the thought that a product in itself can be sustainable, but the product can support and contribute to sustainable activities. Simon and Sweatman (1997) are aware of the fact that the source of the major environmental loads are only indirectly related to industrial products. However, with design determining a large proportion of the resources consumed in the industrialized world, and consumer expenditures on commodities affected heavily by design choices representing a considerable economic volume, products of such kind assume a significant importance for sustainability. Simon and Sweatman (1997) present the principles of sustainable product design (SPD) and the criteria for measuring the “ecoefficiency“ of products, since as they claim only very ecoefficient products can be sustainable. This issue will be discussed later in section 2.3, “Environmental performance”. Furthermore, they distinguish SPD from design for environment (DfE), which they correctly claim is the incremental improvement of existing products which does not challenge the status quo of the consumer society.

Simon and Sweatman (1997) argue that “design for the environment” (DfE) measures relative improvement in existing products as progress--leading to e.g. so-called “factor 4”-products with halved energy and material consumption. The disadvantage of this idea is that it doesn't distinguish between today's worst and best products but only looks for overall progress. They also question the relevance of much of the literature on the subject of environmental improvement of industrial products which don‘t even mention the principles of sustainability.

An absolute measure gives us a spectrum on which we can place all products, as follows (see Figure 2.1):

Figure 2.1 Eco Efficiency of products (after Simon and Sweatman, 1997)



- 100% ecoefficiency: sustainable products, those that can be produced in large quantities indefinitely;

- high ecoefficiency: products which have many environmentally-conscious features but which can only be produced either in limited quantity or for a limited time;
- low ecoefficiency: products whose production depletes non-renewable resources, damages human health or pollutes the environment.

If the average ecoefficiency of all products is steadily increasing, then we are moving towards sustainability. There are clearly very few truly sustainable products. Measuring ecoefficiency can indicate which products should be redesigned or replaced.

The above classification fits the three categories of product defined by the Braungart (WBCSD, 1998):

- consumption products, which are fully biodegradable and can be discarded after use. Braungart (WBCSD, 1998) claims that these products are sustainable, but this author would argue that this is only partly correct, as it requires production using sustainability principles;
- service products, which must be taken back by the producer for treatment and are thus of less than 100% ecoefficiency;
- unmarketable products, which cannot be safely used or disposed and must be stored (such as toxic waste) - these we might say had zero ecoefficiency.

Any quantitative measure of ecoefficiency will contain a valuation, in other words a weighting of the relative importance of the criteria used. One of the existing valuations scales is the Ecopoints system (Goedkoop, 1995) which awards points for all environmental effects in the life span. This scale could be inverted - a low Ecopoints score would mean high ecoefficiency.

Simon and Sweatman (1997) argue that:

> *Sustainable development depends on two things: <u>what types of products</u> are made, and <u>in what quantity</u> they are made. The issue of quantity of production can only be settled by knowing the carrying capacity of the environment. Even then, the concept of restricting production raises complex questions of social and international equality. Consumption is normally limited by market forces. Even with new tax regimes, market economics will be inadequate to restrict consumption of products and the question of social benefit arises - is the product really needed? Hence it is useful to define the nature of a sustainable product or at least to have some absolute measure of "degree of sustainability" - which we will call "ecoefficiency". This will allow social benefit to be set against environmental cost*

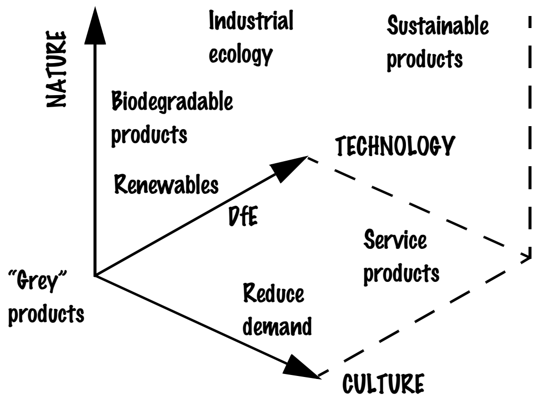
Based on this text, Simon and Sweatman (1997) argue that 'sustainable product design' (SPD) measures (theoretically) absolute benefit according to a scale of ecoefficiency - whereby 100% would be attributed to products that could be made in large quantities indefinitely - and is therefore the preferred approach.

Manzini (1997) presents a model with two axes, representing technology and culture. Progress on both axes is needed to achieve sustainability. Dematerialization can be achieved either by technical advance or by cultural change: by more efficient car engines or by car sharing, for example. This is a useful way of recognizing the importance of cultural factors. Simon and Sweatman (1997) extend Manzini's model to three independent, orthogonal axes of progress: Culture, Technology and Nature (See Figure 2.2).

Figure 2.2 indicates that an absolute sustainable product does not exist. The degree to which we can measure the environmental load of the product converges towards sustainability. This will be discussed later.

Based on the above discussion on the environmental load of industrial products, and how to relate this to the progress towards sustainability, there is an evident need to clarify the principles of sustainable development.

Figure 2.2 A three-dimensional model presenting the degree of sustainability of industrial products (after Simon and Sweatman, 1997)



2.2 Sustainable Development

In the face of growing crisis of environmental problems, the United Nations General Assembly formed the World Commission on Environment and Development in 1983. The resulting report, "our common future" urges all the nations of the world to incorporate sustainable development principles into their policy programme (WCED, 1987).

Sustainable development is broadly presented as

> *development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987)*

The idea of sustainable development brings together contemporary concerns about environmental and ecological threats with reappraisal of the approaches taken to development during the past four decades. It leads to a redefinition of the roles for most major development institutions. The implications of sustainable development, as elaborated in particular by the WCED - sustained economic growth, the elimination of poverty and deprivation, conservation of the environment and enhancement of the resource base - are compelling. The Commission suggested a number of important objectives, but with no proposal for adequate criteria for the setting of priorities among them.

Several institutions have tried to operationalize the concept of sustainable development into guidelines and principles for use in business strategy development and daily activities. The International Institute of Sustainable Development (IISD) have collected a number if these initiatives into a map of 103 different explanations of the concept (IISD, 1998)

The 103 different definitions mapped by International Institute for Sustainable Development vary considerably in seriousness. These definitions span from the business-as-usual-type principles of ORTEE (1992) to the comprehensive Bellagio Principles (Hardi and Zdan, 1997).

The principles of ORTEE tries to justify a business-as-usual approach which indicates a lack of understanding of what sustainability is all about. Several of the principles presented in the IISD list are observations of the same kind. This may indicate that companies and organizations try to justify a business-as-usual approach and fear to attack the environmental problem by its roots and redefine the basic properties of their activities.

It is also a misunderstanding that principles of sustainable development shall be generic and valid for all members of a society. As the general description of sustainable development focuses on present and future needs, principles for preceding in the direction of such a sustainable development will be defined individually on an organizational level. Members of the organization will need to arrange their behavior to cope with these definitions, or try to modify the definitions to cope with their individual needs.

A view often shared by economists is a close relationship to the price mechanisms of the capitalistic society. Scarcity of resources is a phenomenon which will automatically be adjusted through the price mechanisms of supply and demand. This is illustrated by an interview by Raviailo with Friedman in Economists and the Environment (Raviailo, 1995):

Nobel Laureate Friedman: *If we were living on the capital, the market price would go up. The price of truly limited resources will rise over time. The price of oil has not been rising, so we're not living on the capital. When that is no longer true, the price system will give a signal and the price of oil will go up. As always happens with a truly limited resource.*

Raviailo: *Of course the discovery of new oil wells has given the illusion of unlimited oil …*

Nobel Laureate Friedman: *Why an illusion?*

Raviailo: *Because we know it's a limited resource.*

Nobel Laureate Friedman: *Excuse me, it's not limited from an economic point of view. You have to separate the economic from the physical point of view. Many of the mistakes people make come from this. Like the stupid projections of the Club of Rome: they used a purely physical approach, without taking prices into account. There are many different sources of energy, some of which are too expensive to be exploited now. But if oil becomes scarce they will be exploited. But the market, which is fortunately capable of registering and using widely scattered knowledge and information from people all over the world, will take account of those changes.*

What Friedman really says here, is that we just have to wait and see. There is no need to bother about resource scarcity and environmental pollution, because the price mechanisms will take care of it. This will result in an example of an disastrous escape from a technological lock-in, which may be synonymous to the system breakdown as described by Meadows et al. (1972) and Meadows et al. (1991).

Friedman argues that prices will rise as a consequence of environmental problems. The natural answer to this argument is that the economy as a whole must grow larger in order to create enough value to be able to pay the higher prices.

One of the findings of the analyses in *Limits to growth* (Meadows et al., 1991) and *Beyond limits to growth* (Meadows et al., 1972), was related to the growth philosophy maintained by growth economists. These contributors claim that economic growth is needed to simultaneously be able to handle activities to restore environmental damage. These activities are part of the total industrial output in addition to consumer goods. Thus as economic growth in the form of industrial output grows, a continuously larger part of this output is used for producing activities which do not contribute to the intended output of the goods and services, but to restore damage caused by producing the intended output, and consequently, industrial output must grow even larger. Thus, without fundamental changes the growth strategy will turn into a recursive move which eventually will have catastrophic results.

If current economic growth leads to a decline in future welfare, measured as the per capita consumption potential of both marketplace and environmental goods, the growth path would then not be considered sustainable (OECD, 1992). Hence, in per capita terms, “sustainability” can be defined as non declining consumption potential, broadly defined. Consumption potential is in turn linked to future production potential and hence to capital stocks, measured in efficiency terms so as to include the effects of technological progress. If environmental resources are considered as part of the capital stock, the total human made and environmental capital must not decline if total consumption of marketed and environmental goods is to be sustained. Thus, in per capita terms, sustainable growth requires either non declining stocks of both kinds of capital or sufficient levels of substitution of productive capital for environmental capital to keep total capital stocks intact (OECD, 1992).

Several authors argue that the need for economic growth is a requirement to cope with the environmental problems and achieve the utopian goal of a sustainable society. However, the term “development” does not necessarily mean growth, at least not when it comes to size as described above.

What does sustainable development mean?

In general terms, the idea of sustainability is the persistence of certain necessary and desired characteristics of people, their communities and organizations, and the surrounding ecosystem over a very long period of time (indefinitely). Hardi and Zdan (1997) argue that achieving progress toward sustainability implies maintaining and preferably improving, both human and ecosystem well-being, not one at the expense of the other. The idea expresses the interdependence between people and the surrounding world.

Development means to expand or realize the potentialities of, bring gradually to a fuller, greater, or better state. It has both qualitative and quantitative characteristics and is to be differentiated from growth which applies to a quantitative increase in physical dimensions (Hardi and Zdan, 1997).

Sustainable development is not a fixed state. Rather, it is a dynamic process in which people take actions which leads to minimal effects on the surrounding environment. Conversely, actions that reduce the ability of the surrounding environment as a support system, both presently and in the future, should be avoided (Hardi and Zdan, 1997).

Sustainable development of human society has environmental, material, ecological, social, economic, legal, cultural, political and psychological dimensions that require attention: some forms of sustainable development can be expected to be much more acceptable to humans and, therefore, much further away from eventual collapse than others. A just and fair society, for example, is likely to be more securely sustainable than a materially sustainable brutal dictatorship (Bossel, 1999).

Hardi and Zdan (1997) argue that progress toward sustainable development is a matter of social choice; choice for individuals and families, for communities, for organizations in society, and for government. Because it involves choice, change is only possible with the broad involvement of the general public and decision-makers in government and across society. Furthermore, because of the need for this involvement, care must continually be taken to ensure that substantive conceptual and technical issues are considered within the context of the value-driven processes of real, day-to-day decision-making. In this way, new insights can effectively be be included by decision-makers and conversely, the processes of assessment and decision-making can enhance technical and public knowledge (Hardi and Zdan, 1997).

To sustain means “to keep from falling; keep up; maintain” (Hornby, 1974). If applied only in this sense, sustainability does not make much sense for human society. Human society cannot be maintained in the same state. Human society is a complex adaptive system embedded in another complex adaptive system - the natural environment - on which it depends for support. These systems coevolve in mutual interaction, and they each consist of a myriad of subsystems that coevolve in mutual interaction. There is permanent change and evolution. Bossel (1999) argues that this ability for change and evolution must be maintained if the systems are to remain viable and sustainable.

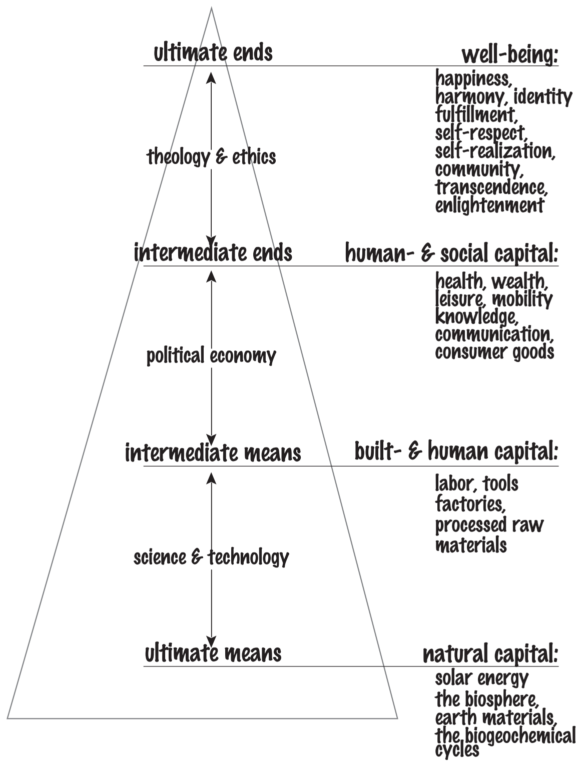
Sustainability is a dynamic concept. Societies and their environments change, technologies and cultures change, values and aspirations change, and a sustainable society must allow and sustain such change, i.e., it must allow continuous, viable and vigorous development, which Bossel (1999) argues is what is meant by sustainable development. The author believes that "continous, viable and vigorous development" is an easier interpretable understanding of sustainable development.

Any theoretical concept of sustainability must obey the physical constraints which for the framework nature has provided us with. These constraints include physical constraints, constraints of human nature and goals and constraints of time (Bossel, 1999).

Meadows presents a model for the identification of indicators for sustainable development based on a diagram of Daly (1973). It pictures the relationship between the human economy and the earth in a way that she claims, is logical, systematic, and clarifying (Meadows, 1998). (See Figure 2.3).

At the base of the triangle, supporting everything, are what Daly calls the ultimate means out of which all life and all economic transactions are built and sustained. This is natural capital, the matter of the planet, the sun's energy, the bio-geochemical cycles, the ecosystems and the genetic information they bear, and the human being as an organism. These ultimate means are not created by us; they are the heritage we were born into, and rely on. They are studied by the sciences and converted through technology to intermediate means (Meadows, 1998).

Figure 2.3 Hierarchy of means and ends (after Meadows (1998) and Daly (1973))



The intermediate means are tools, machines, factories, skilled labor, processed material and energy — built capital and human capital and raw material. These intermediate means define the productive capacity of the economy. Intermediate means are necessary but not sufficient to accomplish all higher purposes. The intermediate ends are the goals that governments promise and economies are expected to deliver — consumer goods, health, wealth, knowledge, leisure, communication, transportation. Intermediate ends are not ends in themselves, but instruments to achieve something yet higher. Any product intends to fulfil a subjective sense of satisfaction with the customer. The customer seeks satisfaction under certain circumstances through getting hold on the product. This satisfaction is achieved by the way the product expresses its properties to an extent the customer finds sufficient to become satisfied. The link between human satisfaction and product property expression is placed at the top of the pyramid. At the top of the triangle is the ultimate end. The ultimate end of human economic activity and human life is often described by happiness, harmony, fulfillment, self respect, self realization, community, identity, transcendence, enlightenment. The impossibility of defining these words, or agreeing on ultimate end or ends, demonstrates that we are discussing something immaterial, not material, though it requires the whole material triangle underneath to support it (Meadows, 1998).

Sustainable development requires systems information

The total system of which human society is a part, and on which it depends for support, is made up of a large number of component systems. Bossel (1999) argues that the whole cannot function properly and is not viable and sustainable if individual subsystems cannot function properly, i.e. if they are not viable and sustainable. Sustainable development is possible only if subsystems as well as the total system are viable. It is therefore necessary to identify the essential subsystems and to define indicators that can provide essential and reliable information about the viability of each and of the total system. There is general awareness within the research community that the present indicators lack the necessary characteristics to provide all essential information about the viability of a system and its rate of change, and to indicate the contribution to the overall objective, which is a continous, viable and vigorous development.

Realizing the inadequacy of current approaches to indicators of sustainable development, Bossel (1999) emphasizes the need to analyze the entire complex of problems and tasks more carefully. This requires a reasonably detailed (mental or formal) model of the total system and its components. There are three separate tasks (Bossel, 1999):

1 We must identify the major systems that are relevant in the context of sustainable development;

2 We must develop an approach for identifying indicators of viability and sustainability of these systems; and

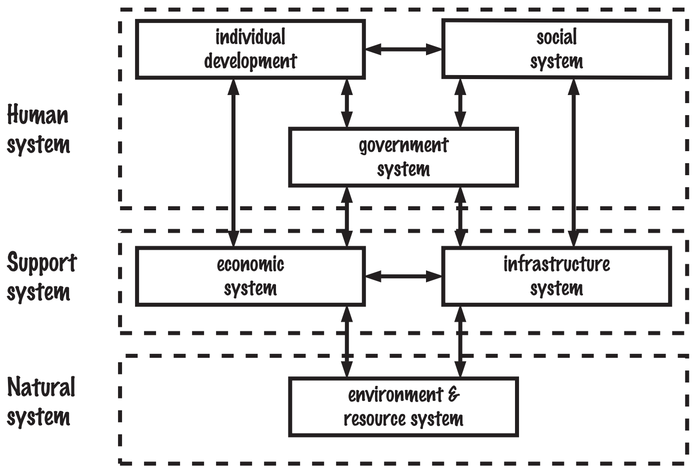
3 We must think about how to use this information for assessing viability and sustainability of human development at different levels of societal organization.

Modelling the total system

In order to define an indicator set for the assessment of societal development, Bossel (1999) proposes different relevant sectors or subsystems of the societal system which include systems that constitute society as well as the systems on which human society depends. A useful distinction of subsystems is the following (Bossel, 1999) (see Figure 2.4):

- Individual development (civil liberties and human rights, equity, individual autonomy and self-determination, health, right to work, social integration and participation, gender and class-specific role, material standard of living, qualification, specialization, adult education, family and life planning horizon, leisure and recreation, arts)
- Social system (population development, ethnic composition, income distribution and class structure, social groups and organizations, social security, medical care, old age provisions)
- Government (government and administration, public finances and taxes, political participation and democracy, conflict resolution (national, international), human rights policy, population and immigration policy, legal system, crime control, international assistance policy, technology policy)
- Infrastructure (settlements and cities, transportation and distribution, supply system (energy, water, food, goods, services), waste disposal, health services, communication and media, facilities for education and training, science, research and development)
- Economic system (production and consumption, money, commerce and trade, labour and employment, income, market, interregional trade)
- Resources and environment (natural environment, atmosphere and hydrosphere, natural resources, ecosystems, species, depletion of nonrenewable resources, regeneration of renewable resources, waste absorption, material recycling, pollution, degradation, carrying capacity)

Figure 2.4 The six major systems of the anthroposphere and their major relationships. These six sector systems can be aggregated to the three subsystems: human system, support system and natural system (after Bossel, 1999).



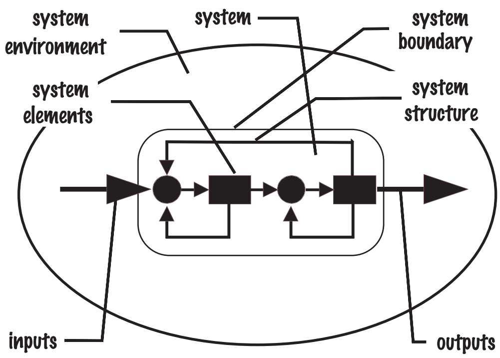
Bossel (1999) argues that these subsystems are all essential parts of the anthroposphere, i.e., the sphere that is affected by and affects human society. Each of these subsystems can be viewed as representing a certain type of potential that is vital to the development of the total system. The term potential denotes a stock or capital of a vital asset, which can grow or deteriorate, and must be maintained in order to contribute its share to the development of the total system.

For each subsystem, a number of indicators to capture all aspects of its viability and sustainability and of their contributions to viability and sustainability of the total system, is needed. The total number of indicators increases with the number of subsystems included. A system is anything that is composed of system elements connected in a characteristic system structure (Figure 2.5). This configuration of system elements allows it to perform specific system functions in its system environment. These functions can be interpreted as serving a distinct system purpose. The system boundary is permeable for inputs from- and outputs to the environment.

Hierarchy and subsidiarity facilitate efficient operation

Systems are termed complex if they have an internal structure of many qualitatively different processes, subsystems, interconnections and interactions. Besides assuring their own viability, the individual systems that are part of a complex total system specialize in certain functions that contribute to the viability of the total system. Viability of subsystems and the total system requires that subsystem functions and interactions are organized efficiently (Bossel, 1999).

Figure 2.5 A system interacts with its system environment through system inputs and outputs



The systems view tries to capture the holistic view showing how each element of the system interacts with each other and the environment. This is essential when considering which actions to take. Optimizing the product through all phases of its life span in isolation may not be the most beneficial activity. Although optimizing the isolated technical system of the product is always in the interest of the producer of this system, an even more beneficial strategy may be to focus on “to do the right thing” based on the holistic view where the product is a component.

Holling et. al. (1995) observes that environmental problems are often systems problems where aspects of behavior are complex and unpredictable and argues that their causes are always multiple (Hodge et al., 1999, Holling et al., 1995). Interdisciplinary and integrated modes of inquiry are needed for understanding. Furthermore, environmental problems typically have non-linear causes; they demonstrate multi stable states and discontinuous behavior in both time and space (Hodge et al., 1999).

Bossel (1999) claims that it is not enough to be concerned with the viability of individual systems: there are no isolated systems in the real world; all systems depend in one way or another on other systems. Hence their viability and ultimately the viability of the total system are also preconditions for sustainable development. This means that a holistic system view must be adopted in the search for indicators (Bossel, 1999).

The principles of hierarchical organization and subsidiarity require that each subsystem have a certain measure of autonomy. In its particular system environment, each subsystem must be viable. The total system can only be viable if each of the subsystems supporting it is simultaneously viable. Thus, developing indicators for sustainable development implies to identify the subsystems that are essential for the functioning of the total system, and must determine subsystem variables (indicators) that can provide essential information about the viability of each subsystem (Bossel, 1999). This requires defining a set of indicators that mirrors the hierarchy of systems.

The concern for health and, more fundamentally, for existence represents very important interests that orient most of our decisions and actions, directly or indirectly. Bossel (1999) introduces the term orientors to represent such interests, values, criteria or objectives. Orientors are labels for certain categories of concerns or interests. The orientors measure the ability of any system to meet environmental challenges by appropriate system responses. Different systems may have the same orientors, but would have different corresponding indicators. Orientors are mostly general terms like health, existence, freedom, security, and so on that represent important interests of people or systems in general, but which cannot usually be measured directly.

Bossel (1999) proposes six fundamental properties of relevance to system environments (see Table 2.1). These are properties of the system environment which all systems have to repond to. Furthermore, Bossel (1999) claims that these properties are fundamental for all systems: technical, biological, social, etc., and unique, i.e. if we want to describe a system’s environment fully, we have to say something about each of these properties. The six properties of system environments are presented in Table 2.1

Basic orientors represent basic system interests

Bossel (1999) argues that corresponding to the six fundamental environmental properties, there are six environment-determined basic orientors (existence, effectiveness, freedom of action, security, adaptability, and coexistence) that apply to all autonomous self-organizing systems. The Bossel orientors are summarized in Table 2.2

Table 2.1 Properties of system environments (from (Bossel, 1999)

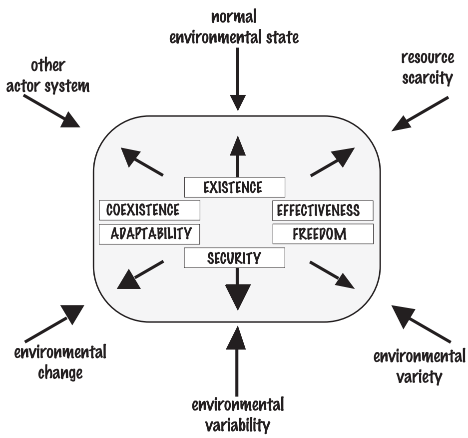
Properties of system environments
• *Normal environmental state:* The actual environmental state can vary around this state in a certain range.
• *Resource scarcity:* Resources (energy, matter and information) required for a system's survival are not immediately available when and where needed.
• *Variety:* Many qualitatively different processes and patterns of environmental variables occur and appear in the environment constantly or intermittently.
• *Variability*: The state of the environment fluctuates around the normal environmental state in random ways, and the fluctuations may occasionally take the environment far from the normal state.
• *Change*: In the course of time, the normal environmental state may gradually or abruptly change to a permanently different normal environmental state, i.e., it shifts to a different normal environmental state.
• *Other systems:* The environment contains other actor systems whose behavior may have system-specific (subjective) significance for a given actor system.

Table 2.2 Basic orientors of systems (from Bossel, 1999, Meadows, 1998)

Basic orientors of systems
• EXISTENCE: The system must be compatible with and able to exist in the normal environmental state. The information, energy and material inputs necessary to sustain the system must be available.
• EFFECTIVENESS: The system should on balance (over the long term) be effective (not necessarily efficient) in its efforts to secure scarce resources (information, matter, energy) and to exert influence on its environment.
• FREEDOM OF ACTION: The system must have the ability to cope in various ways with the challenges posed by environmental variety.
• SECURITY: The system must be able to protect itself from the detrimental effects of environmental variability, i.e., variable, fluctuating and unpredictable conditions outside the normal environmental state.
• ADAPTABILITY: The system should be able to learn, adapt and self-organize to generate more appropriate responses to challenges posed by environmental change.
• COEXISTENCE: The system must be able to modify its behavior to account for behavior and interests (orientors) of other (actor) systems in its environment.

Systems must be compatible with their system environment and its characteristic properties in order to be viable, to exist and contribute to sustainability. The environmental properties can therefore be viewed as imposing certain requirements and restrictions on systems, which orient their functions, development and behavior. This is illustrated in Figure 2.6

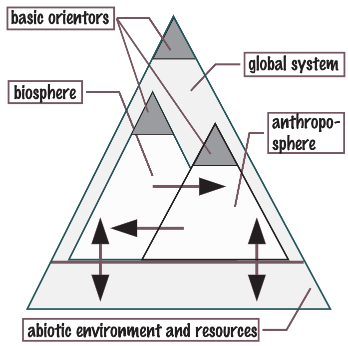
Figure 2.6 Fundamental properties of system environments and their basic orientor counterparts in systems (Bossel, 1999).



Conceptual understanding of the total system

As noted above, Bossel (1999) explains how a conceptual understanding of the total system is needed to understand the contributions from the different subsystems. Full understanding of the total system is not possible, but that cannot be an excuse for not doing the best possible job of collecting information and piecing and put together a comprehensive conceptual or even formal model of the system, its components and their interactions. It is usually possible to capture essential processes and relationships even in crude models, and the model can always be improved as new knowledge is gained about the system.

Figure 2.7 Mutual relationships of systems and their subsystems and supra systems in the total system (Bossel, 1999).



Information is needed to determine which subsystems are of particular importance and where to look for indicator candidates. This quickly grows into an insurmountable task, but can be simplified by identifying individual systems and noting their mutual interactions and relationships to other systems, and to their subsystems and supra systems Figure 2.7.

In this systems view, Bossel (1999) presents a procedure where the identification of indicators of sustainable development for the total or global system reduces to a recursive procedure, where the same questions have to be repeated for all component systems recognized as important or essential, as described in Table 2.3.

The procedure first identifies the major systems contributing to the viability of the total system, then the subsystems contributing to the viability of each major system, then the sub-subsystems contributing to the viability of each subsystem, etc. In this procedure, the viability-affecting systems at all system levels, and their influences on the satisfaction of a particular basic orientor of an affected system, can be identified.

Table 2.3 General (recursive) scheme for identifying indicators of viability (Bossel, 1999).

Basic orientor	Viability of affecting system	Contribution to affected system
existence	Is the system compatible with and can it exist in its particular environment?	Does the system contribute its part to the existence of the affected system?
effectiveness	Is it effective and efficient?	Does it contribute to the efficient and effective operation of the total system?
freedom of action	Does it have the necessary freedom to respond and react as needed?	Does it contribute to the freedom of action of the total system?
security	Is it secure, safe and stable?	Does it contribute to the security, safety and stability of the total system?
adaptability	Can it adapt to new challenges?	Does it contribute to the flexibility and adaptability of the total system?
coexistence	Is it compatible with interacting subsystems?	Does it contribute to the compatibility of the total system with its partner systems?
psychological needs[a]	Is it compatible with psychological needs and culture?	Does it contribute to the psychological well-being of people?

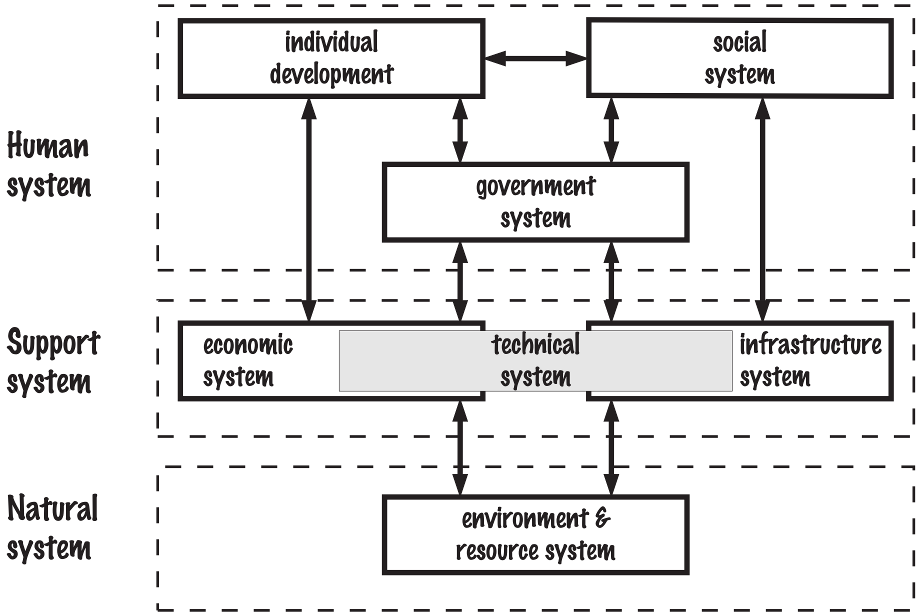
a. only for systems with sentient beings

Meadows (1998) emphasizes the need for indicator sets to present the dynamics of the development of different systems and at different system levels. Therefore indicators should be sought that capture, up and down the pyramid, the extent to which the various forms of capital complement and enhance or undermine and undercut each other. Wherever possible, indicators should be reported as time graphs rather than static numbers. Time graphs show not only the present state of an indicator, but its trend over time. Without an indicator's dynamics, the lessons learned from it becomes invisible.

Where are the Technical systems?

The technical system is missing from Figure 2.4. The technical system is basically a support system, supporting basic needs in society. The technical system gives in this sense either economic benefit for the user, i.e. the technical system is part of the economic system, or infrastructural support for the user, i.e. the technical system is part of the infrastructure system. Normally the technical system is part of both, as illustrated in Figure 2.8.

Figure 2.8 Locating the technical system



Technical systems are more or less only interesting when it is fulfilling some customer needs. An industrial activity arises when this customer is willing to pay the price to fulfill his need by utilizing the technical system.

Industry has been accused for being the source of all environmental problems of the world today. Consequently one may believe that the source lies in the technical systems which altogether makes the industrial system. However, the technical systems are only a part of the industrial activities of the economic system, and hence, it is therefore a need to differentiate the target of the criticism as the source of this major challenge of the world today.

2.3 Environmental performance

2.3.1 Original ecoefficiency approach

Originally, the term ecoefficiency means "doing more with less" - a precept that has its roots in early industrialization. Industry is daily striving at achieving increased productivity by receiving more output with less input.
The term "ecoefficiency" was promoted by the Business Council for Sustainable Development (BCSD), who brought a business perspective to the Earth Summit in 1992. The council presented its call for change in practical terms, focusing on what businesses had to gain from a new ecological awareness rather than on what the environment had to lose if industry continued in current patterns. Several definitions and interpretations on the concept of ecoefficiency have emerged. The World Business Council for Sustainable Development (WBSCD), define ecoefficiency as (WBCSD, 1996):

The delivery of competitively-priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity.

For the business enterprise, sustainable development can mean

adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future

Fussler includes the question of sustainable consumption when presenting the three securities of ecoefficiency (Fussler and James (1996)):

- the reconciliation of environmental care and quality of life by developing sustainable consumption patterns
- the building of greater environmental care into goods and services through clean processes and distributions
- creating value through goods and services, which provide quality of life.

A broader perspective on environmental issues is taken by Organization for Economic Co-operation and Development (OECD). They feel that ecoefficiency as stated by WBSCD is a flexible and pragmatic approach, suitable for translating into action by governments, industry, other organizations and households. However, a wider understanding of the links between economic activity and environmental damage is needed, as the term is insufficient on its own as a basis for policy making. We also need to know more about the driving forces of change, as well as the psychological and ethical motives of producer and consumer behavior. OECD therefore defines ecoefficiency as

the efficiency with which ecological resources are used too meet human needs (OECD, 1997).

Maybe somewhat more operational is the understanding of as

$$\text{Eco-Efficiency} = \frac{\text{Value Added}}{\text{Environmental Impact Added}}$$

in which we understand ecoefficiency to combine the economic and the ecological efficiency (Schaltegger, 1996). Several other authors have presented simplified equations of the same type, replacing value added by Value of products or service or Desired output of product or function. The different equations are basically expressing the same.

Van Nes and Stevels (1997) argue that the ecoefficiency approach should be related to environmental load through the efficiency in the delivery of a service (measured in units of service) per life cycle impact (measured in millipoints, e.g. through the Eco Indicator 95 approach, (Goedkoop, 1995)).

In this way, the ecoefficiency is a way to quantify and compare environmental aspects by taking into account consumer behavior and the products life span. The ecoefficiency approach shows that this is not only a matter of decreasing the Life cycle impact, but also a matter of increasing the utility of a product unit.

$$\text{Eco-Efficiency} = \frac{\text{Utility[units of service]}}{\text{Life Cycle Impact[millipoints]}}$$

Ecoefficiency is at first impression a valuable concept both for society and business in particular, because it is in everyone's interest to remove waste from our economic and infrastructural systems. However, it seems to seek a simplified business-as-usual solution, by skipping the problem of increasing production and consumption in the industrial societies.

Stigson argues that ecoefficiency is a management philosophy designed to encourage businesses to be more competitive, more innovative, and more environmentally responsible (Eik, 1998, Stigson, 1997). Stigson addresses the importance of produce more goods and services by using less resources. He claims that zero growth is not an option, as further global economic development are needed to meet this objective.

The consultants, Peck and Associates, (Eik, 1998, Peck & Associates, 1996) look upon ecoefficiency as a business like approach to sustainability that may be defined as a measure of the relative amount of pollution or resources use required to produce a unit of product or service. To improve ecoefficiency more of the desired outputs (real needs as high quality goods and services, income and meaningful employment for shareholders, customers and community) must be produced, while consuming less resources (such as energy) and generating less waste (such as pollution).

2.3.2 Discussion on original ecoefficiency approach

There has been some critique levelled against the concept of ecoefficiency. One of the main problems with the ecoefficiency concept is that it makes industry believe that they can reach sustainability without deep changes, but through bringing environmental load into the measurement of productivity in production. McDonough and Braungart (1998) and Røine et al. (1998) call ecoefficiency today's industrial buzzword, which will neither save the environment nor foster ingenuity and productivity. They claim that "doing more with less" is nothing more than what Henry Ford did when he started with recycling, minimized the use of packaging etc. McDonough and Braungart think that ecoefficiency is "well meant" but that it does not reach deep enough since it works within the same system as caused the problem in the first place (Røine et al., 1998).

The result will be the opposite of increased environmental performance, since the industry will - by increased recycling, less use of material and energy, the release of fewer dangerous materials into nature and other similar and defensive strategies- not be given the challenges for the necessary changes (Meadows, 1998).

This argument is not in line with the systems approach described by Bossel (1999), as the interactions between the human system and support system is fostering and encouraging rapid increase in man-made needs and thereby a rapid growing consumption of goods and services. Thus, to put all responsibility on the industrial system cannot be strictly correct due to these interactions between the different systems, as described in Figure 2.4. After all, industry is only contributing with what their customers are willing to pay for.

Today's products are seldom designed for recycling, and by doing that; the costs will often be too high and quality of the recycled product poor. This is also supported by the so called paradox of environmental product design (EPD), namely that EPD transfers value from the producer to the customer (Matthews and Chambers, 1997). McDonough and Braungart (1998) are looking for the Next Industrial Revolution, where the industry will be reshaped and where focus will be on design, which they claim is not the case within the present interpretation of ecoefficiency.

The alternative as they claim is ecoeffectiveness and the challenge is to neither mix the technical and natural metabolism, nor to increase the use of material that can enter and be transformed in the biological metabolism. Ecoeffectiveness, therefore, should relate to the overall effect of the system in relation to given objectives. Ecoeffectiveness is a term that should be used in the context of macro scale evaluation, in order to test contributions to sustainable development principles (Røine et al., 1998).

Based on the view of Bossel (1999), it becomes meaningless to raise the question wether or not ecoefficiency only on firm level is sufficient for reaching sustainable development. Monitoring efficiency on a firm level may give input to other entities of the overall system and thereby give valuable contribution to sustainable development.

An example which can illustrate these questions is the strive for improvement of the ecoefficiency of personal automobiles (particularly improvements in toxic emissions during their use phase). However, the total environmental impact from the total number of cars is still increasing. Consequently, by taking only one car into account, the environmental impact in total will suffer from the rebound effect and not be improved if the increased ecoefficiency of one automobile leads to increased production volume and thereby the possibility of higher environmental impacts from the transport sector on the macro level. Eik (1998) argues that cheaper and better cars may remove focus from-, and lead to less use of the often more environmental friendly public transportation (Eik, 1998). What Eik (1998) seems to forget is that there are completely different mechanisms which give rise for new customers for automobile makers than environmental impact. The need for rapid transportation, the cultural requirement satisfying the feeling of freedom and the status of owning a personal automobile are far more important requirement for an automobile customer than toxic emissions. If toxic emissions were an absolute requirement for a potential customer, he shouldn't be a customer of this kind of product.

The critique against the original ecoefficiency approach might sound unfair. The case with ecoefficiency is that is defined (and worked with) very differently, from "implementing of production and consumption within the level of the earth's carrying capacity" to "produce more with less". But when considering WBSCD's and OECD's definitions (OECD, 1997) it is clear that ecoefficiency should be operated at macro-level as well as the firm level.

Design of new technology, infrastructure and society as a whole is in fact stressed very much as a mean to achieve sustainable development. However, every firm or municipality can not perform every task needed to obtain progress on the macro level. ecoefficiency in practice will therefore vary from the incremental changes to changes dealing with social structures.

A change from supply of products to demand of service or function may lead to a decreased environmental load on the macro level. These are issues which seems to be present on a different level that the use of recyclable materials for manufacturing industrial products.

2.3.3 Efficiency and effectiveness

A general distinction between efficiency and effectiveness is obtained from Hornby (1974)

Effective = having an effect: able to bring about the result intended

Efficient =producing a desired or satisfactorily result

Røine et al. (1998) explain the differences between the two terms by an example.

Any product is designed according to a desired function the product shall perform. The finished product may be consistent with the initial objective, and may thus contribute to obtaining the result, the function. If the product fulfills the function, it has an effect, and the effectiveness may be high. The effectiveness is, thus, describing the relation between intended goals and actually obtained results. However, it is difficult to predict the efficiency under which the product is produced. It may have taken years and consumed a lot of resources to complete. In this case, the system has been effective, but not very efficient. On the contrary, in Nature the processes are very effective, but not necessarily efficient because the rate of reactions are often slow. In industrial processes the focus is on efficiency, emphasizing high throughput rates. Talking from an environmental point of view, the effectiveness of these processes are often ignored (Røine et al., 1998).

Both effectiveness and efficiency are measures used to describe a system depending of how the system is defined. They differ from each other by effectiveness being an extensive measure and efficiency being an intensive measure. Effectiveness is dependent on both quantity (volume, weight, energy and entropy) and quality (exergy and renewable/non-renewable materials). These may be added up to show the total amount of the property or resource in question. Hence, the effectiveness can be related to an external point of reference. Quantitatively speaking, effectiveness traces the relation between input, output and the loss of a system. In more qualitatively and general terms, effectiveness concerns the relation between intended objectives and obtained results. In contrast, efficiency, being an intensive measure, cannot be added up. Efficiency refers to the property per unit, and is thereby dimensionless. Efficiency is thus only describing the system, and not the interaction between the system and its surroundings (Røine et al., 1998).

Sink and Tuttle (1989) differentiate between internal efficiency and external effectiveness of any business activity in the following way

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

$$\text{Effectiveness} = \frac{\text{Actual Output}}{\text{Expected Output}}$$

Moseng and Brederup (1993) define efficiency and effectiveness as

- Efficiency being the utilization of resources inside a business
- Effectiveness being how well the customer needs are satisfied

These definitions have their origin in production technology.

Frei and Züst (1997) differentiate effectiveness and efficiency where (Scholz, 1994):

- effectiveness is a measure of attaining goals and
- efficiency is a measure for the means deployment

Consequently, effectiveness becomes “doing the right things” and efficiency becomes “doing the things right”. This definition stems from management literature.

Karlsson (1998) distinguishes efficiency from effectiveness in which the efficiency concept focuses on technical measures, like coefficient of utilization and degree of efficiency while the effectiveness concept starts from more basic questions about the actual demand and valuation of the assessed product or service, and in the sense of Life Cycle Assessment, focuses on “load per function”.

One normal basis for efficiency measures is that they deal with quotients between input and output. The traditional environmental LCA deals with the quotient “environmental load per functional unit of utility“. Similarly, the quotient “environmental impact per unit of per capita GDP“ has been suggested as a sustainability related measure (Karlsson, 1998).

In a case study for mobile phone batteries the quotient's customer utility value is measured as 'talk time capacity per mobile phone weight' and the environmental load is measured as ‘lost metal weights divided by the respective metal concentrations in earth crust’. In this case, the different parameters are measured in terms of different physical units. The result for this particular application shows an ecoefficiency improvement in the order of a factor 4000 in ten years. Karlsson (1998) presents an important issue, as it should be noted that it is difficult to specify the 'point of zero' for both the utility and the load scales of measurement. Karlsson questions the value to use ratios and quotients as assessment parameters when the absolute values are unclear and proposes that the mathematics should be limited to ordinal measures. This means that it seems more relevant to work with differences than quotients when monitoring progress.

Karlsson (1998) proposes one way of evaluating the resulting (net) effect of an activity, as by calculating the difference 'added value minus environmental load'. The added value ought to be measured as the activity's positive net effect on a society's total utility. In order to calculate a readily understandable difference it is necessary to find or develop a common scale of measurement for the added utility and the environmental load despite the fact that, from a natural science point of view, these seem to be incommensurable units. However, the economics methodology contains a rich set of tools for this type of situation. Comparisons of different dimensions are made all the time, by individuals and through the market, in terms of monetary measures. Economics also provides contingency valuation methods such as willingness to pay and willingness to accept. It has been noted that it is difficult to evaluate environmental loads in terms of a monetary measure, and the monetary value is even more unclear for positive externalities. Both individuals and firms have a preference for the own, present and nearby, benefits. To rectify this, environmental taxes have been discussed for negative externalities. However, future and distant effects tend to be neglected also for positive effects, such as the production of long-lasting high quality (e.g. recyclable) materials and systems, that may provide an enhancement of utility also for others than their direct customers. Furthermore, the future values that can be built through synergistic effects are difficult to predict, for example it was difficult to understand the present usefulness of electricity when it started (Karlsson, 1998).

2.4 Discussing the three dimensions of environmental performance

2.4.1 Ecoefficiency and ecoeffectiveness on different level of the hierarchy of systems

It seems that all these definitions distinguishing effectiveness from efficiency, apart from the understanding of the pure language, should be placed on different levels on the micro-macro scale, within the Meadows pyramid of Figure 2.3 and within the total system of Figure 2.4 and Figure 2.8. All three definitions of efficiency described above seems to deal with internal matters of the system. We expect some products out of the system, we put some resources into the system, and we measure the ratio between them. This is the utilization of resources inside the system. In other words: We have to do the things right to achieve the correct utilization of resources. However, we might not do the right thing. We might use the wrong resource. This will make the customer dissatisfied, and the actual output may not be equivalent to the expected output. Thus, ecoefficiency and ecoeffectiveness belong on two completely different levels within the hierarchy of systems within the society as a whole.

The foregoing account suggests that the types of climate-change business opportunities can be characterized along a spectrum from "use efficiency" on one end to "activity efficiency" on the other. "Use efficiency" requires no or little change in the way an activity is performed but involves improvements in the operation of the product. For example, use efficiency could occur when a company makes a television or copier or other appliance that uses less energy. Companies can make these changes; users do not change how they conduct their activities. However, in another step along the spectrum, products such as copiers can be used more effectively as users switch to two-sided copying (Irwin, 1998).

On the other end of the spectrum are changes that go beyond making a more efficient product and using a product more efficiently. In “activity efficiency,” individuals and organizations take advantage of emerging technology to conduct an activity in a significantly different way. More innovation in how activities are carried out will be needed as electric paper and broadband communications infrastructure develop. Electronic paper would allow people to obtain a book by downloading it from the internet instead of going to a bookstore or library or having it delivered. Similarly, obtaining enhanced efficiency through telecommuting means changing the way work is conducted. New work and management practices are evolving as people use improved display technology and faster and better-integrated information networks to work from their homes, in regional offices, or on the road (Irwin, 1998).

2.4.2 The needs and wants: What is sufficient?

One thing is missing in these two distinctions. If the consumer is not satisfied with the product or service, it becomes meaningless to talk about both efficiency and effectiveness. Thus, the product also needs to be sufficient, i.e. have the sufficient characteristics to become attractive to the customer. To achieve benefits from an increased ecoefficiency and ecoeffectiveness of a technical system, it is essential that the consumer behavior is reflected in the selected solutions.

Jansen (1998) argues that improvements in environmental performance of systems should be achieved by way of technologies designed to fulfill peoples needs, varying from simple items up to complex technological systems. This achievement requires intensive changes in culture, structure and technology. In the environmental debate attention is continuously focussed on three elements:

- culture, legitimating nature and volume of societal needs to be fulfilled: sufficiency
- structure, the economic and institutional organization to fulfil legitimated needs: effectiveness
- technology, providing the technical means by which needs are fulfilled: efficiency.

These three elements mutually interact and are interdependent. The “acceptability” and “viability” of environmentally efficient technical means is directly connected to the economic and institutional conditions (structure) and to the demands of society (culture).

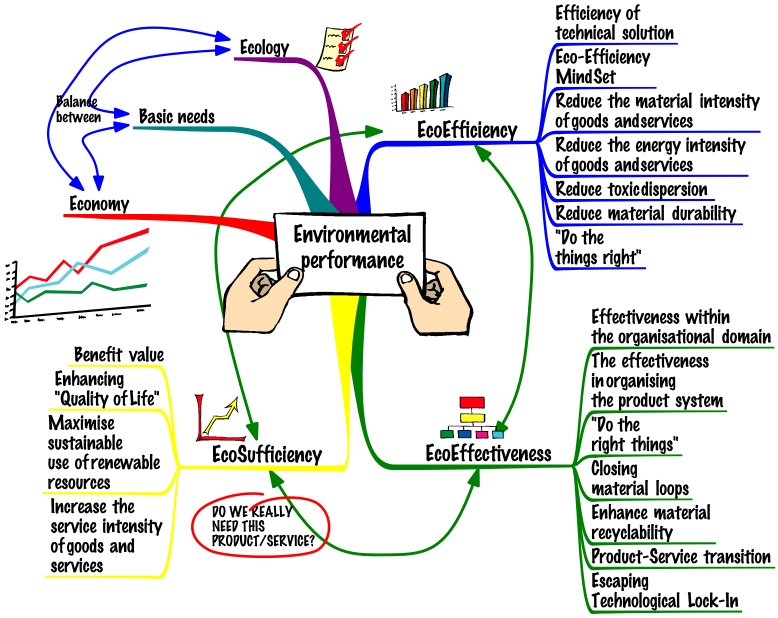
This gives basis to distinguish the two concepts efficiency and effectiveness even more, i.e. they are separated threefold. Thus, the challenge of environmental load of technical system is to find solutions to a threefold problem of

- Ecoefficiency: technical efficiency, which is the internal efficiency of the detailed solution of the product.

- Ecoeffectiveness: organizational effectiveness, which is the infrastructural effectiveness of the product system and interacting support systems.
- Ecosufficiency: Sufficiency within the cultural and social system where human needs are satisfied. This is cultural question. It is a question of human needs and culture. Each culture has its own way of supplying sufficient needs.

The three dimensions are illustrated in Figure 2.9.

Figure 2.9 The three directions of ecoefficiency



The ecosufficiency dimension is needed to complete the interface between the technical- and social system.

The three different directions of economic and environmental performance of technical systems, cannot be combined, but they are simultaneously severely interconnected. The ecoefficiency dimension concerns the basic utilization of the technical solution of the product.

The ecoeffectiveness dimension concerns the infrastructure in which the product operates. Closing material loops is a challenge within the ecoeffectiveness dimension, and cannot be included in an efficiency parameter, which simultaneously covers the technical solution of the product. However, the technical solution affects how the material loops can be closed, and prepares the product for such EOL scenarios. However, even though the concept of ecoeffectiveness focuses on the structures in the economy as a whole, the ecoefficiency of a technical solution will always be present when a technical system is part of the solution.

One organization performing development work on the concept of ecoefficiency is WBCSD (WBCSD, 2000). WBCSD argue that ecoefficiency is a key concept for helping companies, individuals, governments and other organizations to become more sustainable. WBCSD use their ecoefficiency

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approach as measurement and guiding principle for organizations to become more sustainable.

WBCSD claim that eco-efficiency is not limited to achieving relative improvements in a company's use of resources and pollution prevention. Ecoefficiency is much more about innovation and the need for change toward functional needs and service intensity, to contribute to de-coupling growth from resources (WBCSD, 2000). Although WBCSD do accept the need to focus on going beyond simply improving existing processes. WBCSD claims that the ecoefficiency approach does this by changing industrial processes, creating new products and changing and influencing markets with new ideas and with new rules.

The ecoefficiency approach of WBCSD seem to focus generally on improving existing processes in existing companies, and avoids the debate on improving the organizational and infrastructural levels where the process result (i.e. the product) operates, i.e. the ecoeffectiveness dimension. They also reject the sufficiency dimension arguing that WBCSD accepts the need to reduce pollution and resource depletion but does not agree that reducing living standards will achieve a better-balanced world. There is no generally accepted equity between sufficiency and a reduction in standard of living. This issue is a weakness in WBCSD's argumentation. In WBCSD's view, it is more important to opt for a different way of living that can offer a better quality of life and more welfare for all, while limiting the use of resource and pollution to acceptable levels. WBCSD and industry in general must be aware that this vision cannot be achieved without educating the general public that to achieve a different way of living offering a better quality of life and more welfare, they do not necessarily need to consume more materials and energy. The need sufficient amount of materials and energy to fulfil their needs. This level of consumption may be an absolute reduction. WBCSD and industry cannot reject looking into the sufficiency issue as well, despite the risk of reducing markets. It should rather be seen as opportunities for competition.

This give basis for arguing that the WBCSD approach seem to have elements trying to defend business-as-usual. Business-as-usual will not contribute to a sustainable society. Researchers cited above in chapter one agree that such an approach will not end in positive results. However, it does not mean that a sustainable society do not have room for current businesses, but they do need to change their practices concerning material and energy consumption to a significantly lower level.

Resource utilization is an measure for eco-efficiency. For a food product this can imply utilization of raw materials for production of the primary product (Lamvik and Gjerstad, 2000).

Resource utilization can also be a measure for ecoeffectiveness, by describing the utilization of residual products for by-products. This indicator describes that utilization of raw materials is not only a matter of technical processes but also a matter of how well the different production lines are organized and how they interact with each other.

To focus effort for improving environmental performance throughout the whole value chain, it is necessary to divide resource utilization even more. For a fish food supply chain, available resources in the systems can be divided between material (i.e. fish as a raw material), product (aspects which support the creation of the processed goods and energy. The different resources are linked to the value chain at different meetings at different phases of the chain, e.g. catch, manufacturing, distribution and sales phases. By dividing the value chain into these two dimensions, indicators describing eco- efficiency and effectiveness can be found as illustrated in Table 2.4.

Table 2.4 Environmental performance for fish food products related to the whole value chain (Lamvik and Gjerstad, 2000)

Environmental performance	Catch	Processing	Distribution and sales
Material	Residual products	Utilization factor Residual products	Waste
Product	Packaging waste Residual products	Packaging waste Residual products	Packaging waste
Energy	Energy consumption per catch volume	Energy consumption	Transportation distance

For material utilization measures in the catch and processing phases, the share of residual products is important. Linking production processes in an industrial ecology setting can contribute to visualizing the potential relationships between production lines where beneficial solutions can be created. This can turn into improvements in performance of both ecoefficiency and ecoeffectiveness.

In the distribution and sales phases, fish food products can be damaged during transportation or they can be stored without sufficient cooling which deteriorates the quality. This share of waste can be seen as both an ecoefficiency and ecoeffectiveness measure, e.g. ecoefficiency as a measure for the transportation activity and ecoeffectiveness as a measure for the total logistics system of the company through keeping the refrigeration line unbroken, and thus keeping the quality of the products.

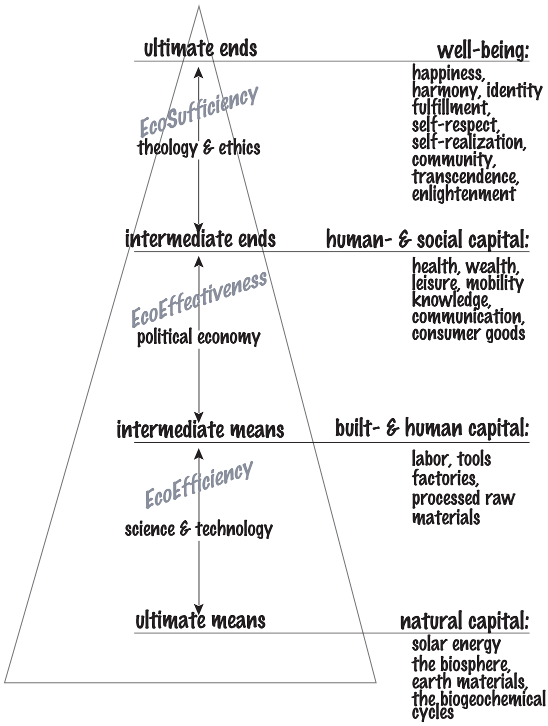
Reduction in packaging is an important contribution for the product in all phases of the value chain. The type of packaging can be disposable, recyclable or reusable. Reduction in disposable or recyclable packaging contributes to an increased ecoefficiency indicator. Changing from disposable or recyclable to reusable packaging introduces a new product system in the value chain. Reusable packaging needs support systems of its own to close the material loop. Improving the use of reusable packaging thus improves the ecoeffectiveness type indicator.

Energy consumption per catch volume gives a measure of energy intensity of the catch activity. This is an ecoefficiency indicator describing the energy efficiency of the catch activity. Transportation distance is a measure for the sustainable development element of local production, and is an ecoeffectiveness measure.

The ecosufficiency dimension concerns the production volume and sales, and thus is an indicator for customer satisfaction. The dimension is present to prevent a boomerang effect where a beneficial improvement of the two other performance dimensions, turns into an increased desire for a product initiating increased production volume where the benefit is absorbed. The ecosufficiency dimension also describes the product's contribution to quality of life.

The natural system is what Meadows (1998) describes as the ultimate means, and the human system is what she describes as the ultimate ends, Figure 2.3. The ultimate ends are the human needs as described by Max-Neef. In between these are the intermediate means and intermediate ends. The environmental performance indicators are measures for how efficiently each level of the pyramid of Figure 2.3 is utilized by the means of the level below. This can be described as the environmental performance of any activity. The environmental performance is subdivided into the three expressions: ecoefficiency, ecoeffectiveness and ecosufficiency. This is illustrated in Figure 2.10.

Figure 2.10 The environmental performance of the total system



2.5 Leap Improvement

Introduction

Improving environmental performance in incremental steps is the approach industry is applying today. This is the easiest approach to apply, because involves adjustments of current practices and thus requires less effort and adaptation compared to a leap improvement. For industry, leap improvement means changing current business practices, and involves adaptation in the way products are manufactured and supplied, in customer relationships, in how to measure value creation and cost of their activities, etc.

Related to Brezet’s Four levels of eco-innovation (Brezet, 1997) described in chapter 1.7.2, leap improvement means innovative solutions on levels three (Alternative function fulfillment) and four (system innovation), illustrated in Figure 1.7. Brezet argues that a transition to longer term innovation is required for reaching environmental performance targets. Creating products on the basis of functionality and redefining systems are the most important aspects of this approach (Brezet, 1997).

It is common belief that technology can provide substantial improvement in products' and services' eco-efficiency. On the other hand social change is believed to be critical for the creation of new socio-economic paradigms that will be possibly more sustainable than the present one (Ehrenfeld, 1994, Jansen, 1993, Morelli, 1998).

The replacement of old products with new products using the best available technology can provide substantial short-term reduction of resource use and emissions (Morelli, 1998). Morelli claims that the results provide a measure of the possible contribution of technological innovation at the current state of knowledge, to the target of factor 10 reduction.

The study has calculated the benefit of replacing the whole stock of different types of old household appliances in Australia. Although the replacement of the whole stock of existing products with the best available technologies is a theoretical scenario, Morelli claims that the calculation gives a measure of the potential of technological innovation currently achievable.

Morelli reports only on technological improvements and without taking into account any social or cultural change that can modify the way products are used. The major environmental impact of household appliances is related to the phase of use, the main issues being energy and water consumption. Energy consumption, in particular, is a major contributor to the emission of greenhouse gases in societies where electric power is based on fossil fueled power plants. The energy and water consumption in product life phases other than use are found negligible. The replacement of old household products with new ones would provide immediate reduction of energy consumption, because any further increase in energy and water consumption due to production of new appliances and recycling of old ones would be very quickly compensated by the reduction in energy use (Morelli, 1998).

The eco-efficiency of clothes washers depends on the result of the product development activity of the producer. Top-loaders and front loaders have different exterior dimensions and thus different material usage, different water consumption due to different mode of operation, different energy consumption due to amount of water which needs heating, etc.

Morelli reports present study considers the replacement of the whole stock of clothes washers in use at present with the most efficient front loader washer. The unit of analysis is the energy and water consumption for each kilograms of clothes washed in 1 year by the present stock of clothes washers, considering 1 wash per day. Such a unit of analysis allows for a comparison between clothes washers with different capacity.

Morelli reports that the total replacement of top loaders and twin tubs with front loaders (Morelli, 1998)

- would allows for a reduction of energy consumption by 2,523Gwh per year, that is 66%of the present consumption. Energy efficiency would improve by a factor of 2.95 times.
- would reduce the amount of water used by 16 billion liters that correspond to 53% of the present amount of water used by clothes washers. The new stock of clothes washers would be 2.1 times more efficient.
- would reduce the overall CO_2 emissions of the existing clothes washers by 3,186 Mt per year, that is 51% of the emissions at present level. Such a reduction is the result of a combination of a reduction in energy use (66%) and a reduction in CO_2 emissions due to detergents (29%).

Morelli claims that the total and partial replacement of the existing appliances with the currently most efficient ones would trigger a mechanism for innovation and change that would encourage such eco-jumps and would be beneficial for industrial business, governments and for household budgets (Morelli, 1998).

Morelli is correct when emphasizing that a replacement policy is a theoretical rehearsal. It is however, an interesting thought experiment which can visualize the opportunities from technological innovation only. These innovative solutions would increase the ecoefficiency dimension, but would leave the ecoeffectiveness and ecosufficiency dimensions untouched. A more holistic view identifying the opportunities for innovations on the infrastructural and social systems would give additional contributions using the already best available technology of the product level.

Is more better?

A basic philosophy which has characterized our materialistic world is the belief that “more and more is better and better” and that “the one who has most, is also more satisfied”. This line of though has characterized both producers and consumers, business and legislators. In practice, this has resulted in that maximum consumption or maximum material standard of living and material prosperity has been the overall goal for social development. This is the basic argument for growth in economic development, growth in turnover, etc (Bomann-Larsen, 2000).

The desire for "more and more" is both in line and in contradiction to some of the basic properties of man and nature. It expresses man's natural desire for a life which becomes "better and better". This desire is the driving force for a qualitatively better social development. The lack of such a desire will result in decline and decreased living conditions. There is however, no clear evidence that there is any sign of equity between "more and more" and "better and better". "More and more" is expressing quantitative growth, while "better and better" is expressing qualitative development.

Growth up to a level where the benefit of growth is equal to its expenses, will keep net advantage a positive value. Growth beyond this optimal condition will result in a negative net advantage. This should indicate that material growth up to a limit may create basis for increased quality of life, while growth beyond this limit will create deterioration of this quality of life (Bomann-Larsen, 2000).

The definition of sustainable development focuses on needs: "satisfy our needs without deteriorating future generation's ability to satisfy their needs". This means that to make prevent decreasing future generation's ability to meet their needs, man has to satisfy our needs while keeping natural capital intact. However, demand in the marketplace seem to express the rich world's desires, rather than poor world's needs. Demand from spending power is expressed in the marketplace. The ones with greatest needs, has no spending power.

Max-Neef (1992) argues that the greatest failure of industrialized countries is that they to a too low extent have differentiated between fundamental needs and the means used to try to satisfy needs. The main contribution that Max-Neef makes to the understanding of needs is the distinction made between needs and satisfiers (Fisher, 2000). Human needs are seen as few, finite and classifiable. Furthermore, they are constant through all human cultures and across historical time periods. What changes over time and between cultures is the way these needs are satisfied. It is important that human needs are understood as a system - i.e. they are interrelated and interactive. There is no hierarchy of needs (apart from the basic need for subsistence or survival) as postulated by Western psychologists such as Maslow, rather, simultaneity, complementarity and trade-offs are features of the process of needs satisfaction.

Max-Neef classifies the fundamental human needs as: subsistence, protection, affection, understanding, participation, recreation (in the sense of leisure, time to reflect, or idleness), creation, identity and freedom. Needs are also defined according to the existential categories of being, having, doing and interacting, and from these dimensions, a 36 cell matrix is developed which can be filled with examples of satisfiers for those needs, as illustrated in Table 2.5.

Table 2.5 Max-Neef classification of fundamental human needs (Max-Neef, 1992)

Fundamental Human Needs	Modes Of Experience Being (qualities)	Having (things)	Doing (actions)	Interacting (settings)
Subsistence	physical and mental health	food, shelter, work	feed, clothe, rest, work	living environment, social setting
Protection	care, adaptability autonomy	social security, health systems, work	co-operate, plan, take care of, help	social environment, dwelling
Affection	respect, sense of humour, generosity, sensuality	friendships, family, relationships with nature	share, take care of, express emotions	privacy, intimate spaces of togetherness
Understanding	understanding critical capacity, curiosity, intuition	literature, teachers, policies educational	analyze, study, meditate, investigate,	schools, families universities, communities
Participation	receptiveness, dedication, sense of humour	responsibilities, duties, work, rights	cooperate, dissent, express opinions	associations, parties, churches, neighborhoods
Recreation	imagination, tranquillity, spontaneity	games, parties, peace of mind	day-dream, remember, relax, have fun	landscapes, intimate spaces, places to be alone
Creation	creation, imagination, boldness, inventiveness, curiosity	abilities, skills, work, techniques	invent, build, design, work, compose, interpret	spaces for expression, workshops, audiences
Identity	sense of belonging, self-esteem, consistency	language, religions, work, customs, values, norms	get to know oneself, grow, commit oneself	places one belongs to, everyday settings
Freedom	autonomy, passion, self-esteem, open-mindedness	equal rights	dissent, choose, run risks, develop awareness	anywhere

Satisfiers also have different characteristics: they can be violators or destroyers, pseudo satisfiers, inhibiting satisfiers, singular satisfiers, or synergic satisfiers. Max-Neef shows that certain satisfiers, promoted as satisfying a particular need, in fact inhibit or destroy the possibility of satisfying other needs.

Synergic satisfiers, on the other hand, not only satisfy one particular need, but also lead to satisfaction in other areas: some examples are self-managed production; popular education; democratic community organizations; preventative medicine; meditation; educational games.

This model forms the basis of an explanation of many of the problems arising from a dependence on mechanistic economics, and contributes to understandings that are necessary for a paradigm shift that incorporates systemic principles. Such a paradigmatic shift in a deeper understanding of customer real needs and the needs which can be satisfied with output from businesses can be an important element contributing to leap improvement in environmental performance.

Leap improvement in environmental performance is not achieved overnight. The mind pattern of economic growth seems to be permanent in the economies of the western world. Economic growth is seen as a prerequisite to cope with environmental damages caused by industrial activities. When the factor 4 and 10 concept was introduced in 1997 (Von Weizsäcker et al., 1997, Factor Ten Club, 1997), the authors claimed that a reduction of material and energy throughput through the economy of four-fold in a decade and ten-fold in a generation is needed to achieve the goals of a sustainable development. This means that the environmental performance of production systems must rise substantially. In addition, since all gains from efficiency can be overcompensated by unlimited growth of consumption, sufficiency strategies should be pursued: people and service providers alike can learn to generate more satisfaction from each service unit so that people more enjoy a less material way of life.

Half of the time schedule of Von Weizsäcker's hypothesis of a four-fold reduction in a decade, has soon passed. However, there are no indications that this vision is reached in time. The reason for this may be that the market forces supporting the factor 4 vision are not strong enough. Market forces sustaining present business practices are still strong enough to keep supporting consumption growth without improvements in material and energy use. Customers are simply not ready for integrating reduction thinking into their criteria for selection. Another reason may be that industry is not ready for establishing a long term vision of their environmental perspective, and develop strategies to reach this vision.

Thus, leap improvement in environmental performance can be seen as a leap increase of the service efficiency of a given material stock. This means that the stock of produced material goods is conceived as a store of potential service units which are consumed if the material products are applied. In present practice this potential is used only to a small share. The focus on service or the function delivered by products, and optimization of the delivery of this service or function, is to reduce the material throughput of the economy without losses in the overall availability of service units in the domain of consumption by utilizing the service capacity of material stocks to a higher degree.

Leap increase in this utilizing the service capacity can be achieved if

- the materials and energy resources are utilized more efficiently
- more potential service units are generated from the same material and energy stock

- the potential service units are consumed more efficiently and based on sufficiency considerations by customers.

Business plays a significant role in shaping the ways in which people are able to satisfy their personal desires as to their individual quality of life. There is concern that, whether well-intentioned or unknowingly, business drives the demand by the goods and services which it chooses to offer, and it places a significant responsibility on individual businesses to understand the effects that their products and services have on the “quality of life” of those that use them. This must be done within the changing societal context - including how others, business and non- business may respond to any particular reaction. Business (and government) need to consider the possible rebound effects resulting from their actions.

All stakeholders, but industry itself in particular will have to take a major role in redesigning production and product systems towards more sustainability promoting principles. On the other hand, actors outside industry, such as governmental decision-makers and planners and experts in academia, must also take lead roles in the reorientation of social structures in order to achieve ecoeffectiveness within the economic system. Furthermore, the consumers in general should become the most important actors to facilitate change, as economic demand factors are most likely more powerful than industrial supply factors.

2.6 Conclusion

This chapter discussed the elements which should be included in a strategy for development of product and product systems to measure to which degree the result is contributing to moving forward towards a sustainable society.

First of all measurements is needed to understand the current status of a business regarding environmental performance. Furthermore, measurement is needed to establish the perspective for improving environmental performance. The current status forms the basis for all improvement related activities. without measurement, establishing a vision for goals of the future becomes impossible. As all improvement measures are relative to some viewpoint, current status regarding efficiency of material and energy flows through the company as a system with its interfacing upstream and downstream network of systems, is vital. Especially, when establishing a vision for leap improvement it is essential to know and understand current status, and develop goals and system boundaries for product and product system development projects. Thus, hypothesis A *Methods for measuring environmental load of a product system in a sufficient way is needed to keep track of progress of environmental performance* is supported through this research.

A society cannot be sustainable if its subsystems don’t function properly and are viable. Therefore, a conceptual understanding of the total system is needed.

When the system is established, the question becomes: how satisfying is the output from the system compared to the input? Intense discussions are still going on among researchers around the world trying to define the concept of ecoefficiency and whether ecoeffectiveness is the concept to measure. This dissertation explains that both are needed concepts and are operating on different levels within the hierarchy of systems. However, if the consumer is not satisfied with the product or service, it becomes meaningless to talk about both efficiency and effectiveness. Thus, the product also needs to be sufficient, i.e. have the characteristics to become attractive to and sufficiently fulfill customer needs. To achieve benefits from an increased ecoefficiency and ecoeffectiveness of a technical system, it is essential that the consumer behavior is reflected in the selected solutions.

This gives basis to distinguish the two concepts efficiency and effectiveness even more, i.e. they are separated threefold. Thus, the challenge of environmental load of technical system is to find solutions to a threefold problem of

- Ecoefficiency: technical efficiency, which is the internal efficiency of the detailed solution of the product.
- Ecoeffectiveness: organizational effectiveness, which is the infrastructural effectiveness of the product system and interacting support systems.
- Ecosufficiency: Sufficiency within the cultural and social system where human needs are satisfied. This is cultural question. It is a question of human needs and culture. Each culture has its own way of supplying sufficient needs.

The ecosufficiency dimension is needed to complete the interface between the technical- and social system.

The three different dimensions of economic and environmental performance of technical systems, cannot be combined, but they are simultaneously severely interconnected. The ecoefficiency dimension concerns the basic utilization of the technical solution of the product. The ecoeffectiveness dimension concerns the infrastructure in which the product operates.

Closing material loops is a challenge within the ecoeffectiveness dimension, and cannot be included in an efficiency parameter, which simultaneously covers the technical solution of the product. However, the technical solution affects how the material loops can be closed, and prepares the product for such EOL scenarios.

The ecosufficiency dimension concerns the production volume and sales, and thus is an indicator for customer satisfaction. The dimension is present to prevent a boomerang effect where a beneficial improvement of the two other performance dimensions, turns into an increased desire for a product initiating increased production volume where the benefit is absorbed. The ecosufficiency dimension also describes the product's contribution to quality of life.

Leap improvement in environmental performance can be achieved through a leap increase in utilizing the service capacity of material and energy resources by

- utilizing the materials and energy resources more efficiently

- generate more potential service units from the same amount of material and energy resources
- consuming the potential service units more efficiently where customers base their considerations on sufficiency principles.

These elements are located on different levels of the hierarchy of systems. To achieve a leap improvement in environmental performance it is necessary to understand and measure each level's contribution to the overall performance. Thus, strategies for product development focusing on reducing environmental load must contain elements for measuring to which degree the product system contributes to ecoefficiency, ecoeffectiveness and ecosufficiency.

CHAPTER

3

INNOVATION AND PRODUCT DEVELOPMENT

This chapter describes a number of different models for product development and innovation. These models are analysed and diagnosed. Models which focus specifically on environmental aspects of industrial products are also described, analysed and diagnosed. The chapter describes a case study from the Nordlist LCA-project where components from three different products were analysed focusing on environmental load. The intention of the chapter is to identify missing elements of traditional product development and present way of managing enviornmental properties in products, discuss these findings in relation to achieving leap improvements in environmental performance.

3.1 Introduction

In the literature, a number of descriptive and prescriptive design methodologies have been developed for general engineering design problems (Altshuller (1984), Asimow (1962), Dixon and Finger (1989), Pahl and Beitz (1996), Pugh (1991), Ullman (1992), Ulrich and Eppinger (1994)) describe the entirety of design as sequences of stages from needs analysis to conceptual design to final manufacture. Rather than adopting this universal view, other researchers consider different types of design processes and methods. Pahl and Beitz (1996) describe a very detailed design process that works well for “medium” complexity systems. Ulrich and Eppinger (1994) describe the formulation, evaluation, and completion of design decisions, including customer and manufacturing information (Otto and Wood, 1999).

During the last decade, researchers and product designers have become aware of the need to integrate all phases of the product lifespan into the design process. This is essential especially in order to get an overview of the environmental load caused by the product and its interactions with its environment during all phases of its lifespan. In order to close material cycles it is important to prepare the product for disassembly at the end of the product lifespan and thereby transfer the lifespan into a lifecycle.

The goal of product life-cycle engineering is to maximize the values of the manufacturer's line of products, while containing its costs to the manufacturer, the user, and society. In the past decade, researchers around the world have proposed various systematic methodologies that apply to the early stages of product development in integrating life-cycle quality (Ishii, 1998).

3.1.1 Defining the terms design, development and innovation

The oxford dictionary explains *design* as (Hornby, 1974)

- drawing or outline from which something may be made
- general arrangement or planning (of a picture, book, building, machine
- pattern; arrangement of lines, shapes, details, as ornament
- purpose; intention; mental plan

The oxford dictionary explains *develop* as (Hornby, 1974)

- (cause to) grow larger, fuller or more mature, organized; (cause to) unfold
- (of something not at first active or visible) come or bring into a state in which it is active or visible

Miller (1996) defines design as

> *Design is the thought process comprising the creation of an entity*

which summarizes the essence of design. The actual making of this entity is the manufacturing process. The dictionary seems to define design as the materialization of something based on a plan, while develop is the making of this plan.

The terms product design, engineering design and product development are both in literature and in practice used without clear definitions. The most comprehensive process is commonly product development, in which product design or engineering design is embedded. Product development according to Roozenburg and Eekels (1995) comprise the development of the design of a new product in coherence with the plans for its production, distribution and sales.

Today product development through ecodesign and life cycle design must also include plans for take-back, i.e. collection, disassembly and reuse / recycling.

The term innovate is defined by the Oxford Dictionary as make changes; introduce new things, and innovation as innovating; instances of this; something new that is introduced (Hornby, 1974). Here the term new is introduced. Innovation includes an element of originality not by itself, but also an element of acceptance by its audience. Innovation is not limited to technological innovation. It also includes changes in: work practices involving both technical and organizational systems; in the way products and services are created, distributed and marketed; in the ways products and services are used.

Technological change is the phenomenon of change in industrial and social behavior based on the findings of new technological solutions. Technological change is the consequence of innovation. Freeman distinguishes four types of technological change (Freeman, 1987, Hinterberger and Meyer-Stamer, 1997):

- everyday, “incremental” technical change in small steps – an improvement in a production process, an improved product, a new service. It is this type of innovation that ensures that the productivity of firms will grow.
- radical change due to radical innovations, which alter the course of development of an entire industry
- changes in a technological system that affect more than one industry
- changes in a techno-economic paradigm – new technologies prevail throughout entire societies, new industries emerge, old industries lose significance, conventional organizational patterns are invalidated.

Hinterberger and Meyer-Stamer (1997) argue that innovations are in general not sporadic sensations; instead, they have a process character. Incremental innovations – at least in developed capitalist industrial societies – are part and parcel of the essence of industrial production. Firms do not simply remain at a productivity level once achieved. They engage in constant efforts to improve their production processes and products. The most important incentive is provided by economic competition, for if a firm neglects to innovate or fails to innovate sufficiently, it will be unable to assert itself against its competitors.

As the dictionary explains, innovation can denote both a process (innovating) and its result (something new that is introduced). According to the definition proposed by the OECD in its “Frascati Manual” (European Commission, 1995, OECD, 1992a), innovation involves

> *the transformation of an idea into a marketable product or service, a new or improved manufacturing or distribution process, or a new method of social service.*

The term thus refers to the process.

3.2 The innovation process

In the first sense of the term (innovation process), the emphasis is on the manner in which the innovation is designed and produced at the different stages leading up to it (creativity, marketing, research and development, design, production and distribution) and on their breakdown. This why more and more importance is attached in practice to mechanisms for interaction within the firm (collaboration between the different units and participation of employees in organizational innovation), as well as to the networks linking the firm to its environment (other firms, support services, centres of expertise, research laboratories, etc.). Relations with the users, taking account of demand expressed, and anticipating the needs of the market and society are just as important than a mastery of the technology.

In the second sense (result of the innovation), the emphasis is on the new product, process or service. A distinction is made between radical innovation or breakthrough and incremental innovation, which modifies the products, processes or services through successive improvements.

Lundvall (1988) and OECD (1992b) consider it important that

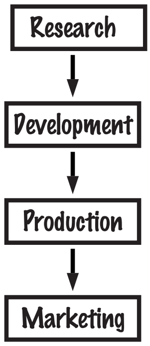
> *by using terms such as "the process of innovation" or "innovation activities" to indicate that traditional separations between discovery, invention, innovation and diffusion may be of limited importance in this perspective*

Thus, in this dissertation the term innovation denotes the process and not its result.

Linear Model of Innovation

In the Linear Model of Innovation, one does research, research then leads to development, development to production and production to marketing, as illustrated in Figure 3.1

Figure 3.1 Linear Model of Innovation.



The notion that innovation begins with a discovery in "basic science," proceeds with an application or invention derived from this fundamental work, and ends with the development of a new product or process was widely used to explain technological development (Freeman (1996)). Today researchers agree that the process is more complicated. In the linear model, there are no feedback paths within the ongoing work of development processes. Nor are there feedbacks from sales figures or from individual users. But all these forms of feedback are essential to evaluation of performance, to formulation of the next steps forward, and to assessment of competitive position. Feedbacks are an inherent part of development processes (Kline and Rosenberg , 1986).

In understanding the process of technological change, modern theory begins from Schumpeter's view that competition is primarily a technological phenomenon. The basis of competition is the quality, design characteristics and performance attributes of products. Firms seek competitive advantage on the one hand by continuous development of technologically differentiated products, and on the other by changing processes so as to generate these products with competitive cost structures. Usually, innovation takes the form of incremental change within fields in which firms have specialized skills and experience; that is to say, firms seek to establish a technically differentiated product range within an established technological paradigm. Alternatively, firms can seek to innovate by changing the paradigm itself (Smith, 1994).

What is involved in the innovation process itself? Most modern research sees innovation (Kline and Rosenberg , 1986, Smith, 1994)

- first, as an interactive social process which integrates market opportunities with the design, development, financial and engineering capabilities of firms,
- second, as a process characterized by continuous feedbacks between the above activities, rather than by linear transitions,
- third, as a process characterized by complex interactions between firms and their external environments
- fourth, as a process which is continuous

The primary problem for the firm is to build a set of technological competences and capabilities which will enable it to create distinctive areas of competitive advantage. Through marketing exploration, and general relationships with customers or product users, firms attempt to identify opportunities for innovation; but this is usually done within the context of an existing set of technical skills, and an existing knowledge base. Search for new and novel technological solutions is usually performed only when firms face problems which they cannot solve within their existing knowledge bases. In other words, research is not necessarily the primary process generating innovative ideas but seen as problem-solving activity within the context of on-going innovation activity (Smith, 1994).

Firms can combine these various components of the innovation process. Firms not only produce differentiated products, they generate innovations in different ways. This has two important implications (Smith, 1994):

- Firstly, the process of differentiation generates a high level of variety and diversity among firms. There is no single model of the innovation process: firms can differ very significantly in their approaches to innovation.
- Secondly, the fact that firms attempt to specialize around existing areas of competence means that there are limits to their technological capabilities and awareness.

Innovation does not belong to technology only

Innovation is not just an economic mechanism or a technical process. It is above all a social phenomenon. Through it, individuals and societies express their creativity, needs and desires. By its purpose, its effects or its methods, innovation is thus intimately involved in the social conditions in which it is produced. In the final analysis, the history, culture, education, political and institutional organization and the economic structure of each society determine that society's capacity to generate and accept novelty.

Innovation can and must offer a response to the crucial problems of the present. It makes possible an improvement in living conditions (new means of diagnosis and of treating illnesses, safety in transport, easier communications, a cleaner environment, etc.). It also makes it possible to improve working conditions and safety, protect the environment, save natural and energy resources, promote new forms of work, etc. An example is teleworking which, while it can occasionally have repercussions in social and health terms or be a means of out-sourcing, is also a means of urban decentralization and of creating jobs in rural areas. While innovation generally improves living and working conditions, care has to be taken that new methods of organizing work do not jeopardies employment.

Innovation is a collective process which needs the gradual commitment of an increasing number of partners. In this respect, the motivation and participation of employees is critical for its success.

3.3 Models of innovation

3.3.1 The Roozenburg & Eekels model

Roozenburg and Eekels (1995) defines innovation as a process including the generation of a policy and ideas to the utilization of the final product, as illustrated in Figure 3.2.

Innovation starts with an idea. Someone within a company have come up with an idea to redesign a product or develop a completely new design. A company that wants to innovate has to know very well what it wants to achieve. It has to produce fruitful ideas for innovation, develop these ideas into comprehensive plans for action and then realize those plans efficiently (see Figure 3.2). The product policy presents the company's goals in addition to the planned strategies for obtaining these goals (Roozenburg and Eekels, 1995).

A properly crystallized policy is the basis for the next phase. Generation of product ideas is needed before the product can be developed. In addition to looking for ideas, ideas for potential products must also be found. This is the idea finding phase which hopefully will bring up one or more promising ideas for further development into a new business idea (European Commission, 1995).

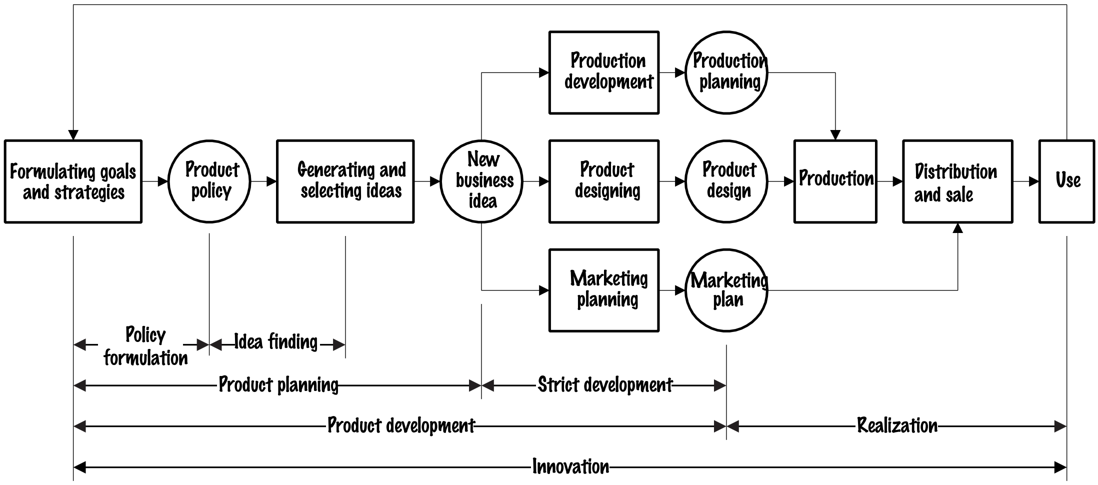
The next phase is by Roozenburg and Eekels (1995) denoted strict development to distinguish it from product development which is by many researchers a term used on the process from idea to final product.

The last phase of the model of Figure 3.2 is realization. Here the product design, production plan and marketing plan is put into action, and includes production distribution and sale and the use phase.

The Roozenburg model combines a model of product development with innovation, indicating that product development is a part of innovation. The model thus focuses on the technical aspects of innovation.

The Roozenburg model includes all phases involved in the product lifespan until the use phase. In a product lifespan context, a lot of valuable information is missed concerning collection, disassembly, reuse and recycling, when the remaining life phases are left out.

Figure 3.2 Model of innovation process (Roozenburg and Eekels, 1995)



3.3.2 Chain-linked model

The Chain-Linked model has its community of supporters within the economic literature (Kline and Rosenberg , 1986, OECD, 1992b)

Kline and Rosenberg (1986) argue that the Chain-Linked model is consistent with a detailed evaluation of the nature of technology, the concept of innovation, and the failures of a simple linear model which are often assumed, and the necessity that the linear model be replaced with a more complex model in order to understand the nature of innovation. The Chain-Linked method emphasizes the socio-technical nature of industry and technology and the necessity to look at it as a complex system. The chain-link model shows a situation where research, development and knowledge are inter-twinned with all phases of product, process and service life cycles (Kline and Rosenberg, 1986). The chain-linked model is shown in Figure 3.3.

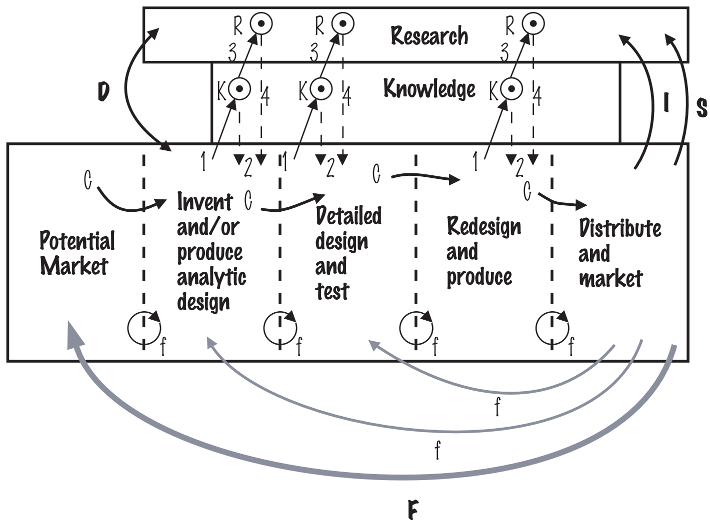
In this model there are not one major path of activity, but five.

The central chain-of-innovation begins with a design and continuos through development and production to marketing. It is indicated by the arrows labeled "C" in Figure 3.3. It is important to note immediately that the second path is a series of feedback links marked "f" and "F" in Figure 3.3. These feedback paths iterate the steps and also connect back directly from perceived market needs and users to potentials for improvement of products and service performance in the next round of design. In this sense, feedback is part of the cooperation between the product specification, product development, production processes, marketing and service components of a product line (Kline and Rosenberg , 1986).

A perceived market need will be filled only if the technical problems can be solved, and a perceived performance gain will be put into sense only if there is a realizable market use. Furthermore, Kline and Rosenberg argue that the importance of "market push" versus "technology pull" becomes in this sense artificial since each market need entering the innovation cycle leads in time to a new design, and every successful new design, in time, leads to new market conditions (Kline and Rosenberg , 1986).

Kline and Rosenberg probably underestimate the push-pull conditions. None ever thought of a portable cassette player with headphones until Sony promoted the first unit. This is a clear example of creation of a market which did not exist until the product was available.

Figure 3.3 The Chain-Linked-Model of Innovation (from Kline and Rosenberg, 1986)



The linkage from science to innovation is not solely or even preponderantly at the beginning of typical innovations, but rather extends all through the process - science can be visualized as lying alongside development process, to be used when needed. This linkage alongside the central-chain-of-innovation, is shown in Figure 3.3 by arrow "D" and links "K-R", and is the reason for the name "chain-linked model" (Kline and Rosenberg , 1986).

New science does sometimes make possible radical innovations (indicated by the arrow "D" in Figure 3.3). These occurrences are rare, but often mark major changes that create whole new industries, and they should therefore not be left from consideration.

The last path, marked by the arrow "I" in Figure 3.3 is the feedback from innovation, or more precisely from products of innovations, to science. This pathway has been very important in the past and remains so even today.

Previous inventions leads to the discovery of new phenomena which adds to the multitude containing all knowledge.

At the level of the firm, the innovation chain is visualized as a path starting with the perception of a new market opportunity and / or a new science and technology-based invention; this is necessarily followed by the 'analytic design' for a new product or process, and subsequently leads to development, production and marketing. Feedback relations are generated:

short feedback loops link each downstream phase in the central chain with the phase immediately preceding it and longer feedback loops link perceived market demand and product users with phases upstream. Problems identified by the processes of designing and testing new products and new processes often spawn research in engineering disciplines but also in science (Kline and Rosenberg , 1986).

The second set of relationships links the innovation process embedded in firms and industries with the scientific and technical knowledge base and with research. In an industry-focused, interactive approach to innovation, a useful analytical distinction can be made between the two different uses of science and technology by firms, the use of available knowledge about physical and biological processes, and the work undertaken to correct and add to that knowledge. Generally, innovation takes place with the help of available knowledge. When corporate engineers confront a problem in technical innovation, they will call first on known science and technology, most often in serial stages. Only when those sources of information prove inadequate does a need arise for research. This analysis of the role of industrial R&D in the innovation process applies directly to large firms. Firms below a certain size cannot bear the cost of an R&D team (Kline and Rosenberg , 1986).

3.4 Models of product development

Comparing economic and technical literature indicates that the term innovation used in economic- and product development used in technological actually denotes the same process. The definition of words is the essential issue.

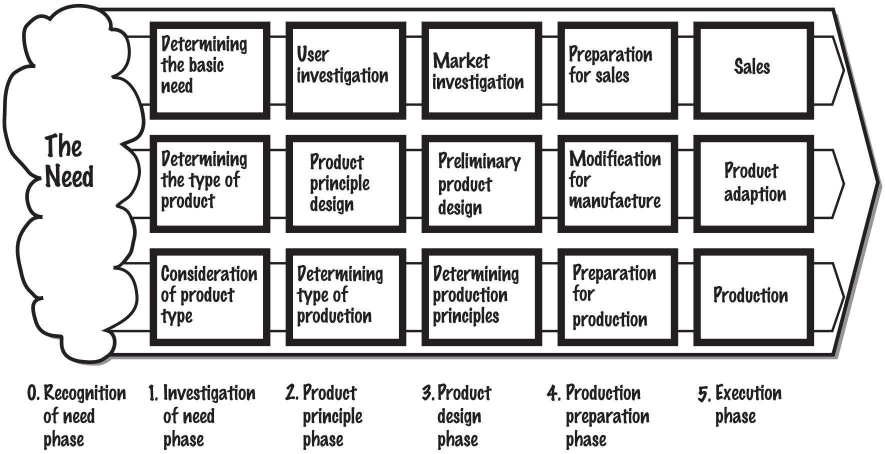
As discussed above, the innovation involves the process of developing something new. Product development is also a process for development of something which is not presently available, i.e. the creation of something new.

Innovation is not a process applicable to technical systems only. Innovation is also applicable for organizational- and social systems where an unsatisfied need occurs. Product development models are basically created for development of technical systems. However, apart from the word product which may be connected to technical systems, there is no argument for applying these models to technical systems only. Using a wider definition of the word product, any need can be satisfied by examining the phases of product development.

3.4.1 Integrated product development model

Integrated product development, IPD, is a systematic approach to product development, as illustrated in Figure 3.4.

Figure 3.4 Integrated Product Development (Andreasen and Hein, 1987)



The IPD model structures the product development process and constitutes a framework for integrating methods and disciplines to approach the same goal. The starting point is the recognized need. A business for the company is obtained through integration of the functions market, product and production.

The model of the product development process is idealized where these functions are integrated into a holistic system. The IPD-model separates the process into six phases which starts with recognition and clarification of needs and ends into the business area of the enterprise. Laterally the three main lines in the model, sufficient information exchange is taking place and with sufficient insight that the correct decisions are made at the right time towards the market, the product and the production system within the company. This is the essence of integration where each main line are mutually dependant of each other to reach a satisfying result.

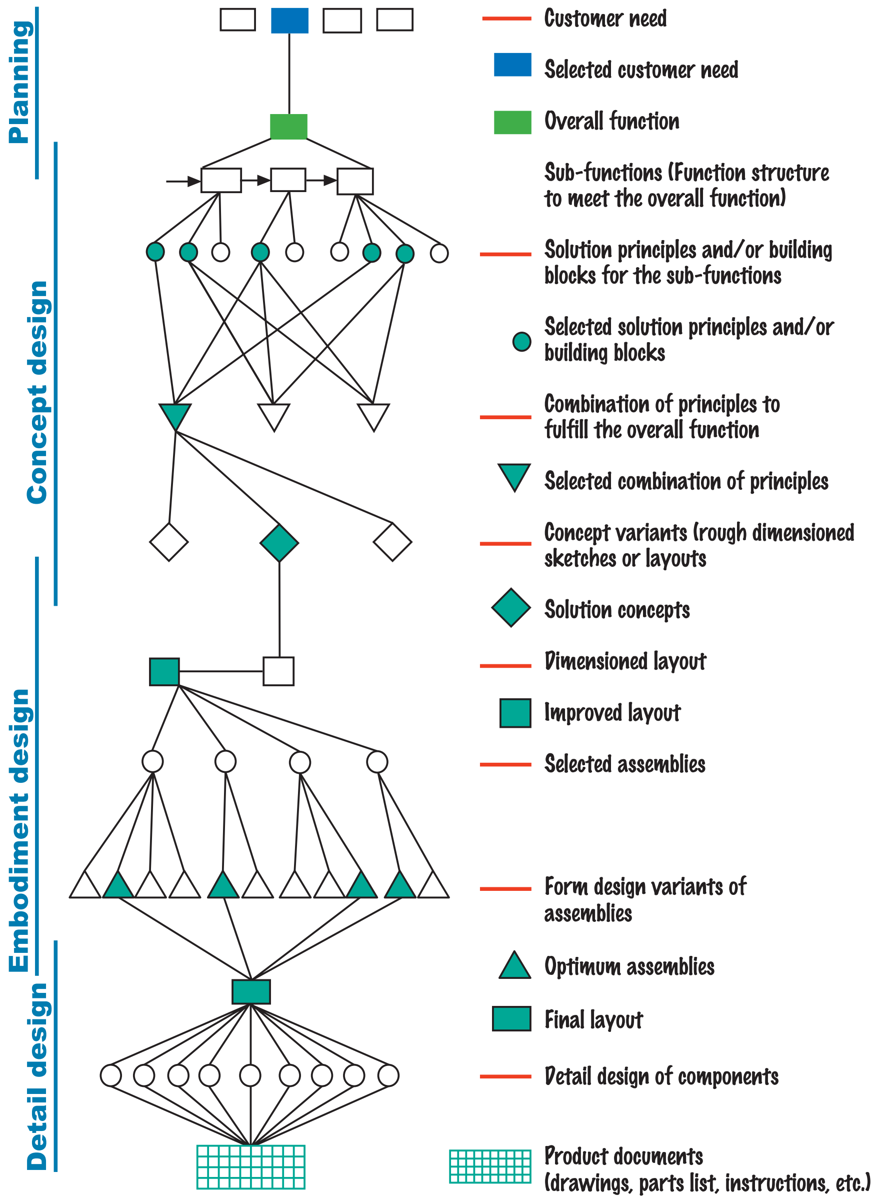
The integration is within phases followed by decisions, and IPD is understood as controlled by milestones. Product strategy and planning is also emphasized.

The IPD-model does not take into account the subsequent phases of the product lifespan beyond the sales situation. This limitation can be tracked to the year of creation where lifespan thinking in industry and product development was hardly on the agenda. Consequently, the information needed to optimize energy consumption during use, design criteria for product collection systems, design criteria for product disassembly, criteria for reuse of parts and components in addition to material recycling, etc. is never considered using this product development model.

3.4.2 Systematic approach to engineering design methodology

Pahl and Beitz (1996) state that design problem-solving is a variant of general problem-solving. When designing a product, the designer normally follows a path consisting of certain fundamental activities - identification of need, problem and requirements formulation, search for alternative solutions, evaluation and selection of solution and finally, documentation and communication of results. Design methodologies provide specific design methods and design knowledge to support this process.

Figure 3.5 Systematic approach to engineering design (Pahl and Beitz, 1996)



Pahl and Beitz (1996) divide the design process into a number of phases. Each pahse leads to certain decisions. This is illustrated in Figure 3.5 The bondaries between the different phases are overlapping making a need for iteration and recursion.

Planning

This phase involves the collection of information about the requirements that the products should meet, and about the constraints. The result of this phase is a detailed design specification.

Conceptual design

This phase starts by analysing the design specification in order to identify the core design problem(s) to be solved. The design problem is formulated keeping in mind not to restrict the solutions space. This is important as any attempt to decide on a certain solution prior to consideration and evaluation may make valuable alternatives invisible. The next step is to decompose the problem into sub-problems and establish the function structure. A search for alternatives for satisfying the sub-functions are performed. This process is supported by creative methods, conventional methods and systematic methods. The systematic methods make use of design catalogues with physical and chemical effects and machine elements. Morphological matrices are used to combine sub-function solutions into system solutions. Promising system solutions are developed further into concept variants. Use-value/cost-benefit analyses are used to evaluate the concept alternatives, and the “best” concept is selected for further development (Malmqvist et.al. (1996).

Pahl and Beitz too emphasizes the importance of decisions taken in the conceptual design phase, since it is very difficult to correct fundamental shortcomings of the concept in the later embodiment and detail design phases (Pahl and Beitz, 1996).

Embodiment design

In the embodiment design phase the product developer develops the product structure and form of the final system, based on the descriptions of the selected product concept. Also in this phase several alternative designs may be considered. The system is in this phase developed to the level where a clear check of function, durability, production, assembly and other requirements can be performed. Pahl and Beitz (1996) provides support to these activities by means of rules, principles and guidelines (Malmqvist et.al. (1996).

- The rules state three important conditions that must be fulfilled if the design is to meet requirements: clarity, simplicity and safety.
- The principles state fundamental engineering design knowledge. Examples are the principles of sub-division of tasks and of the use of self-reinforcing solutions.
- The guidelines are more domain-specific, such as design for assembly guidelines.

Detail design

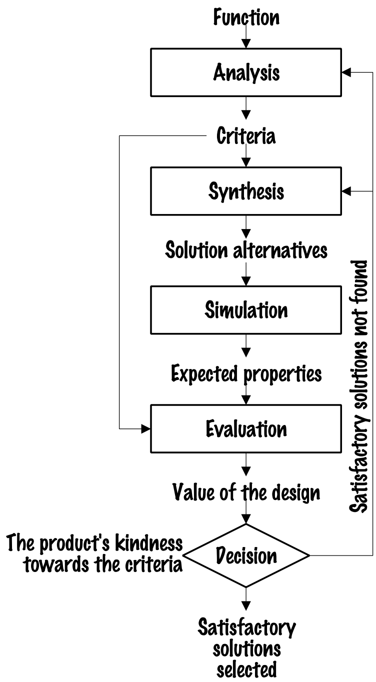
In the detail design phase, detail drawings and documents preparing production are completed. While most high-level decisions will have been made at this point, Pahl and Beitz (1996) alerts the designer not to believe that the rest is routine work only. Excellent concepts can be ruined by a lack of attention during the detail design phase (Pahl and Beitz, 1996, Malmqvist et.al., 1996).

3.4.3 Description of the product development process

The purpose of product development is, based on an idea or a defined need, to create and deliver a product with optimal properties and its appurtenant supplemental services and documentation.

The product development process runs through different phases, where each phase is more detailed in describing the solution than its predecessor. Within each phase in addition to between each phase the designer is iterating, i.e. the activities are repeated, to find better solutions. The iterations within each phase and between phases resembles the general problem solving process of Roozenburg, as shown in Figure 3.6.

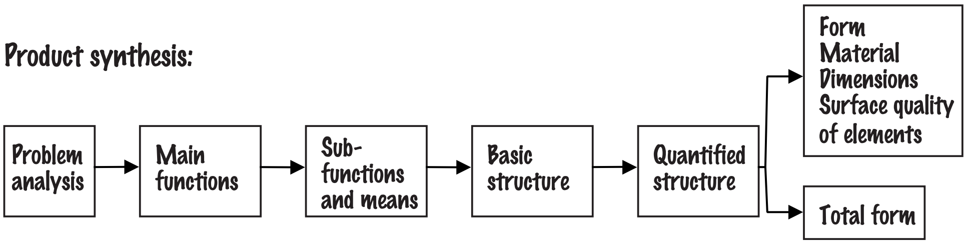
Figure 3.6 Basic Design Cycle (from Roozenburg and Eekels, 1995)



This problem solving cycle is alternating creative and analytic. The synthesis is primary the creative process where the solution is generated, while simulation, evaluation and decision is primary analytic processes. The synthesis can be seen as diverging, by that very fact that alternative solutions to the problem are generated. The synthesis can also be seen as converging, by that very fact that a limited number of solutions are generated from a theoretically unlimited solution space. In the evaluation- and decision processes one is moving towards fewer solutions by the selection of the best solution, that is one converges additionally.

On the level of product synthesis effort is concentrated on the technical system itself (Mørup, 1993). The model of product synthesis in Figure 3.7, is applicable for the design of mechanical products, (Mørup, 1993, Tjalve, 1979). It is not to be considered as an 'algorithm' of activities, but rather an indication of the stages, or domains, characteristic of machine systems within which design work must take place (Mørup, 1993). The product developer has the capability of freely jumping back and forth between domains in his mind in an iterative sequence. This is where the identified functions are linked to potential means satisfying the function, and represents the phase where the main solution principles are selected, i.e. the phase where the dispositions which have large effects on the subsequent phases of the product life span.

Figure 3.7 Product synthesis (Mørup, 1993).



3.4.4 Business contributions by product development

The mission of the product development activity for the business is to consolidate that the product reaches the market in time, with optimum properties and characteristics.

Integration of the business functions

All business functions (e.g. marketing-, accounting-, production- and R&D-departments) cooperates and contributes with proposals and evaluations during the whole product development process. This occurs already in the early phases of the process, where the flexibility for changing solutions are still at large present. Here, communication and information together with the capacity and possibility to cooperate stand as vital elements.

Concurrent appreciation and optimization of important product characteristics.

All relevant product characteristics (function, environmental properties, ease of manufacturing, safety, etc.) are appreciated and optimized throughout the product development process, by effective methods and tools accommodated into an integrated design process.

Integration of marketing/societal/environmental aspects

The market's and the society's interests are integrated in the product development process, to safeguard that the users receives an optimal product, which has a lowest possible harmful impact on human health and other societal issues and on the environment. Communication with the market must run continuously, giving the business the opportunity to

1. support the development of needs in the market
2. survey the response of the products of the business in the market

Communication with the societal aspects, safeguards updating regarding legislators, labor parties and other stakeholders.

Success in product development make special demands on management, organization and administration of the process, together with the supporting systems which shall contribute to increasing the efficiency of the integrated product development process. These are aspects which run continuously within the enterprise.

In an integrated product development environment, downstream activities, prior to actual start-up, starts accumulating information from the previous phases. This accumulation starts simultaneously with the start-up of the project, so that the information basis about downstream activities is collected when the phase in reality starts. It is also important to be aware of that the information about downstream activities is needed early, even though it is not available until the properties of the product and the production process to be used. This implies the need for iterations between product function analyses together with the development of functional solutions and production solutions. This is even more important when considering the total lifespan of the product as information outside a company’s internal information source is needed.

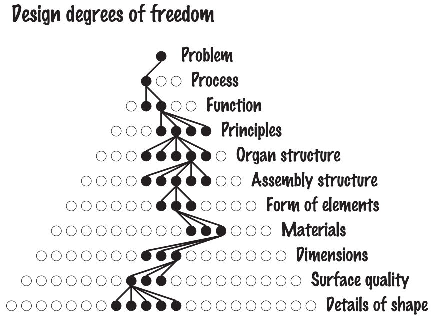
Simultaneously there is a continuos information and communication flow between several phases when these phases overlap. Both of these phenomena in the information flow reduce the development time, through safeguarding that problems do not occur within the different phases due to lack of communication.

3.5 Degrees of freedom

The objective of the designer is to select solutions on the functional criteria for the product. This applies both to primary criteria for the overall functionality of the product and to secondary criteria for subsystems and components of the product.

In theory there are an infinite number of different potential solutions to each function of the product, and in the product development activity, the solution space is constricted through the selection of concepts and structures to the final selection of components. Each selection has consequences for the product life span and the final embedding of properties into the product. Thus, each selection of solutions leaves a disposition (Olesen (1995). The possibility for influencing the properties of the product are large while the original needs and product concept solutions are considered, but when the product development activity is finalized and the solutions are selected, the framework for the properties of the product are determined and the producer, the distributor, the user, the collector and the disposer or recycler can only suboptimize subsystems within this framework. This is illustrated in Figure 3.8.

Figure 3.8 Degrees of freedom during the product development process (Andreasen and Hein, 1987)



3.5.1 The Theory of Dispositions

One of the most fundamental recognitions in design theory is that basic decisions about properties must be taken in the early stages of the product development process (Olesen and Keldmann, 1994).

The great economical responsibility of development and design regarding the entire product life is well known. Studies showed that the stage of design causes a large share of 70% of the future production costs whereas the cost for the design itself only has a share of 10% of the final costs for the product. Regarding environmental aspects this ratio becomes even more drastic since the amount of ecological damages resulting from the design of the product are by far higher than the ecological damages caused by the process of design itself (Anderl and Katzenmaier, 1995).

Olesens (1992) treats the theory of dispositions within technical systems of production engineering. Olesen (1992) describes a theory on how decisions in one functional area affects other functional areas, and describes it by the concepts of dispositions, defined by the following (Olesen, 1992):

> *By a disposition we understand that part of a decision taken within one functional area which affects the type, content, efficiency or progress of activities within other functional areas.*

As shown in Figure 3.9, a decision taken during an activity in one functional area, for example design of a product, consists of two parts (Olesen, 1992):

1. A data part describing the task. This part is typically represented by drawings of the object concerned.
2. A dispositional part describing the conditions affecting activities in other functional areas.

The generic disposition model shows the nature of the phenomena of dispositions by that it always exist in a decision, as illustrated in Figure 3.10 (Olesen, 1992).

Figure 3.9 Schematic illustration of a disposition phenomena (Olesen, 1992)

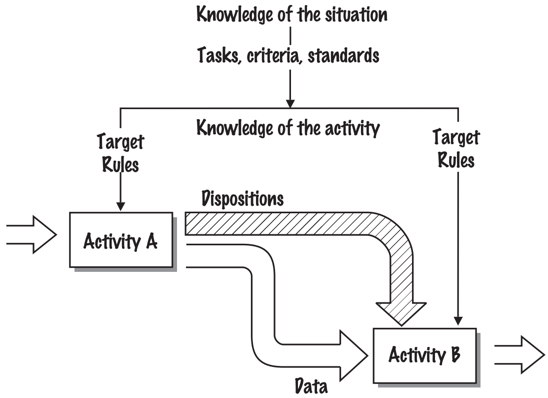
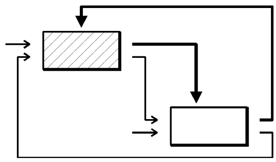


Figure 3.10 Generic disposition mechanism



The generic model for dispositions is valid for any situation where two functional areas are simultaneously renewed, or where existing systems add boundaries. If the product development team needs a complete picture of all systems the product affects or is affected by, the team needs to view all systems of the product lifespan, the relations between them, and the development of these systems (Olesen, 1992).

The theory of dispositions is fundamental in its nature. It is fundamental not only within the area of product development with a focus on environmental properties, but also for the other universal virtues by which a product is measured. Any decision in any point in the functional level in the product lifespan, adds directions for the subsequent product life phases. Here, the main causal relations between the lack of basis for decisions during the early phases of the product development activity, and the lack of decision space of the late phases of development projects (Olesen, 1992).

3.6 Reverse engineering and redesign

While the methodologies described above are applicable to different types of design problems, Otto and Wood (1999) argue that they tend to emphasize either design problems that seek “original solutions” or well-posed parametric formulations. Otto and Wood (1999) believe that for the class of problems known as redesign (adaptive, variant, etc.), an emphasis on original design may be too general. Sferro et al. (1993) argue the legitimacy of this claim, based on an analysis of the current variant design processes in the automobile industry.

As with original design, redesign problems include the process steps described above but also focus on an additional step, referred to here as “reverse engineering” (Ingle, 1994, Otto and Wood, 1999). Reverse engineering initiates the redesign process, wherein a product is predicted, observed, disassembled, analyzed, tested, “experienced,” and documented in terms of its functionality, form, physical principles, manufacturability, and assemblability. The intent of this process step is to fully understand and represent the current instantiation of a product. Based on the resulting representation and understanding, a product may be evolved, either at the subsystem, configuration, component, or parametric level (Otto and Wood, 1999).

3.6.1 General redesign methodology

Figure 3.11 shows the general composition of a reverse engineering and redesign methodology proposed by Otto and Wood (1999). Three distinct phases embody the methodology: reverse engineering, modeling and analysis, and redesign. In the first phase, reverse engineering, the intention is twofold. First, a product is treated as a black box, experienced over its operating parameters, and studied with respect to customer needs and predicted and/or hypothesized functionality, product components, and physical principles. The second step of the reverse engineering phase is to experience the actual product in both function and form. This sub phase includes the full disassembly of the product, design for manufacturing analysis, further functional analysis, and the generation of final design specifications.

The second stage of the methodology involves the development and execution of design models, analysis strategies, model calibration, and experimentation. The third and final stage of the methodology then initiates product redesign based on the results of the reverse engineering and modeling phases. Parametric redesign may be pursued using optimization analysis of the design models (Otto and Wood, 1999).

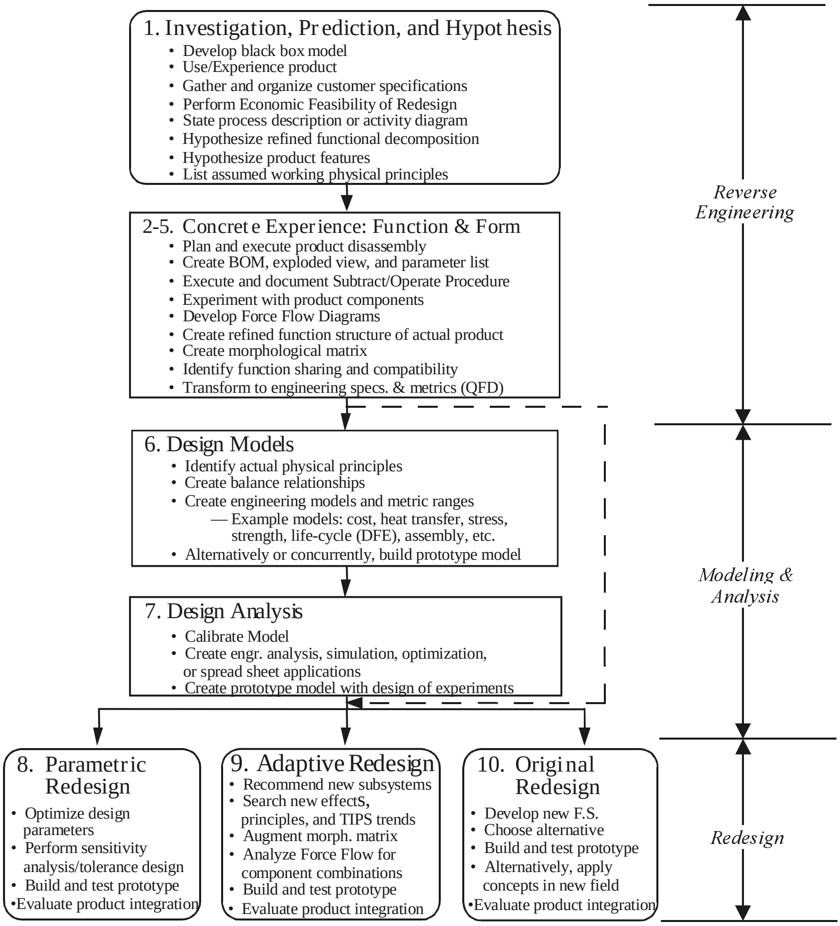
Beyond parametric or adaptive redesign, an original redesign effort may be needed to satisfy the customer needs. An original redesign, in this context, implies that a major conflict exists between the customer needs and the current product in the market. Because of this conflict, it is deemed that an entirely new product concept is needed. Functional analyses from the reverse engineering phase will direct the redesign effort (Otto and Wood, 1999)

In sum, unbiased prediction, customer-driven design, analysis using basic principles, and hands-on experimentation are the philosophical underpinnings of this redesign methodology (Otto and Wood, 1999). The intent of the methodology is to be dynamic, depending on the needed evolution for a product.

For some product redesigns, it may be appropriate to perform adaptive or original changes before creating and optimizing a design model; similarly, the model development of phase two may lead to a better understanding of the product, bypassing parametric redesign and leading directly to adaptive.

Alternatively, another product redesign may call for simple parametric modifications to produce dramatic S-curve response in quality and profit margin.

Figure 3.11 Reverse Engineering and Redesign Methodology (Otto and Wood, 1999).



3.6.2 'Know your product'-philosophy

Andreasen and Støren have developed a methodology for redesigning products based on an intensive investigation of the product to be redesigned, known as 'Know your product' (Andreasen and Støren, 1993).

In 'know your product' the product is analyzed from the customer to production, with all the customer properties traceable through the entire analysis. This makes it possible to determine which of the product properties should be improved and which parts of the product and the production systems cannot be changed. 'Know your product' covers three areas: house of quality, the product/property picture and the product/production quality picture.

House of quality

'Know your product' maps the quality and the competitiveness of the product and thereby the weakness of the product are exposed. The tool for this purpose is the quality house which shows the connections between the how the customer experiences the product ('voice of customer') and the technical properties of the product (Andreasen and Støren, 1993).

Product life phases

Through the product life, the product will interact with its surroundings. The surroundings are all elements of the product life phase system which interact with the product in one way or the other along the value chain. Therefore the combination of the product properties are weighted differently in view of the combinations of stakeholders with interests based on each specific element of product life phase system. When considering the product life phase system, the quality perspective has to be separated into two different components: Q-quality and q-quality. Q are the qualities which the customer experiences and q those which ensure that Q are reached efficiently and with low costs. The internal qualities (q) are mapped to the different product life phases using the same technique as for mapping customer requirements onto technical functions using the house of quality (Andreasen and Støren, 1993).

The product/property study

When redesigning a product it is a prerequisite for a satisfying result to fundamentally understand the properties, characteristics and functional principles of the existing product. The theory of domains explains four different viewpoints of a technical system (Andreasen, 1980). The four views are

- a system of transformation processes
- a system of functions
- a system of organs or structural elements
- a system of components

The system of transformation processes describe the processes transforming the utilized resources into the intended result. The system of functions describe the effects which the product creates. The system of structural elements are the function carriers describing basically that the product is more than the sum of the physical components. The structural elements or organs are the link describing how the physical components combined can create the function. The system of components describe the physical parts of the product. The components does not explain how the product functions.

As for the product life phase mapping, the technique is repeated for the relations between the different viewpoints and technical functions.

The product/production quality picture

The last step in 'know your product' is to describe the result of the interaction between the production system and the product. Analyzing an existing product/production system relationship makes it possible to visualize potential problems in the production phase before it actually occurs.

The three different pictures of relationships between the product and its different properties visualize potential for improvement when redesigning a product.

In view of environmental load of the product, an equivalent technique as described here could be utilized. This technique would here only use the component view of the product as environmental load is only related to material and resource use, i.e. the materialization of the product. Combining this with the product/product life phase map, a complete picture of the environmental load and its primary origin in the product model is visualized. This approach is utilized in the case studies described in chapter 3.10, "The Nordlist LCA Project".

3.7 Drivers for innovation

Innovation is largely forced along by changes in social behavior and lifestyles, which it helps to modify in return (European Commission, 1995).

Smith (1994) argues that one of the most important sources of modern innovation analysis lies in the work of Joseph Schumpeter. Schumpeter's work is open to various interpretations, but it is based on three central ideas:

1. that competition in industrial economies is primarily technological - firms compete not in terms of the efficiency with which they produce given products, but rather by changing products and processes.
2. that this dynamic process of change and replacement - "creative destruction" - is the source of both instability and economic growth in industrial economies.
3. that the generation and management of such change is the primary internal problem in the modern corporation.

Each of these ideas has had major impacts on modern research; but broadly speaking we can distinguish two main themes deriving from the influence of Schumpeter (Smith, 1994):

- a theme which attempts to develop the theory of the innovation process itself - to explore how firms innovate, to develop a more subtle understanding of the processes involved.
- a theme which explores how innovation at firm level affects the evolution and dynamics of industrial structures, and general economic performance.

Schumpeter argued that competition in capitalist economies is not simply about prices, it is also a technological matter: firms compete not by producing the same products cheaper, but by producing new products with new performance characteristics and new technical capabilities. The search for new technologies is thus an integral part of competitive economies, and the development of new technologies is a continuous process (Smith, 1994).

Creative destruction is at the heart of the growth process by the removal of old technologies to make way for the new (Smith, 1994). New technologies lead to increased investment, and results in the use of technologies with better performance and higher productivity, which is the transition from one s-curve to a new one. Schumpeter argued that growth occurred in discontinuous bursts, with “clusters” of innovations leading to investment booms and thus to cycles of growth: for him growth was not an equilibrium process, but rather a process involving major structural change.

Chaharbaghi and Newman (1996) consider that innovating takes place because it has to happen in order to fulfil the need or desire of the individuals and the organization to achieve a result that is somehow new and meaningful. Such a result reflects problems or opportunities which are the reason why the individuals and the organization see the world from a different perspective and change their way of doing things in order to realize it. Furthermore, without creativity, problems and opportunities cannot be seen and hence there is no context for innovating. Without doing things differently, innovating does not take place. Thus, Chaharbaghi and Newman (1996) argue that innovation is a natural human process to improve and modify technical systems in order to realize the need or desire of individuals or organizations.

However, Rønningsbakk (1994) describes the innovation process by viewing the process through a dialog perspective, i.e. between industries and their customers. Rønningsbakk (1994) argues that the push-pull approach should be re-interpreted. *“Innovation processes are dialogs. They are not either market-push or technology-pull driven, but a two-way process of sense creation”* (Waagø, 1995). This view is also supported by Kline and Rosenberg (1986).

Kline and Rosenberg (1986) describe how innovation is controlled by a distinct set of forces that interact with one another in a subtle and unpredictable way. On the one hand are the market forces, that is such factors as changes in incomes, relative prices and underlying demographics that combine to produce continual changes in commercial opportunities for specific categories of innovation. On the other hand, the forces of progress at the technological and scientific frontiers often suggest possibilities for fashioning new products, or improving the performance of old ones, or producing those products at lower cost. Successful outcomes in innovation thus requires a combination of the commercial- (market-pull) and the technological factors (technology-push).

3.7.1 Sustainable development as a driver

In overcoming the confusion and complexity surrounding sustainable development as described in Chapter 2, it is necessary to understand that sustainability can only be achieved through innovation (Chaharbaghi, 1998). The continued failure to understand innovation ensures that sustainability remains a rhetorical concept without a useful purpose. The traditional perspectives have disguised the nature of the change that society must face. What the manufacturers of these perspectives are doing instead is to distract society from the learning process that is necessary for creating and exploiting new opportunities for to achieve sustainability. The change necessary to support sustainability cannot possibly take place by focusing on partial perspectives because at best all they can do is to equip society with the language to talk about sustainability without making any real difference (Chaharbaghi, 1998).

One of the key obstacles that constrains sustainability is the optimization paradigm. The desire to maintain existing values has emphasized the stability mind-set which has meant that efforts towards sustainability have focused on the optimization of existing practices and destroyed the ability to make a real difference. Sustainability therefore demands a capability in itself that can only be sustained by innovation which implies that innovation has to be treated as a continuous process. If this process is retarded, such a capability diminishes and, therefore, the only remaining alternative is to optimize existing practices (Chaharbaghi, 1998).

As without creativity there is no context for innovation, sustainable development requires acknowledging and treating creativity as one of the most important assets. Implicit within such logic is the principle that today's unlimited creativity will represent tomorrow's unlimited potential for sustainability.

Thus, sustainability is not about stability but rather about constant change which is linked to innovation. By treating change as constant, society will ensure a continuous supply of new opportunities that will form the basis of wealth creation, environmental protection, generation of new productive capacities and the consumptive use of the world's resources in ways that are sustainable (Chaharbaghi, 1998).

Van Hemel (1998) reports from the dutch ecodesign project studying strategies, incentives and barriers for implementing ecodesign approaches in 77 dutch small and medium sized companies (SMEs). To which degree internal- and external drivers the SMEs perceived to have strong influence on implementing environmental considerations are shown in Table 3.1.

Table 3.1 Overview of the number of stimuli / barriers mentioned, the number of DFE options involved and the top three types of stimuli / barriers, according to the frequency at which they were reported in the Ecodesign Project (Van Hemel, 1998).

	External stimuli	Internal stimuli	Barriers
Total number?	130	795	414
For how many of the 596 DFE options?	111 (19%)	339 (62%)	322 (54%)

Table 3.1 Overview of the number of stimuli/barriers mentioned, the number of DFE options involved and the top three types of stimuli/barriers, according to the frequency at which they were reported in the Ecodesign Project (Van Hemel, 1998).

	External stimuli	Internal stimuli	Barriers
Which stimuli/barriers were the most frequently reported?	**1** Customer demands (56) **2** Government regulation (43) **3** Supplier development (16)	**1** Environmental benefit (201) **2** Cost reduction (177) **3** Image improvement (102)	**1** Conflict with functional requirements (108) **2** No distinct environmental benefit (51) **3** Commercial disadvantage (51)
Which stimuli/barriers have the most influence?	**1** Customer demands **2** Governmental regulation **3** Branch of industry initiatives	**1** Innovational opportunities **2** Increase in product quality **3** New market opportunities	**1** Not perceived as responsibility **2** No distinct environmental benefit **3** No alternative solution available

Table 3.1 clearly shows that internal stimuli were not only reported more frequently than external drivers, but also had stronger influence on the success rates of the implemented design for environment approach. Table 3.1 also reveals that out of the external drivers, customer requirements appears to be the strongest driver, and even stronger than governmental regulation drivers. These two drivers appears to have much larger influence than other external drivers affecting company decisions.

THus the views of Chaharbaghi (1998) seems to be supported by findings in industry. Drivers for innovative solutions for improving enviornmental performance are reported more frequently internally than from external stakeholders. Naturally, due to e.g. motivation, these have also a stronger influence on success rates of implementation.

3.8 Discussion on innovation- and general product development models

All four models presented in chapter 3.3, “Models of innovation” and chapter 3.4, “Models of product development”, indicates that planning for a product life span reaching from the idea and need formulation phase through manufacturing to the sales activity. Considerations beyond these phases are not present in the models presented.

The integrated product development model of Andreasen and Hein (1987) emphasize the need for integration among engineering disciplines like marketing, product design and production (see Figure 3.4). In product development teams (if teamed up wisely), each individual would contribute with complementary knowledge and skills forming a powerful team to cope with the complex tasks of developing a new industrial product with success in the marketplace. Furthermore, no information feedback loops during the development process for verification of the validity of the identified needs are available in the model. The model does not include the life span approach to prepare the product for product life phases beyond the sales situation, e.g. use phase, service and maintenance, disassembly and recycling. The lack of considerations regarding environmental performance can be explained through the age of the model. It was published in 1987 when none seemed to bother about these issues.

In the Pahl and Beitz model, the aspect of integration among disciplines is missing in Figure 3.5. However, this model also uses the market or customer need as the basis, but lacks the parallelity and integration of different tasks and disciplines respectively. Furthermore, no checkpoints and information feedback loops during the development process for verification of the validity of the identified needs are available. The Pahl and Beitz model also lacks considerations on the subsequent life phases.

The Roozenburg and Eekels model of innovation also uses the market or customer need as the basis, and emphasize the need for parallelity and integration of different tasks and disciplines. The lifespan approach is missing, although this model expands downstream to include the use-phase.

These three models seem to contain some similarities with the linear model of innovation as described in Figure 3.1. The lack of feedback loops illustrates this aspects. All models use customer needs as a basis, but customer needs are dynamic requirements following market trends, resulting in alternating requirements for product development teams to cope with.

The Chain-Linked-Model of Kline and Rosenberg contains information feedback loops between all product development phases. The development process begins with a design idea and continuos through development and production to marketing. The feedback loops provides valuable information from stakeholders along the development process. These feedback paths iterate the development steps and also provides feedback from perceived market needs and users to potentials for improvement of products and service performance in the next round of design. In this sense, feedback is part of the cooperation between the product specification, product development, production processes, marketing and service components of a product line. The lifespan approach is missing for the model, where life phases following distribution and marketing are absent.

The need for integration between disciplines is normally advocated in modern product development models, mainly due to the complex interactions between engineering- marketing- and economic issues. When improving environmental performance of products during the development phases, integration along the value chain is also essential. This aspect is missing from all four models above.

These findings are elements supporting hypothesis B. It was hypothesized that additional elements are needed in traditional product development models to take environmental considerations sufficiently into account in the development activities of both a redesign project and a project developing a completely new product system.

One missing element is the issue of lifespan thinking. All four models discussed here lack the coverage of product life phases beyond the “supply to the market” phase. As the largest contribution to environmental load may lie in the phases subsequent “supply to the market” phase, a model covering all product life phases is important.

Another missing element is the emphasis for information feedback loops. When considering environmental performance, large amounts of information is needed to understand the environmental interactions between the product and its meetings with the product life phase system. However, it is not enough to acquire the product life span perspective, and gather information on the meetings between the product and product life systems. The information must be relevant and meaningful with respect to protecting the environment and human health and / or improving the quality of life. Moreover, the information must be able to inform decision making in the product development activity to improve the performance of the product or product system

3.9 Environment focused product development

3.9.1 The product system in a holistic view

The main dispositions occurs early in the development process, where the primary concepts are selected as described in chapter 3.5. There is a large constriction of the solution space in the subsequent phases. The disposition of environmental properties at this point in time, is similar to other properties, like quality and cost. The product is to be optimized according to environmental properties which are more or less spread out through the total product design life. It is therefore reason to believe that the main environmental properties are determined when the development progress move into details. This is a necessary recognition to support the product development activity early in the development process by tools which already in the definition of goals and concept development, can manage the attractive solutions while the options are still available (Olesen, 1992).

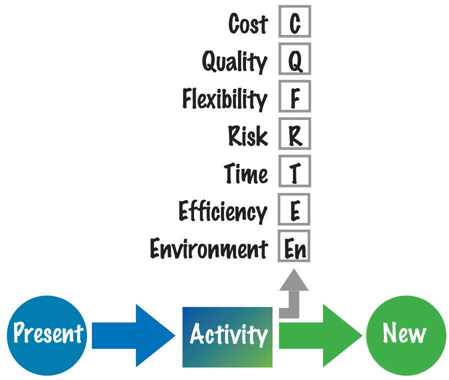
It is therefore necessary to understand the lifespan of the product. It is necessary to map which product life scenarios can occur, and the likelihood for such a scenario to happen. Through the product development, the designer or design-team can try to influence the user by the enclosure of elements in the product, which increases the probability for a product life scenario to occur.

3.9.2 The universal virtues

The competitive power of the product is measured in all activities throughout the product life span, e.g. throughput time and flexibility in production, user apprehension, cost of end-of-life management, etc. Olesen et.al. denotes these the universal virtues. The universal virtues are the measurement tool which the product developer measures to which degree the development activities have been successful. Olesen (1992) claims that all properties of a product, can be connected to one of the seven universal virtues Cost, Time, Quality, Flexibility, Efficiency, Risk and Environment as illustrated in Figure 3.12.

The universal virtues are decomposed in the specific projects and activities into concrete measurement parameters. In development projects, concrete goals for improvement are specified, and the quest for solutions are focused on alternatives which give improvement within the prioritized areas.

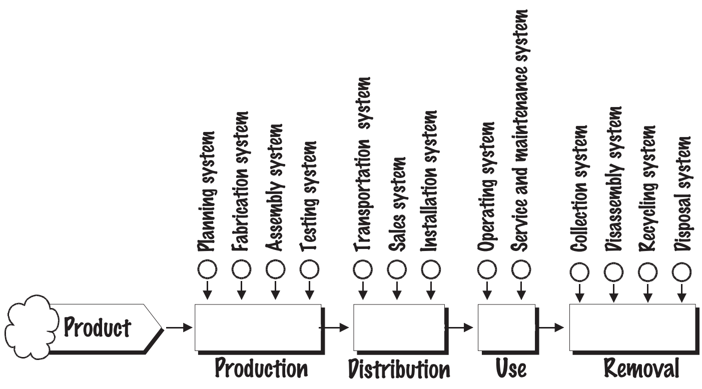
Figure 3.12 The environmental kindness is measured by the universal virtues



3.9.3 Total life models

During the life span of a product, it meets a series of product life systems. The product life systems are e.g. the assembly system, the transportation system, the recycling system, etc. Some of these are illustrated Figure 3.13.

Figure 3.13 Product life systems (from Mørup, 1993 and Olesen, 1992)



To all these meetings between the product and the product life system, activities are connected which represents costs, environmental load, user apprehension, etc. Mørup (1993) differentiates between

- Q-quality which is the customers apprehension of the quality of the product, measured by the universal virtues, and

- q-quality, which is quality apprehension of the internal stakeholders within the company.

These two interests are partially opposing. Mørup (1993) assigns the conception of quality to the universal virtues, and states that quality is created within a product through the product development activity. The quality of the product is made visible when the product experiences a situation where properties built into the product makes the product capable to manage the specific situation. The product properties are otherwise not visible to the user. Quality is not something which occurs by itself, i.e. by extremely accurate control of the processes related to the product. Quality is built into the product across the total product lifespan.

There are many similarities between quality- and environmental properties of a product (Olesen and Keldmann, 1994). Keldmann and Van Hemel (1996) describe and compares different X's in the design for X toolbox. They argue that there are two levels of environmental considerations within a company (Keldmann and Van Hemel, 1996):

1. Strategic level of making product policy decisions, which is primarily the domain of management
2. Operational level, referred to as the domain of product designers

Mørup (1993) argues that in DFX, the 'X' can have two meanings:

- $DFX_{Life\ phase}$: X denotes a product life phase or life phase system, e.g. purchase, manufacture, assembly, logistics, use, maintenance and recycling
- DFX_{Virtue}: X denotes a 'universal virtue' in all life phases, namely (Olesen, 1992): Cost, Time, Quality, Flexibility, Efficiency, Risk and Environment.

DFX is a goal oriented activity with the purpose to either (Mørup, 1993)

- fit the product and life phase system to each other, e.g. $DFX_{Manufacture}$, $DFX_{Assembly}$, $DFX_{Recycling}$, etc.
- Optimize a product with respect to one or more of the virtues, e.g. DFX_{Cost}, $DFX_{Reliability}$, $DFX_{Environment}$ (also called DFE), etc.

A very important source to the creation of DFX-tools is the knowledge of dispositional mechanisms, i.e. where the relationships between certain product characteristics and their effect on X_{Virtue} and $X_{Life\ phase}$ are known and categorized (Mørup, 1993).

Keldmann and Van Hemel (1996) claim that the reason that the DFX's belonging to the $DFX_{Life\ phase}$ group seem to be more widely implemented in industries than DFX_{Virtue} tools, is because the latter are perceived as more complex. The DFX_{Virtue} tools have to take all life phases simultaneously into account, while $DFX_{Life\ phase}$ tools focus on just one life phase with more concrete goals for resource concentration.

Keldmann and Van Hemel (1996) argue that DFE is clearly a DFX_{Virtue} type, and the $DFX_{Recycling}$ and $DFX_{Disassembly}$ are of the $DFX_{life\ phase}$ type which is only one element of DFE. They argue that DFE has a combination of characteristics due to which it will not diffuse autonomously. Therefore the majority of companies will need extra stimuli, such as low cost demonstration projects legislation and financial rewarding to implement DFE in total into their business strategies.

Similar to DFE, $DFX_{Quality}$ is regarded as DFX_{Virtue} type tool. The similarities between $DFX_{Environment}$ and $DFX_{Quality}$ tools, give reason to believe that $DFX_{Quality}$ tools may be beneficial for implementation also to the environmental area (Olesen and Keldmann, 1994). Consequently, the environmental properties must be built into the product in a way which makes the appropriate property visible to its customer at specific stages during its product life.

For cost properties related to the product life span, the conditions are similar. The product developer employs the costs which inflicts the user in the utilization - and End-Of-Life phase of the product lifespan. The decisions made by the product developer during the conceptual and detail development phases of the product development activity, arranges not only the cost for acquisition of the product, but the total lifespan costs for the user.

Roozenburg and Eekels (1995) describe this as the core of the product development activity. In principal, one can think of all possible primary functions of the product, and try to develop products which fill these functions. Each product contain different properties in addition to the necessary basic properties the product needs to fill the primary functions. Each property represent a possibility to function. However, the function presuppose that the product is utilized in a predefined manner. The properties are only visible when the user manages the product in a predefined fashion. A product with the necessary functions therefore work according to the intentions only if it is used in and environment and in a way which the product developer has considered during the development activity. This is the core of product development. Given a function, the designer has to develop scenarios for form and use, and in a way in which the user, if he acts as presupposed, the intended function is realized. This is valid for all situations the product can meet during the product lifespan. If the product developer never considered “simple assembly” during the development activity, the assembly of the components into the product may become difficult. Accordingly, if the developer never considered “simple disassembly” during the development activity, disassembly of the product for maintenance, reuse and recycling becomes difficult.

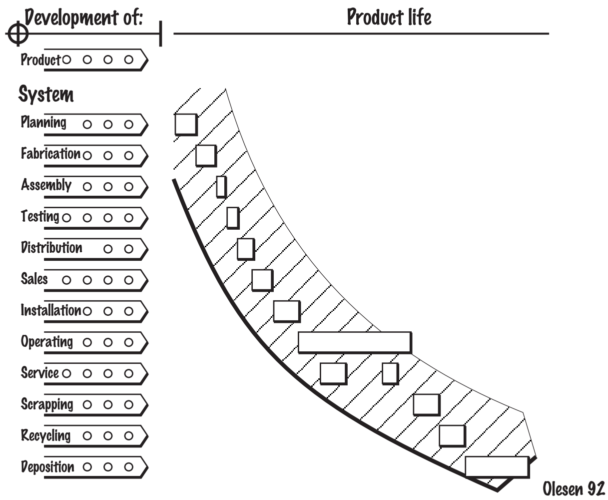
Thus, companies have significant interests in seeing their products in a holistic view where the total value chain is seen on the basis of all stakeholders (stakeholders within the company, customers, legislators, professional bodies, etc.) asserts towards the product developer. It is therefore natural to model product development scenarios to identify environmental loads, product lifespan costs and other qualities which occurs- and are summarized along the product lifespan, and to identify the properties to be embedded into the product to achieve the most beneficial product life system.

This is simultaneously one of the main challenges: to link the product model and the product life system model for the specific product. This is lacking in the general product development models, and will be beneficial to identify the relationships between the product and the different product life phases and the embedded properties which are created during the product development activity.

3.9.4 The Score model

Olesen (1995) further describes the theory of dispositions by what he calls the Score-model, see Figure 3.14, which includes the development process of the product, and an in principal a complete set of product life phase system. The Score-model describes schematically the interaction in the meetings between the product design phase and the product life phase system, and the model illustrates the large number of areas where dispositions affects the resulting product life phase system meetings in a development situation. Olesen describes the model based on production engineering considerations, but the approach also applies to environmental issues.

Figure 3.14 The Score-model for description of the development of production related systems simultaneously with the development of the product (Olesen, 1995).



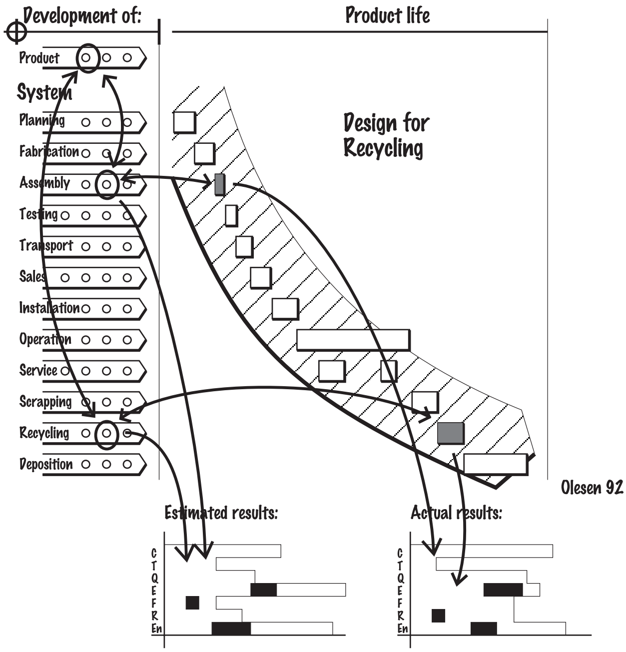
In the Score-model, the development of all functional areas represented by the wide arrow "from defined need to complete documented system", which is also present in the IPD-model (Andreasen and Hein (1987)). Not all product life phase systems are developed from the bottom, but are redesigned based on an existing product or production system.

The model visualizes the need for looking into the future when developing new products. It is shown by several sources, that the main part of the costs related to products, are set through decisions made during the idea generation and conceptual phases of the development project. The identical situation is valid for environmental loads due to the product and related product life phase systems. The Score-model visualizes the product life phase systems the product is to meet during its lifespan, and is beneficial for the inclusion of these functional areas into the product development work.

Dispositions are measured by their effect on the universal virtues in the development phase, even though it is not visible until the actual phase of product life phase system occurs. Consequently, the Score model can also be used to evaluate results as the development project proceed.

Figure 3.15 shows the Score-model schematically for a Design for Recycling project. Preparing the dispositions explains the relationship between recycling and assembly. Thus, a recycling programme which implies changes in the preceding disassembly activity always include considerations on the assembly properties of the product.

Figure 3.15 The Score-model illustrates the relationships between assembly and disassembly of a product, in addition to evaluated and real results (Olesen, 1995).



3.9.5 EcoDesign

The Ecodesign program

The ecodesign program was established in The Netherlands in early 1990. The aim was to provide examples of ecologically improved products that had been the result of ecological product design in regular projects and within the normal business constraints of cost, time-to-market and functionality (Kalisvaart and Van Der Horst, 1995).

The results of the program were quite encouraging: it appeared feasible to combine the ecodesign work with other design work. With the appropriate information and expertise, the product development team could make substantial improvements. The program also showed that product cost did not necessarily rise (Kalisvaart and Van Der Horst, 1995).

At the start of the ecodesign program, the only tool available for ecological analysis of products was life cycle analysis. At that point, the methodology for life cycle analysis was still under development. As many methodological questions had to be considered in each life cycle analysis, it had to be considered an expert tool. Also, the method was time-consuming. This made the method not very suitable as the only tool for the ecodesign program. Using LCA could mean that analysis work would take so much time that most of the product would have been defined by its completion. Possibilities for changing the design based on the analysis would have been very limited (Kalisvaart and Van Der Horst, 1995).

During the ecodesign program, an additional tool was developed—the materials cycles, energy and toxicity (MET)-method. The aim of the tool was to structure communication in the product development project. It was sometimes used as rough checklist and presentation tool.

From the many approaches that exist in the area of ecological product design, three common approaches were selected that are most directly related to the product under consideration (Kalisvaart and Van Der Horst, 1995):

1. materials cycles: design for re-use, recycling disassembly; weight reduction, waste reduction
2. energy consumption: reduction of fuel/electricity consumption, low energy materials
3. toxicity: suspected substances, black-listed substances, substitutes, maximum concentration

These three themes are plotted against the life of a product in the so-called MET-matrix (see Table 3.2)

Table 3.2 The materials cycles, energy and toxicity (MET)-matrix. From Brezet and Van Hemel (1997), Kalisvaart and Van Der Horst (1995).

Five Year	Materials cycles	Energy use	Toxic emissions
Production and supply of materials and components	Material consumption during production and supply	Energy consumption during production and supply	Toxic emissions during production and supply
In-House Production	Material consumption during in-house production	Energy consumption during in-house production	Toxic emissions during in-house production
Distribution	Material consumption during distribution	Energy consumption during distribution	Toxic emissions during distribution
Utilization			

Table 3.2 The materials cycles, energy and toxicity (MET)-matrix. From Brezet and Van Hemel (1997), Kalisvaart and Van Der Horst (1995).

Operation	Material consumption during operation	Energy consumption during operation	Toxic emissions during operation
Service	Material consumption during service	Energy consumption during service	Toxic emissions during service
End-of-life			
Recovery	Material consumption during recovery	Energy consumption during recovery	Toxic emissions during recovery
Disposal	Material consumption during disposal	Energy consumption during disposal	Toxic emissions during disposal

The MET-method appeared useful as it gave engineers and designers a grip on the issues they were dealing with. Its titles appeared more suitable than rather technical ecological terms such as: greenhouse effect, acidification and ozone depletion (Kalisvaart and Van Der Horst, 1995).

One of the conclusions from the Ecodesign project was that using LCA for the ecological assessment of the product seemed unsuitable for engineers as it uses processes rather than parts and product structure (Kalisvaart and Van Der Horst, 1995).

Life cycle analysis on a part-by-part level is instructive, but leads designers into the “analysis trap”. Rather than concentrating on main effects and functions, they tend to collect more and more detailed information. An analysis at a black-box level seems more appropriate. Furthermore, end-of-life scenarios are not modeled explicitly in LCA: assumptions about the degree of disassembly are never checked explicitly for realism with regard to cost (Kalisvaart and Van Der Horst, 1995).

LCA plays an important role in supplying the underlying theory and data for the design tools. LCA tools will, however, remain the domain of experts. The outcomes of LCA can be communicated well by use of single-figure indicators like the MET-points (Kalisvaart and Van Der Horst, 1995).

It appears to be possible to develop ecological tools for engineers and designers that are compatible with their present way of working Using the tools does not require a special background or extensive ecological training. The introduction of these tools structures the way ecodesign is performed. The tools consider parts and product structure, rather than processes (as in LCA). Using MET-points, disassembly costs and ecological issues can be studied in ways completely analogous during the same analysis. With these tools, a middle way between the complexity of LCA and unbalanced or oversimplified tools seems to have been found (Kalisvaart and Van Der Horst, 1995).

EcoDesign Manual

The Ecodesign project included investigations on how SMEs implement environmental strategies into their product development processes. Out of the number of different potential strategies, only a small number of strategies were found beneficial by the participating companies (Van Hemel (1998)).

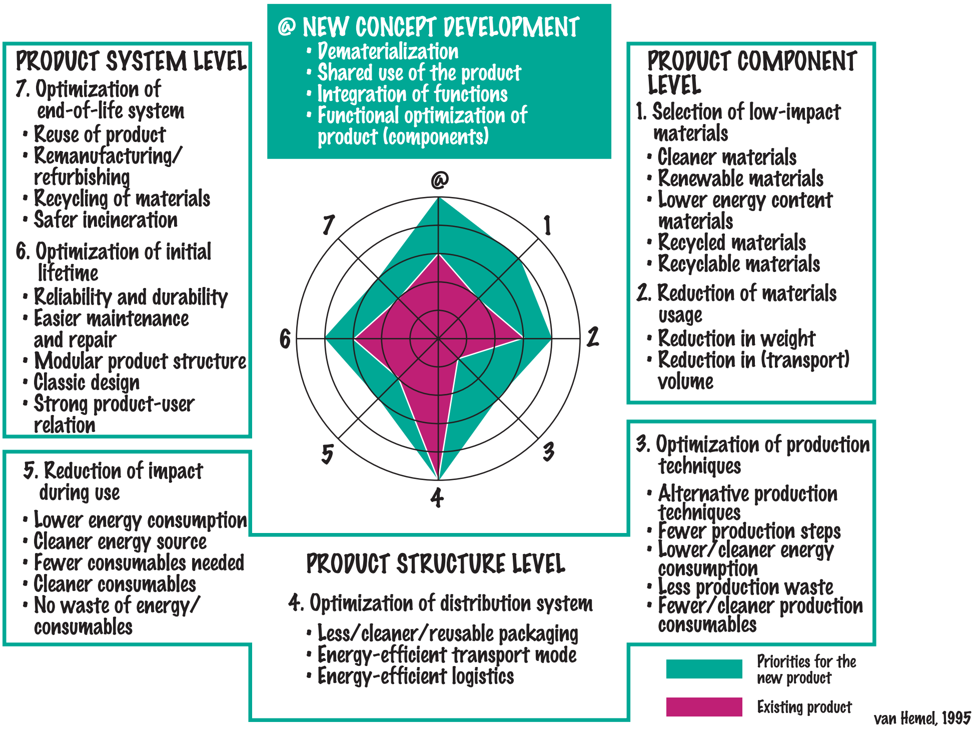
The results from the investigation on the implementation of strategies were gathered in the EcoDesign Manual (Brezet and Van Hemel (1997)) to guide companies not familiar with ecodesign, into the implementation process. The EcoDesign Manual is a comprehensive guide for implementing environmental aspects into product development projects.

The manual contains a seven-step method to guide the business through an ecodesign pilot project and assist in further planning and development of the business environmental strategy.

Based on the experience with the resource consuming Life Cycle Assessment tools, the manual promotes the use of other tools which do not consume the same amount of time and other resources. e.g. the EcoDesign Strategy Wheel, The MET matrix, and assessment of internal and external drivers for identifying resources to utilize. However, the holistic view of the product system is still the underlying principle: focusing on all product life phases and its contacts with the corresponding surroundings and product life phase systems. The methodology is summarized in the Ecodesign Strategy Wheel illustrated in Figure 3.16. Life Cycle Assessment and Life Cycle Cost is added to the methodology for documentation purposes.

The methodology focuses on how to make businesses think differently from the usual pattern with regard to the product or product concepts principal way of satisfy requirements and exercise a function.

Figure 3.16 EcoDesign Strategy wheel (Brezet and Van Hemel, 1997)



The Ecodesign manual is primarily a methodology preparing companies for their first project improving the environmental properties of their products. The methodology introduces different strategies for implementation into existing products and give advise for how to perform this implementation work. The different strategies represent an increasing degree of difficulty where finalizing in the fundamental redesign giving advice on alternative function fulfillment. This is a difficult task and the methodology give advise on dematerialization, shared use, integration of functions and functional optimization. These advises are supported by examples. They lack a deeper explanation which could make the strategies transferable to other product systems.

Design for Environment (The EDIP programme)

Olesen (1996) presents a methodology for development of environmentally friendly products. The environmental friendliness of a product is a property which is determined by the use and efficiency of technology in addition to the harmful environmental effects in all product life phases and the probability for these effects.

Olesen (1996) argues that the disposition mechanisms are essential to get hold on and understand the relationships between decisions in the design phase and environmentally harmful effects due to the product during its contacts with its product life phase systems along the product life span (Olesen, 1996). Consequently, when the designer determines the degree of freedom of the product, the environmental friendliness along with all other properties are employed. Olesen (1996) emphasizes the need to view the product and all product life phase systems in relation and on the right level corresponding to the progress of the development project. The largest improvement profits are achieved by simultaneously determine the product and the routes for the product life, i.e. product life phase systems (See Figure 3.13). It is therefore necessary to develop scenarios to evaluate the most beneficial combination of product solutions and product life phase systems with corresponding probabilities (Olesen, 1996). To create attractive routes for a product requires insight and conscious attitude towards the product life.

The EDIP approach is based on analyses of the structure of a product. It is based on the theory of domains which presents four different viewpoints to view a technical system. The EDIP approach focuses on capturing the relationships between elements of the product structure and product life phases. Seeing these relationships in a from a holistic viewpoint gives the product developer valuable insight into the sources of environmental load in addition to insight into how the other six universal virtues satisfies the overall function of the product system. Environmental design principles to consider are illustrated in Table 3.3.

Table 3.3 Elements to consider for improving environmental properties of a product system (Olesen, 1996)

Product level	Elements to consider	
Need level	• Transformation process	
Concept level	• Functions • Man / machine interface • Process sequence	• Technology and solution principles • Total design and features
Organ or structure level	• Subsystems: Integration or differentiation of subsystems	• Product structure: Structural concepts
Component level	• Subassemblies • Component design • Dimensions and tolerances	• Material selection • Surface quality

Life Cycle Design

Behrendt et al. (1997) present guidelines and design principles to enable designers in small and medium sized companies to include environmental considerations into the design process. Behrendt et al. (1997) claim that although some successful ´Ecodesign´ demonstration projects had been carried out, many companies lack the experience to systematically include environmental considerations in their product design processes.

Behrendt et al. (1997) claim that most approaches lack detailed criteria for environmentally sound product design. They only concentrate on one single criteria and do not take the whole life span into account.

Behrendt et.al. (1997) present a catalogue of principles and criteria in order to make ecologic design operational. This list of requirements can be used to check whether or not the design team has explored the entire range of environmental product development.

Furthermore, Behrendt et al. (1997) truly explain, that there is no such thing as a homogeneous solution for the ecological product. The rules are intended to be used for a systematic development of ecologically sound design products. In practice, the main objective will be the implementation of as many criteria as possible in agreement with the demands on functionality, quality, design and cost of the product as well as the consumers' claims.

3.10 The Nordlist LCA Project

3.10.1 Mission of Nordlist project

NordList was a research and development programme in the Nordic countries focusing on lightweight structures for transportation. The program concluded in 1996.

Nordlist was a four year programme with the mission of bringing nordic industry to a higher competitive level within industries where present competence is good and where the weight of structures is a vital parameter for saving resources.

3.10.2 Mission of Nordlist LCA-project

The goal of the Nordlist LCA project was to combine the description of the product structure with the life span structure into a relation database software application (Lamvik et al., 1997b). The goal was to systematize ecological-, technical- and economical information about the product, its components and relationships between them into a computer system for performing analyses for environmental and economical evaluation of product systems. Furthermore, comparing existing alternatives with improvement options should make this a valuable tool for product developers.

The goal of the project was to validate the usability of the software tool, and not to perform detailed analyses of products and product systems.

To identify the usability of the developed LCA tool for designers, three case studies were carried out in three different Nordic companies. The case studies were:

- Borealis Industries, Tidaholm Sweden where a knee-bolster produced from polymer and steel was compared with a knee-bolster produced from GMT, composite.
- Maritime Seanor, Asker, Norway, were a well protection structure for subsea installations was studied to find potentials for environmental improvement within the life cycle context.

- Carrus Oy/Kabus Oy, where production of a bus frame produced from stainless steel was compared environmentally with a bus frame produced from alumna.

The Carrus Oy/Kabus Oy test case is deliberately skipped in this dissertation. For details, see Nordlist LCA Project Final Report (Lamvik et al., 1997b).

The basis for the tool is a modification of the 'Know your product'-philosophy described in chapter 3.6.2. Combining the product structure with life span thinking is hypothesize to give valuable insight into the sources for environmental load and valuable information for generating improvement options. In view of environmental load of the product, a technique equivalent to the one used to describe the 'Know your product'-picture, was utilized to trace all product system related environmental load onto the different elements of the product life phase system structure. This techniques here only utilized on the component view of the product structure as environmental load is only related to material and resource use, i.e. the materialization of the product. The functions view and the structural or organ view is left out as it was found to be difficult to connect environmental loads to immaterial elements of the product structure. The transformation process view was used to define the functional unit to be used in the analyses.

Combining the different environmental loads with the product/product life phase map, a complete picture of the load and its primary origin in the product model is visualized.

Life Cycle Assessment (LCA) is a systematic procedure for tracking environmental load generated by technical systems throughout its life span. The procedure is standardized in ISO 14040 (1997), ISO 14041 (1998), ISO/ CD 14042 (1999), ISO/ DIS 14043 (1999), ISO/ TR 14048 (1999), SETAC (1993). Other information sources on Life Cycle Assessment are among others Goedkoop (1995), Nordic Council of Ministers (1992), Steen and Ryding (1992).

One problem with the LCA as described in the standards mentioned above, is that they are regarded as too resource consuming to be applicable in product development. This view is supported by Behrendt et al. (1997), Brezet and Van Hemel (1997), Jones et al. (1999), Kalisvaart and Van Der Horst (1995), Lamvik et al. (1997a), Low and Williams (1999), Olesen (1995), Olesen and Keldmann (1994), Olesen (1996), Van Hemel (1998), Van Nes and Stevels (1997). The reason for this is the availability of reliable data to be included in the analyses. This is information about materials and energy consumption of the actual processes.

However, one of the conclusions from the Ecodesign project was that using LCA for the ecological assessment of the product seemed unsuitable for engineers as it uses processes rather than parts and product structure (Kalisvaart and Van Der Horst, 1995). This means that LCA is more valuable for documentation purposes, where the need for accuracy and detailedness is more vital. Although LCA plays an important role in supplying the underlying theory and data for the design tools, Kalisvaart argues that LCA tools will remain the domain of experts. The outcomes of LCA can be communicated on a satisfying level by use of single-figure indicators like the MET-points (Kalisvaart and Van Der Horst, 1995).

One issue Kalisvaart misses here is that the source of environmental load lie in the processes which produces the physical parts. In addition, the use of MET-points or the MET-matrix requires that the operator capture the relationships between the product structure and a holistic product life span view, which may be easier to obtain using a more detailed analysis.

An analyses tool to be utilized in product development activities must be easy to use and rapid enough to keep up with the constantly decreasing requirement on time to market.

Furthermore, the LCA approach require that a product is available. This can be an old generation of a product or the product of a competitor. When a completely new product is developed, there are no physical parts or processes to link environmental load onto, and a simplified qualitative type tool is more applicable (Kalisvaart and Van Der Horst, 1995).

The approach here is to apply the methodology on a redesign situation, to validate the methodology based on the 'Know your product'-philosophy. For details, see Nordlist LCA Project Final Report (Lamvik et al., 1997b).

3.10.3 The Borealis testcase

Reference product

Reference product for this case study is a common knee-bolster for SAAB. A product life phase system model is built using the components view of the theory of domains with the production processes bringing each component into being. Figure 3.17 illustrate the product life phase system structure with its system boundaries.

Alternative solution

An alternative product life phase system is built based upon development work performed within the company. During a product development activity, alternative solutions are developed simultaneously. When selecting alternatives, evaluation of environmental load is performed. When comparing alternatives, it is important to compare components, subsystems or complete products utilizing an equivalent function, i.e. a functional unit. The functional unit should not only contain the component, subsystem or complete product, but also elements of its product life. This makes the analyses take care of the possibility that the largest contribution on environmental load lie outside the product structure, but still inside the product life phase system. The alternative product life phase model is illustrated in Figure 3.18

Figure 3.17 Reference product Knee-bolster

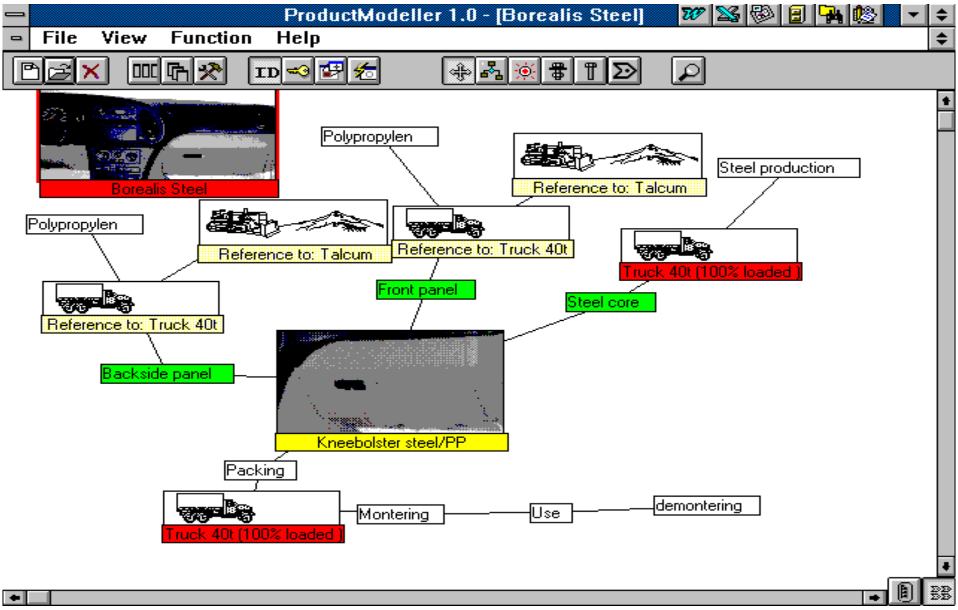
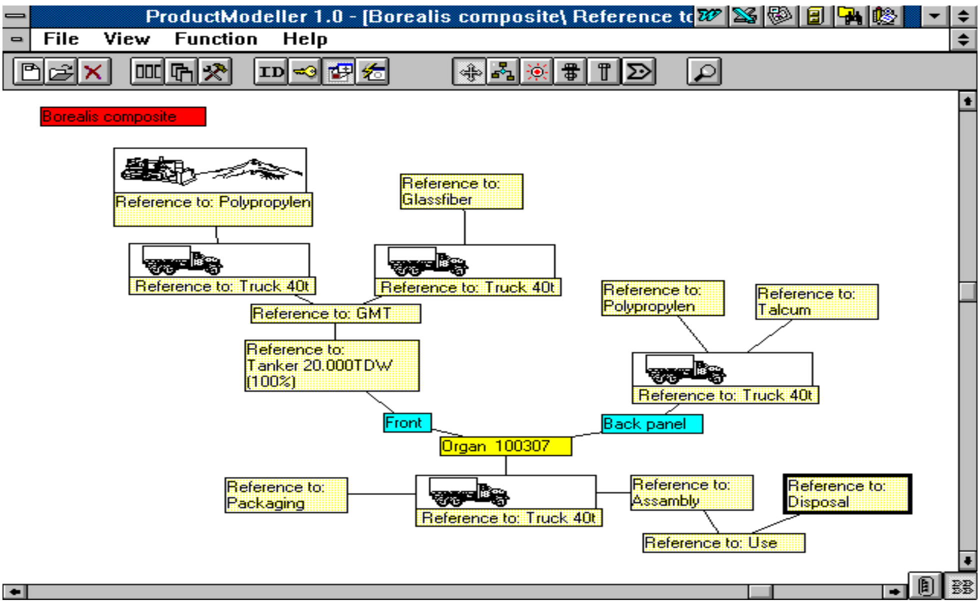


Figure 3.18 Alternative solution, Knee-bolster.



Main contributor to environmental load

Reference Product

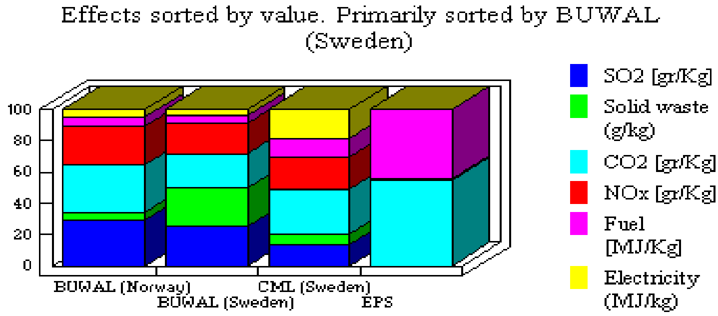
The environmental load is further calculated using different valuation models. For details on the different valuation models see

- BUWAL model: Ahbe et al. (1990)
- CML model: Heijungs (1992)

- EPS model: Steen and Ryding (1992)

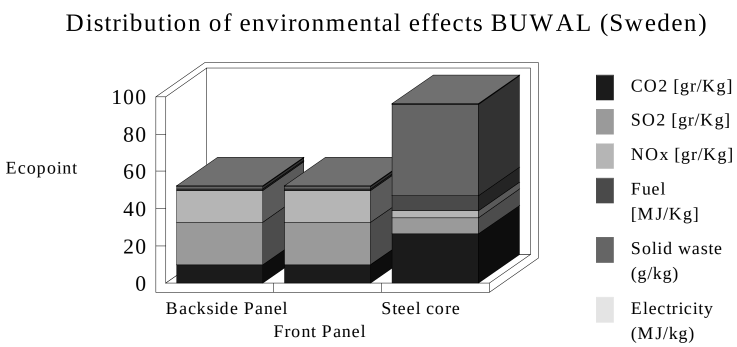
Based on the product structure and materials and energy data included in the model, the largest contributor on environmental load is visualized and illustrated in Figure 3.19

Figure 3.19 Most important environmental emissions and resource depletion according to four valuation models when BUWAL is chosen as the main model.



Furthermore, the location of these loads within the product structure can be visualized, as illustrated in Figure 3.20.

Figure 3.20 Distribution of environmental impacts distributed on different parts in the product system.



As may be ascertained from Figure 3.20, based on CO_2-emissions and the production of solid waste, steel core seems to represent the largest contribution. The front and backside panel emit the highest amount of SO_2 and NO_x.

Downstream production line is assessed to find what element in the steel core that makes the largest impact. This in order to find potential areas for CO_2 reduction. Figure 3.21 illustrates the environmental impacts deriving from the downstream production line.

Figure 3.21 Environmental impacts distributed on elements in the downstream production line.

Distribution of environmental effects BUWAL

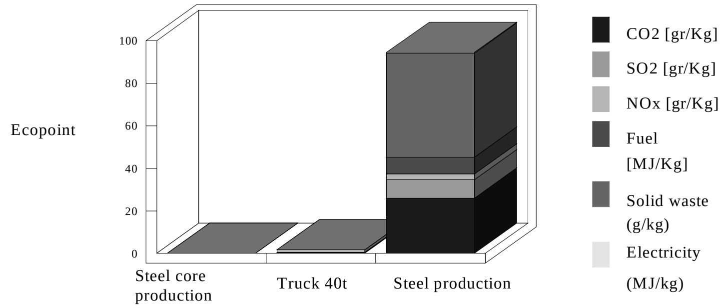


Figure 3.21 illustrates that steel production is the main element contributing to environmental impacts, during the production of the reference product system. To decrease the CO_2 emissions in the system, the designer will see that one option might be to decrease the use of steel.

Alternative Solution - Composite

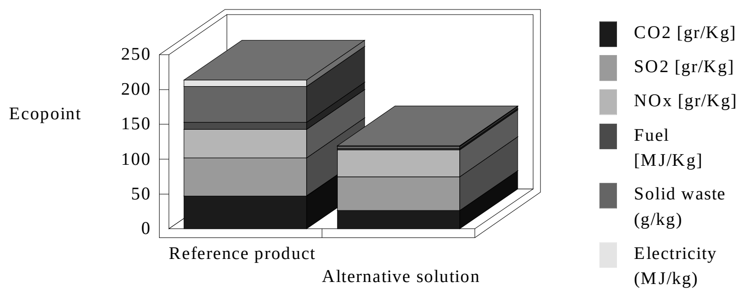
The alternative product life phase system model is analyzed in the same manner.

Results from the Borealis test case

The two solutions are finally compared and the preferable solution is selected, as illustrated in Figure 3.22.

Figure 3.22 Comparison between knee-bolster made by composite and made by polyester and steel; according to BUWAL

Distribution of environmental effects BUWAL



From Figure 3.22, we observe that composite based solution when compared with polyester/steel core, is preferred from an environmental point of view for manufacturing of the knee-bolster.

3.10.4 The ABB Maritime Seanor test case

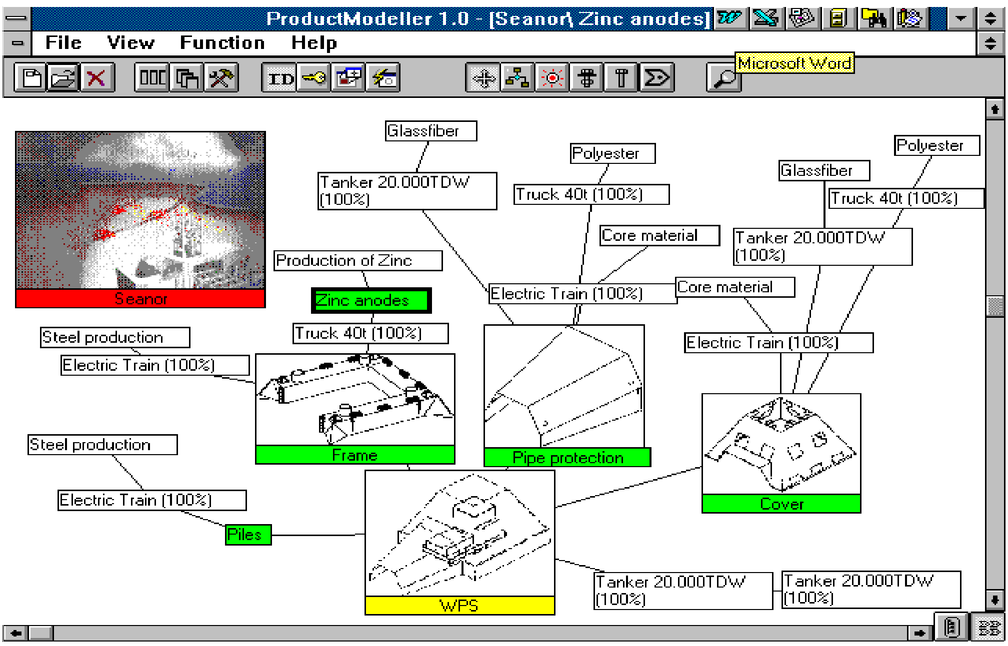
Reference Product

The reference product for this case study is a well protection structure for a subsea installation. The protection structure consists of a frame and piles manufactured from steel with sacrificial zinc anodes, for corrosion protection. The frame is equipped with a well and a flowline protection cover manufactured from a composite material. The composite material consists of a hand laid sandwich structure containing a core with layers of glass fiber reinforced polyester on both sides.

This protection unit is needed for protection of the well from trawling gear and other fishing equipment, and protection of the installation from possible dropped objects. Considerable environmental impacts might come about if these protective structures did not exist. Figure 3.23 illustrate the product life phase system with its system boundaries. The functional unit of the systems is defined as:

> *Production and waste treatment of one well protection structure unit transported on barge to the field.*

Figure 3.23 Reference product well protection structure



Main contributor to environmental load

Identical analytical path as for the Borealis test case is applied to the ABB Maritime Seanor test case.

The analyses shows that the zinc anode-component of the product system is the largest contributor to environmental load, as illustrated in Figure 3.24. Downstream production line is assessed to find what element in the steel core that makes the largest impact, in order to find potential areas for Zinc and Cadmium reduction. Analyses of the downstream production line for the sacrificial anodes shows that the raw material is the largest contributor as illustrated in Figure 3.25.

Figure 3.24 Distribution of environmental impacts distributed on different parts in the product system.

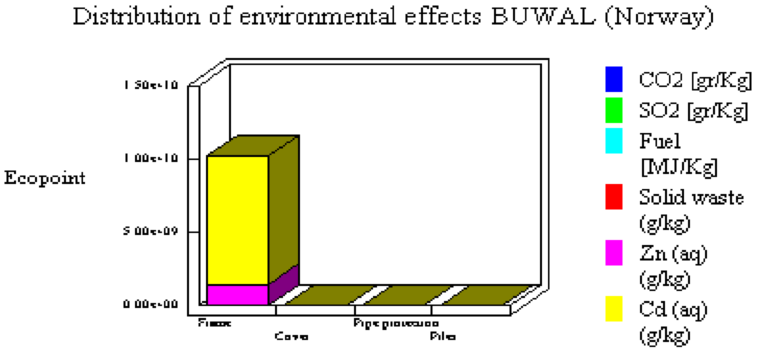
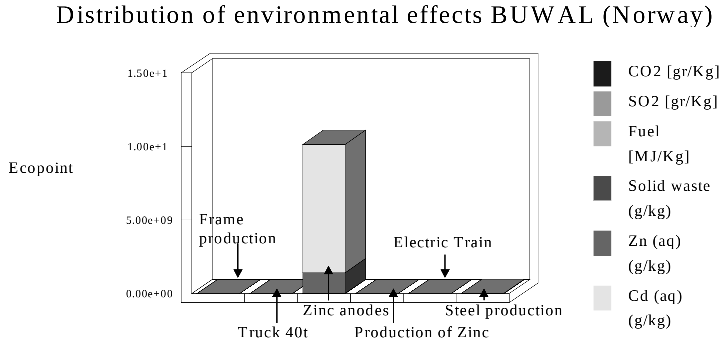


Figure 3.25 Environmental impacts distributed on elements in the downstream production line



The sacrificial anodes are applied for protection of the steel surface from corrosion. Due to the fact that damage to offshore installations might cause huge environmental impacts, risk for corrosion damage cannot be accepted. Corrosion protection of steel construction is therefore needed. Zinc anodes can be replaced with aluminium-based anodes may give an environmental improvement to the product system without any fundamental modifications, but by changing one of the materials.

3.10.5 Results from the ABB Maritime Seanor testcase

The analyses shows that the element with largest contribution to environmental load is the sacrificial anodes with for corrosion protection of the steel surfaces. The polluting elements are the heavy metals Cadmium and Zinc.

One approach for environmental improvement of the product system is to apply alternative corrosion protection means. Use of aluminium anodes is an alternative solution. There are also alternative solutions excluding anodes and replacing them with paint coatings. However it is unlikely that any paint producers today, will guarantee their products for up to 50 years, on a subsea applications. Paint-coating, yet should not be written off as a possible future solution as the durability of coating materials is constantly being improved.

Even when anodes are excluded from the study, steel constructions as piles and frame, present higher contributions to the total environmental impact index than parts made of composite material. The use of zinc anodes will also be decreased when use of steel is decreased. Relevant options for environmental improvement seem thus to be centred upon steel reduction efforts.

The main objective when considering the Well Protection Structure in a holistic view regarding cost is weight. When dealing with subsea installations within the offshore industry in the North Sea, weight is the essential parameter due to competition between installation vessels. If the weight of the construction becomes too high, the vessels capable of transporting and installing the unit is reduced to one, i.e. the cost and time of installation is defined by the contractor. This is critical for the operator as the return on investment for such cost intensive projects is depending on the cash flow at an early point in time as possible.

3.10.6 Discussion on the Nordlist LCA test cases

McAloone (2000) has made some thoughts on the present work within the research on ecodesign supporting the critical issues on the design approach reported above.

> *Many papers claimed to be reporting on ecodesign when they were reporting on Design For Disassembly, many claimed to be reporting on sustainable design research, when they were actually reporting on eco-redesign. The eco-design subject seems to have reached a plateau at the moment, where achievements beyond a collection of environmental DFX's and a good environmental management scheme seem to be difficult for the community to perceive. (McAloone, 2000))*

What McAloone is stating is that too many ecodesign research projects are focusing on specific details of a product system without critically addressing the underlying problems. The source of the underlying problems are more likely to be found on the functional level of the product structure. This results in incremental improvements by utilizing the collection of environmental DFX's where isolated phases of the product life span phases are analyzed and improved. The holistic total life span view becomes absent. McAloone calls for research projects which confront step-change examples in design and discuss how industry might methodically and realistically achieve them - in a business and economic sense (McAloone, 2000).

The results of the case studies described above shows that the presented methodology can be valuable for evaluation of improvement options of environmental performance. Combining the 'know your product'-philosophy with environmental considerations give valuable insight into the actual location of the environmental loads within the product structure. Improvements of components, parts and subsystems are valuable in themselves, and are valuable in terms of optimizing the selected overall solution. However, the approach generates curiosity for new analyses which makes the product developer dig deeper into the details of the product system. This often give improvements on the parts level through the simple strategy of material- or parts substitution. Using a different view of the product system, like the transformation process- or functions view may give a more holistic understanding of how the main functions of the product system operates and find alternative solutions which have a higher potential for improvements. This approach will need to utilize the more difficult strategies of the ecodesign strategy wheel, as described in chapter 3.9.5, which may have a higher potential for improving environmental performance.

The focus on the components view of the theory of domains only miss the core issue described in chapter 3.5, "Degrees of freedom" and in the theory of dispositions, that the main dispositions are made in the early phases of product development. This means at least prior to the detailed design phase where components and parts are defined. During this phase, only minor changes are available with only minor potential for contributions to improvement of environmental performance.

The reason for this can be the focus on the different specific environmental contributions, like CO_2, SO_2, NO_x, etc. Focusing on these specific elements automatically draws attention to identifying their source. Finding the source means digging deeper into the details of the product structure, which consequently means digging into components and parts, i.e. the physical materials and their environmental loads. Finding the source of the emissions will not give any contribution to an alternative solution. It merely helps identify where the problem is located. Locating the problem may be valuable although it give no contribution to evaluating wether or not we are solving the correct problem. Consequently, there is a risk that the product developer is solving the wrong problem when using the 'know your product'-approach combined with life cycle assessment. Therefore this approach will hardly contribute to a leap improvement in environmental efficiency, but stay within the first and partly the second step of the BCS ladder as described in chapter 1.7.2, "Leap improvement in environmental performance".

Climbing higher in the function-means tree (see Figure 3.8) will give the product developer a larger solutions space, and the possibility for identifying a solution with higher potential for improving overall environmental performance. This involves a different analysis of the environmental loads due to the fact that specific harmful elements like CO_2, SO_2, NO_x-emissions must be connected to the physical elements of the product structure.

3.11 Concluding remarks on innovation and product development

This chapter has presented different theoretical models of the product development activities. The theoretical models describing the phases of activities involved in development work, are fundamental in all product development projects, including projects where the focus is improving environmental performance.

The link between the function means tree (i.e. the abstract level) and the product structure of components and parts (i.e. the physical level) is identified as a weak point when developing strategies for developing alternative solutions for improvement. This is one of the main challenges: to link the product model and the total life system model for the specific product. This is absent in the general product development models. It will be beneficial to identify the relationships between the product and the different product life phases and the embedded properties which are created during the synthesis phase of the product development activity.

Thus, the findings support hypothesis B *Traditional product development models lack sufficient elements making them suitable for environmental considerations in development of industrial products*. Traditional product development models lack the element of life span thinking, which is essential in development products when focusing on environmental performance. Life span thinking involves acquiring an overview of the different product life span meetings the product is likely to go through. These meetings are the situations where the product meets other product life phase systems, and where the potential environmental load arise. Keeping the life span system with its relationships through different meetings with support systems in mind, can contribute to optimizing the product system, and avoid suboptimizing small details which only have minor potential for improving environmental performance.

Furthermore, traditional product development models lack the element of integration along the value chain. It is not enough only to see the relationships between the product and product life phase systems. The product developer needs to understand the effects of the meetings between the product and product life phase systems, and integrate this information into the design activity. This finding also support hypothesis B. The theory of disposition illustrates the need to include this integration dimension, i.e. all decisions performed during product development, affects type, content, efficiency or progress of activities in subsequent product life phases.

When considering environmental performance, large amounts of information is needed to understand the environmental interactions between the product and its meetings with the product life phase system. However, it is not enough to acquire the product life span perspective, and gather information on the meetings between the product and product life systems. The information must be relevant and meaningful with respect to protecting the environment and human health and / or improving the quality of life. Moreover, the information must be able to inform decision making in the product development activity to improve the performance of the product or product system.

Consequently, integration along the value chain is essential for leap improvement of environmental performance of industrial products.

The tools for estimating environmental load is identified as belonging to the physical level of the product structure, i.e. the lower levels of the function-means tree. Here the consequences of dispositions selected in the conceptual phases are visualized and alternatives for improvements are limited. This finding supports hypothesis C *Traditional product development models lack the support systems to conquer barriers and break out of existing mind patterns of technological lock-ins to create completely new systems with significantly improved environmental performance for delivering customer needs.*

Traditional product development models focus too much on existing mind patterns. The demands of time to market makes using existing information and redesigning existing product systems important elements to reach milestones on the time schedule. Traditional models favour the need for rapid product development. Although the models do not support performing the work insufficiently, it can turn into rush jobs spoiling the opportunities to make a real difference in improving environmental performance.

The discussion above, i.e. the lack of product life phase perspective, and the lack of elements to treat information from the product life phase perspective, can be used as an explanation of why the use of traditional product development only do not result in leap improvements in environmental performance.

By explicitly expressing the important link to creative methods for systematic generation of ideas, the situation described here can be avoided. The models emphasize the need to focus effort on the conceptual stage of the development activity. Brilliant ideas may arise from nowhere, but this situation rarely occurs when new ideas are needed. A product development team cannot rely on serendipity when they have a deadline to meet.

Development of tools and guidelines are needed for guiding the thinking process of the product developer into alternative solutions which breaks the present apprehension on how identified functions are satisfied using traditional means. This statement calls for investigating how methods of creativity can contribute in breaking the psychological inertia and come up with the correct balance between traditional and untraditional means to satisfy the identified functions. Traditional means to fit with present apprehension on how a need normally is satisfied and to satisfy a business' short term economic goals, and untraditional means to consolidate a component carrying the radical innovation contributing to moving forward towards sustainability, both in environmental and economic sense.

CHAPTER 4

CREATIVITY IN PRODUCT DEVELOPMENT

This chapter describes a number of different models for creative thinking. The intention of the chapter is to describe how elements to support and maintain creative thinking unified with the product development models can provide a better basis for achieving leap improvement in environmental performance.

4.1 Introduction

The innovation- and product development models all use the triggering of an idea as a starting point after a need has been identified. These models are guides for structuring the tasks of bringing this idea into a business activity in the market. An idea is not enough to produce a business activity. Ideas must be developed further into marketable products or service. The creative process of bringing up, fostering and developing ideas and to bring the present situation into new and improved situation is therefore necessary for bringing forth the change required to obtain the competitive advantage in the marketplace.

4.2 The importance of creativity

The fact that *creativity* is the anagram of *reactivity* explains why creativity is important. Creativity Engineering (1999) argue that the concept of creativity is the core organizing principle of our work because it represents the ultimate optimistic attitude. Rather than capture a reactive attitude to a challenge, stressor, or a sudden shift in the market environment, the creative and proactive organization can react quickly and inventively through generating ideas and develop these into useful solutions. Successful organizations do things faster, cheaper, and better because of their ability to protect, nurture and fully develop (initially) fragile ideas into useful solutions. This is an important element in the proactive organizations which see environmental challenges as opportunities rather than threats. This view is supported by Chaharbaghi (1998) who states that innovation is a prerequisite for identifying solutions supporting sustainability.

There is general agreement among most researchers within the area of sustainable production and consumption that industrial activity cannot proceed as before but must be replaced by practices significantly improving environmental performance (Bossel, 1999, Brattebø and Hanssen, 1998, Brezet, 1997, Brezet and Van Hemel, 1997, Chaharbaghi, 1998, Ehrenfeld, 1994, Ethernally Yours, 1996, Factor Ten Club, 1997, Fussler and James, 1996, Hardi and Zdan, 1997, Holdren et al., 1995, McDonough and Braungart, 1998, Meadows, 1998, Meadows et al., 1991, Meadows et al., 1972, Schmidt-Bleek, 1995, Stigson, 1997, Te Riele et al., 1998, van den Hoed, 1997, Van Hemel, 1998, Van Nes, 1997, Von Weizsäcker et al., 1997, WBCSD, 1996, WCED, 1987, Weterings and Opschoor, 1992, Wuppertal Institute, 1996). What is needed is a different way of creating industrial output, i.e. the values we demand as customers. Simultaneously, a change in customer demand is needed. This can only be solved through developing innovative solutions where creativity is and essential element.

4.3 Definitions of creativity

There are many definitions of creativity. Creativity is most often used to describe individuals and organizations who have discovered or invented whole new solutions to major problems or concerns in a field of research or product development. Oxford Advanced Learner's Dictionary of Current English give the following explanations (Hornby, 1974):

> *create*: cause something to exist; make (something new or original); give rise to; produce
>
> *creative*: having power to create; of creation, i.e. requiring intelligence and imagination, not merely mechanical skills

Carr and Johansson (1995) note that (Dean, 1998):

> *Very simply, we define creativity as the generation of ideas and alternatives, and innovation as the transformation of those ideas and alternatives into useful applications that lead to change and improvement. We've found that, in today's business environment, an essential element to an organization's success is adaptability. You must be able to manage at the speed of change, and that takes creativity and innovation.*

A simpler definition of creativity is

> *the action of combining previously uncombined elements (Cave, 1999).*

Another way of looking at creativity is as playing with the way things are interrelated, e.g. the relationships between elements of the product structure.

Originality is an important parameter in creativity and innovation which is often difficult both to measure and determine. A process might be seen as creative when it is accepted as original and innovative by its normal audience. Creativity can also be seen as a process of increasing awareness.

Through the process, the product developer becomes aware of the form and through the proceeding process his perception of the environment is changed and developed (Hermansen and Lerdahl, 1997).

The product developer has acquired new knowledge and will experience his surroundings through new eyes. Creativity can thus be seen as an internal and external mastering process where a transformation has occurred in form and understanding, from something diffuse, unpleasant and chaotic to something clear, pleasant and concrete (Hermansen and Lerdahl, 1997).

Being creative involves at least two different kinds of creativity. The first is the creativity displayed by geniuses like Mozart, Picasso, Einstein, Hawkings and others. Some individuals are more gifted than others. This creativity seems to be genetically programmed to produce genius discoveries and thinking mechanisms. The second kind of creativity shows up e.g. in a work environment, as a well constructed report, insightful conclusions drawn from rigorous analysis, or a breakthrough application of a new technical solution to a difficult problem. This creativity is often perceived as mainstream behavior and therefore not recognized as creativity. However, elements of creativity are indeed utilized in these situations of daily work, and is the elements that should flourish in a product development team. All individuals have the ability to create, and, more important, the ability to learn to be creative. These elements of creativity can produce the required difference between success and failure of a product development team. A “skill set” is a collection of attitudes and behaviors we can employ at will to accomplish tasks and get measurable results. The personal skill set describes our individual abilities to explore the creative process and make it applicable in a normal work environment. Organizational skill set is the skill set the manager rely on to explore creativity from others and combine the creativity of individuals into complimentary skills of the product development team.

In a product development environment, this is the contribution by the theoretical models for innovation and product development, i.e. methodologies on how to effectively reach the defined goal of satisfying the identified customer need.

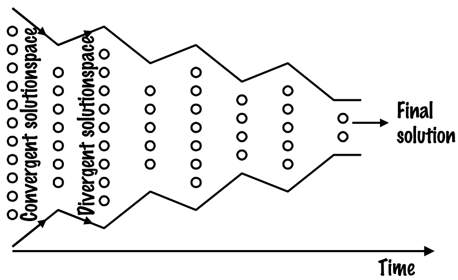
Both modes of creative thought can further be divided into divergent and convergent reasoning which are required for both personal and group creativity:

- *Divergent thinking* is the intellectual ability to think of many original, diverse, and elaborate ideas.
- *Convergent thinking* is the intellectual ability to logically evaluate, critique and choose the best idea from a selection of ideas.

The synthesis in a product development activity is primary the creative process where the solution is generated, while simulation, evaluation and decision is primary analytic processes. The synthesis can be seen as diverging, in such a way that alternative solutions to the problem are generated. The synthesis can also be seen as converging, in such a way that a limited number of solutions are generated from a theoretically unlimited solution space. Divergent thinking is essential to the novelty of creative products whereas convergent thinking is fundamental to the appropriateness of the solution (Cave, 1999). In the evaluation- and decision processes the product developer is moving towards fewer solutions by the selection of the best solution. Both are fundamental processes in product development. Thus, any general definition of creativity must account for the process of recognition or discovery of novel ideas and solutions. Such a process is illustrated in Figure 4.1, modified from (Clausing, 1994). The synthesis phases are where the identified functions are linked to potential means satisfying the function, and represents the phase where the main solution principles are selected, i.e. the phase where the dispositions which have large effects on the subsequent phases of the product life span.

Thus, the dictionary (Hornby, 1974) proposes to include innovation into the concept of creativity. Although the terms ar interrelated, creativity here is defined as the process for generating ideas for innovation. As described in Chapter 3, “Innovation and Product Development” innovation involves cyclic processes of generation, simulation, evaluation and decision to decide one sub solution among several options. Consequently, creativity is a vital part of innovation, but innovation is a broader term than creativity.

Figure 4.1 The product development process as a converging and diverging process



4.4 Models of creative thinking

4.4.1 Introduction

While there are many different models for the process of creative thinking, there are several similarities and distinctions between them (Plsek, 1997).

- The creative process involves purposeful analysis, imaginative idea generation, and critical evaluation. The total creative process is a balance of imagination and analysis / evaluation.
- Older models tend to imply that creative ideas result from subconscious processes, largely outside the control of the thinker. Modern models tend to imply purposeful generation of new ideas, under the direct control of the thinker.
- The total creative process requires a drive to action and the implementation of ideas. Ideas must be further developed into concrete solutions.

Business people often have strong skills in practical, scientific, concrete, and analytical thinking. The models of creativity supply skills complementary to these, i.e. thinking skills to support the generation of novel insights and ideas. We also need to acquire the mental scripts to balance and direct these new thinking skills in concert with traditional thinking in a product development environment (Plsek, 1997).

Plsek (1997) argue that models for creative thinking endeavour to capture the holistic view of something in a overall, integrated fashion. Models also show sequence, interconnection, pattern, flow, and organization. Models are critically important to mental functioning because they allow us to anticipate future actions, needs, and steps. Models of the creative thinking process are symbol models using symbols to describe the activities involved (Plsek, 1997).

4.4.2 Models of the creative process

Analogous to the various models used in business to guide strategic planning, quality improvement, problem solving and other activities, there are models to guide creativity and innovation.

In the book Creativity: The Magical Synthesis, Arieti (1976) catalogued eight models of the creative thinking process. Some experts on creativity dismiss the notion that creativity can be described as a sequence of steps in a model. Vinacke (1953) argue that creative thinking in the arts does not follow a model. Wertheimer (1945) claims that the process of creative thinking is an integrated line of thought that cannot be separated into individual steps of a model (Plsek, 1997).

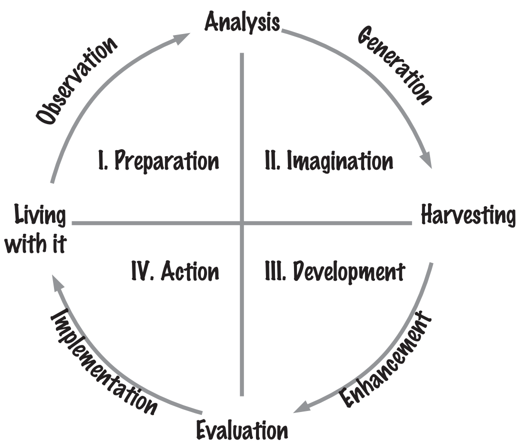
Theoretical models of the creation process is required to be aware of the different phases of creative thought to be able to teach, learn and train the creative abilities of individuals. Further more, the process of creating should be repeatable by others. However, the same outcome is not necessarily achieved as the creation process heavily relies on subjective perceptions of the individual.

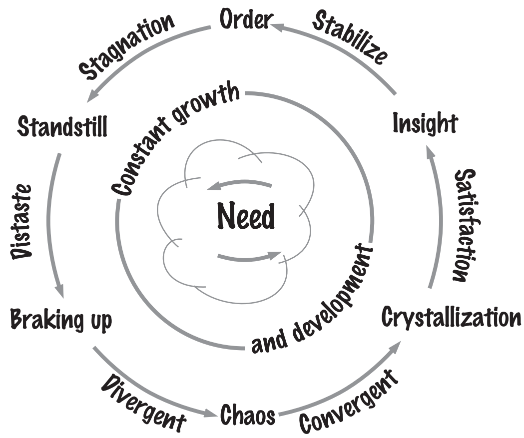
A Synthesis Model of the Creative Process

Plsek (1997) presents his view of creative thinking through the directed creativity cycle. The Directed creativity cycle is a synthesis model of creative thinking. Lerdahl (1997) presents a similar cyclic model for the creative process. Both models are illustrated in Figure 4.2 and described below.

Creative thinking begins with careful observation. This is the phase where everything is well organized and structured. Staying within this situation too long may develop a feeling of stagnation. Here, there is a feeling of no development and general dissatisfaction with the situation. Most organizations would feel that they were performing poorly if they had dissatisfied employees. Constructive dissatisfaction is the phenomenon where a product developer feels dissatisfied with the present situation and tend to improve this situation through new paths although there is no obvious indication that the present solution is performing poorly. Innovative organizations has people who are not satisfied with doing their jobs the same old way. They are always challenging the system, looking for better ways to deliver the same or better desired output (Harrington et al., 1997, Lerdahl, 1997, Plsek, 1997).

Figure 4.2 The Directed creativity cycle to the left (Plsek, 1997) and Model of the creating process to the right (Lerdahl, 1997)





Constructive dissatisfied employees personally believe that they can make things better. They think there is a better way, and they are committed to finding it. Finding this new and better way involves thoughtful analysis of how things work and fail. These mental processes create a store of concepts in a product developer's memory. As analyses indicates that the situation is dissatisfying, a feeling of breaking up becomes present where the product developer searches to break with the existing, and forces him into new paths. The following process is the diverging process towards a chaotic situation where the product developer distances himself more and more from the existing situation. This phase is followed by a converging process towards a crystallizing situation where all the loose ends are linked together and a new structure slowly is formed. This is the phase where the product developer uses the store of mental concepts to generate novel ideas to meet specific needs by actively searching for associations among concepts. There are many specific techniques that we can use to make these association; for example, analogies, branching out from a given concept, classic brainstorming, and so on. Following the crystallization situation is a process of increasing insight and satisfaction as solutions fit more and more together. Seeking the balance between satisficing and premature judgment, the product developer harvest and further enhance his ideas prior to a final evaluation. New knowledge and form enters sight and becomes integrated with existing knowledge. However, it is not enough just to have creative thoughts; ideas have no value until we put in the work to implement them. This is the phase of stabilization, which creates a new phase of order and structure. Every new idea that is put into practice changes the world we live in, which re-starts the cycle of observation and analysis (Harrington et al., 1997, Lerdahl, 1997, Plsek, 1997).

Lerdahl (1997) argues that it is the consciousness about the existing situation which give room for the feeling of distaste and dissatisfaction and which drives a product developer to create and to go through the process. The essential issue is to let go of the present facts and move into chaos. Through the creating process, the diffuse and abstract feeling becomes concrete and clear. Furthermore, Lerdahl (1997) argues that the time it takes to pass through the whole creating process may take years or just minutes, dependant on how comprehensive it is. The creating process model can be seen as a building block where a circle within a narrow area can be part of a broader area, where every piece of insight contributes to the larger lines of the broad area (Hermansen and Lerdahl, 1997).

Both models of the creative process above, asserts that creativity is a balance of imagination and analysis. The models avoid taking a stand on the controversy of whether imagination is a conscious or subconscious mental ability. Both models supports the notion that innovation is a step beyond the simple generation of creative ideas. The Action phase of Plsek's model and the stabilization phase of Lerdahl's model makes it clear that creative ideas have value only when they are implemented in the real world.

4.5 The three basic principles behind all tools for creative thinking

4.5.1 Introduction

There are many tools for creative thinking in the literature

- de Bono presents 13 tools in his book Serious Creativity (De Bono, 1992)
- McGartland has 25 tips and techniques in Thunderbolt Thinking (McGartland, 1994)
- VanGundy covers 29 tools in Idea Power (VanGundy, 1992)
- Michalko describes 34 techniques in Thinkertoys and Cracking Creativity (Michalko, 1991), Michalko, 1998)
- von Oech has 64 methods in his Creative Whack Pack (Von Oech, 1983)
- Koberg and Bagnall give guidance on 67 tools in The Universal Traveler (Koberg and Bagnall, 1981)
- Higgins tops them all with his book 101 Creative Problem Solving Techniques (Higgins, 1994))
- Plsek presents guides for making customized tools for creative thinking (Plsek, 1997)

While there is overlap among these compilations, there are at least 250 unique tools in these seven books. Plsek (1997) argue that the tools of creative thinking are simply various combinations of practical ways to implement this heuristic—to

- focus attention,
- escape the current reality, and

- continue mental movement.

The relative weights given to attention, escape, and movement, and the mechanics of directing these three mental actions, vary among the methods. This variation makes sense because each situation of synthesis in the product development activity is different, each product development team is different, and each designer is different (Plsek (1997).

4.5.2 Attention

Creative preparation (see Figure 4.2) is primarily about the principle of attention. During this phase of the creative cycle, the product developer seek to pay attention to something in an uncommon way, for the purpose of extracting useful concepts (Plsek, 1997).

Creativity requires that the product developer focus his attention on the problem area he finds unsatisfying. Most true innovations are the product of much thought over an extended period of time. Furthermore, the quality of creative ideas depends on the quality of the preparation to generate them. The primary innovation of the Apple Macintosh computer in the early 1980s was that its designers focused on the issue many computer users found unsatisfying, i.e. the command line interface. Through this attention, creative techniques can prepare the minds of product developers for breakthrough thinking and improve the unsatisfying solution with a better one (here, the graphical user interface) (Plsek, 1997).

Methods for creative thinking require some action to focus attention. Wonder and Donovan (1984) propose constructing a mental, slow motion movie of a situation looking for aspects that we have previously overlooked. Nadler and Hibino (1994) suggest structuring alternative statements of an issue in a purpose hierarchy, rather than simply diving into the issue (Plsek, 1997).

Acquiring overview of the situation

Acquiring overview of the situation is a prerequisite to be able to focus attention in the correct location. This means that the product developer must be able to draw a map showing the elements of the system and their relationships with each other.

Mind mapping is a means to structure information about a subject. Mind maps abandon the list structure of conventional note-taking completely in favour of a two dimensional structure. A good mind map shows the relative importance of information and ideas, and the relations between information elements. Mind maps can be used to summarize information, to consolidate information from different research sources, to think through complex problems and as a way of presenting information that shows the overall structure of a subject.

According to Buzan (1993), mind maps work the way the brain works, which is not in nice neat lines. Mind maps allow associations and links to be recorded and reinforced. Mind maps use just key words and key images instead of full text which contracts the amount of information. Because mind maps are more visual and depict associations between key words, they are much easier to recall than linear notes. Figure 4.3 explains Lateral thinking (see also page -132) using mind map technique.

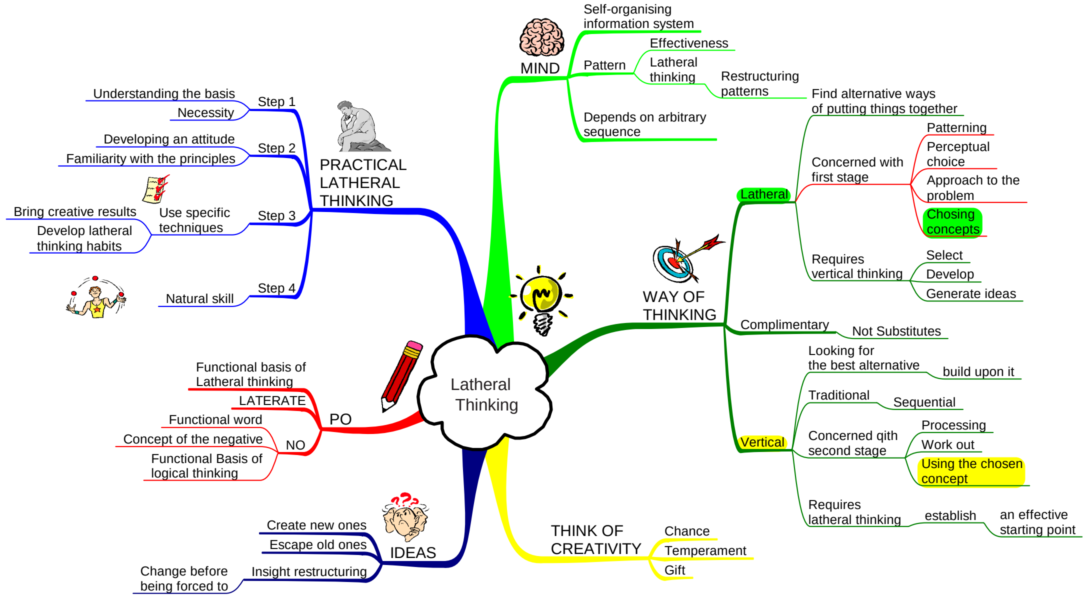
A variant of mindmaps is the fishbone diagram (Ishii and Lee, 1996). The fishbone diagram is a way to visually organize and examine all factors affecting a given situation by identifying all possible causes that produces an effect. An effect is a desirable or undesirable result produced by a series of causes. The main problem to be solved is formulated in the center or head of the diagram. The major causes to this problem are placed on main branches around this head, and minor causes are grouped around each major branch. Once all causes are identified, alternative ideas and solutions can be generated and placed next to each cause. The major contribution by the fishbone diagram is to acquire an overview of the problem. The overview makes it easier to locate the most important contribution to the problem instead of digging deeper into the details of the problem.

Ishii and Lee (1996) use what they denote the reverse fishbone diagram to analyze requirements in product retirement planning during product development activities.

Jones et al. (1999) present a technique to combine the standard design process form of BS7700, Mind maps and the Eco-compass/Ecodesign strategy wheel which results in the Product ideas tree (PIT)-diagram. The PIT diagram is a visual record of the output from the design project.

The basis for the PIT diagram is the Ecocompass or the ecodesign strategy wheel with their design strategies. Using mind mapping, all ideas and decisions are mapped radially upon the ecocompass/strategy wheel. This is repeated for each phase of the standard design process (Jones et al. (1999)). The PIT diagram is a creative approach to document ideas throughout the design process and represents a valuable contribution to track decisions made during a product development project. There is a risk however, that the diagram will soon hold too much information and become difficult to follow for the purpose of creating.

Figure 4.3 Lateral thinking explained using mind maps



Problem identification

Attention involves finding the correct location to focus attention. Many researchers claim that finding the correct problem is as much as 80% of the problem solving effort. The figure indicates that problem definition and problem formulation are important issues concerning attention. As stated above, breaking with existing patterns is an important part of the creating process. Finding the correct problem to solve is vital for finding a satisfying solution. The problem is that while product developers have the ability to think in new patterns, their minds are optimized to think with existing patterns. Their minds take in inputs from the world through the sub-processes of perception, and then retrieve patterns from memory through past experiences, to make sense of these inputs (Plsek, 1999).

If the problem we're trying to solve is 'similar' to one we've already solved, we are likely to attempt to solve it using what de Bono described as 'vertical' or 'logical thinking' (De Bono, 1992). In such a scenario, we have already started digging a hole, we've already found some gold in it, and we are expecting to find the solution to our new problem simply by digging – vertically, logically – deeper. Each of the products or solutions that emerges will generally have been obtained by digging an existing hole a little deeper (Mann, 1998).

To break the existing pattern, the problem becomes where to start digging a new hole. Looking for new ways to satisfy the goal without the existing pattern means improvisation for a product developer who is used to the traditional way. Improvisation totally without guidance never ends with

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success (Kao, 1996). The problem is not the method of digging, using the same analogy as above. The problem is how the product developer manage the method. If a product developer holds uncritically on to a method, it becomes suffocative for creativity. However, if he sees the method as a dynamic pattern and functions as a tool for improvisation, it will contribute for the creating process. Improvisation is necessary for creating new form and breaking existing patterns (Lerdahl, 1997).

Constraints are necessary for the creating process. After identifying the limitations, the possibilities becomes visible. Limitations gives a feeling of direction and freedom to create, given freedom within these limitations. Without limitations, the confusion about the direction to proceed becomes inevitable (Lerdahl, 1997).

Function analyses

As stated in chapter 3.11, breaking patterns on the function level of the product structure is needed to obtain an overall view of the real source of environmental load of industrial product systems. Thus, decomposing the primary function of a product system into sub functions supporting it and generating new solutions on how and which means can satisfy these functions are needed. Functional decomposition is the process of asking "how" for each higher level function to derive lower level functions. Functional composition is the process of asking "why" for each lower level function to derive higher level functions. The result is a tree or systematic diagram of functions which fall under some ultimate top level function (Dean, 1998).

Function analysis as used here is the process of analyzing the functional, rather than the physical, characteristics of a system.

Akiyama notes that:

> *Function analysis reveals the intentions or purposes behind the creation of a product or service and thereby identifies the nature of that product or service. Although products and services exist as physical objects or systems, they are not created out of nothing. They are preceded by an idea - a concept - which is the basis of their creation. Function analysis identifies the nature of products and services by revealing these concepts (Akiyama, 1991).*

Through the determination of the nature of an object, the product developer can conceptualize many physical realization alternatives which support this function and choose the alternative with the best value (Dean, 1998).

For management, the top level function of the hierarchy of organization functions is the mission (purpose) of the organization. The next lower level functions are things the organization must do (means) to accomplish the mission. The lower level functions are the means to accomplish the purpose. For a multidisciplinary group, the language of what the system must do is independent of the languages of the disciplines, but is common to all (Dean, 1998).

Other tools

Of the more simple and traditional techniques to find the real problem the “Five Times Why” is probably the easiest to introduce in a product development environment where problem solving is a generic element: Ask “Why” a problem is occurring and then ask why four more times. For example on the problem of the machine stopping (Cave, 1999):

1. Why has the machine stopped? *A fuse blew because of an overload*
2. Why was there an overload? *There wasn't enough lubrication for the bearings*
3. Why wasn't there enough lubrication? *The pump wasn't pumping enough*
4. Why wasn't lubricant being pumped? *The pump shaft was vibrating as a result of abrasion*
5. Why was there abrasion? *There was no filter, allowing chips of material into the pump*

One solution (and probably the easiest to perform) may be to install a filter, but this may not be the only available solution, an may not be the ideal solution in the long run.

Another easy technique for identifying the source of the problem is the basic six questions: what?, where?, when?, how?, why? and who?. Answering these simple questions for a problem, the source of the problem is likely to be visualized (Cave, 1999).

4.5.3 Escape

Having focused our attention on the way things are currently done, the second principle behind all creative thinking methods calls us to mentally escape our current patterns of thinking.

Edward de Bono argues that provocation is an essential element of escaping current situation and present ideas which significantly differ from the present solution. The product developer must be forced out of the present pattern of thinking. This mental operation cannot be based on serendipity (De Bono, 1992).

Edward de Bono uses the “po” tool to signal that the product developer’s intention to make a statement of mental escape. Po is a tool for provoking outrageous ideas to come forward without embarrassing the idea maker (De Bono, 1992). A “po”-statement invites the product developer to escape his current paradigm about the present situation and, for a moment, imagine a very different world (Plsek, 1997). The point is that the mental escapes which tools like po trigger, can give beneficial contributions for the generation of fruitful ideas.

Lateral thinking

Edward de Bono divides thinking into two methods. He calls one ‘vertical thinking’ that is, using the processes of logic, the traditional-historical method. He calls the other 'lateral thinking', which involves disrupting an apparent sequence and arriving at the solution from another angle.

The entry in the Concise Oxford Dictionary reads (Hornby, 1974): *seeking to solve problems by unorthodox or apparently illogical methods.* In other words, what apparently seems illogical, may give growth of new ideas, and may seem logic after all. The word apparently is important to explain the power of lateral thinking.

Lateral thinking is about moving sideways when working on a problem to try different perceptions, different concepts and different points of entry. The term covers a variety of methods including provocations to get us out of the usual line of thought. Lateral thinking is cutting across patterns in a self-organizing system, and deliberately forces the thinker to change perception. Therefore, lateral thinking is a technique for escaping current patterns, step aside and look at the problem in a different way.

Lateral thinking and vertical thinking are complementary. A product developer needs skills in both types of thinking. Differences an similarities are shown in Table 4.1

Table 4.1 Differences and similarities between vertical and lateral thinking (Cave, 1999).

Latheral and vertical thinking
1 Vertical thinking is selective while lateral thinking is generative. To be correct is very important in vertical thinking while lateral thinking focus on richness. Lateral thinking generate alternatives for the sake of generating them while vertical thinking seeks best approach.
2 Vertical thinking moves only if there is a direction to move while lateral thinking moves in order to generate a direction and thereby develop a solution.
3 Vertical thinking is analytical while lateral thinking tries to be provocative to generate ideas. For the provocative qualities of lateral thinking to be useful one must also allow for follow up with selective qualities of vertical thinking.
4 Vertical thinking is sequential while lateral thinking allows for non-continuous shifts.
5 With vertical thinking one has to be correct at every step, which is not the case for lateral thinking.
6 In vertical thinking one uses the negative to block up certain pathways, while lateral thinking refuses to see the negative attitude.
7 In vertical thinking one excludes what is irrelevant while lateral thinking see the irrelevant as potential idea generators.
8 In vertical thinking categories, classifications and labels are fixed while in lateral thinking, classification and categories are potential guides for movement rather than fixed identification parameters.
9 Vertical thinking follows the most likely path while lateral thinking explores the least likely to visualize all potential solutions.

Table 4.1 Differences and similarities between vertical and lateral thinking (Cave, 1999).

Latheral and vertical thinking
10 Vertical thinking is a finite process while lateral thinking is probabilistic. Vertical thinking provides at least a minimum solution while lateral thinking focus also on how to increase the chance of a maximum solution but without giving any promises regarding reaching this goal.
11 In vertical thinking information is used for its own sake to move forward to a solution while lateral thinking use information provocatively to break out of existing patterns and generate ideas.

Several researchers emphasize the advantage of defining ambitious goals to actually make a difference (Altshuller, 1984, Brezet, 1997, Brezet and Van Hemel, 1997, Chaharbaghi, 1998, Ethernally Yours, 1996, Factor Ten Club, 1997, Lovins et al., 1993, Manzini, 1997, McDonough and Braungart, 1998, O_2 Global Network, 1998, O'Rourke et al., 1996, Ottman, 1998, Von Weizsäcker et al., 1997).

One of J. Ottman's strategies illustrates the use of escape as a trigger for identifying environmentally beneficial ideas (Ottman, 1998): *Set Outrageous Goals*. Ottman asks for the kind of goals that are so extraordinary and perceived as foolish because this cannot be done according to vertical thinking. Aggressive goal setting forces individuals to think out of the current pattern box for new solutions. Incremental modifications required for solving less aggressive goals will not be enough. This approach forces product developers to think along new paths simply because it becomes obvious that the normal path will not lead to a satisfactory result. The question what actions must be taken if we had to eliminate waste, water, energy or another environmental impact by 100% and still meet customer needs? This is a true escape from a present situation and require new ideas to come up with solutions (Ottman (1998)). Companies like DuPont and Xerox know the value of setting outrageous goals. Their environmental goals are "zero waste," and "waste-free products from waste-free facilities." Aggressive goals like these send a message to stakeholders that a company is serious in its intent (Ottman, 1998).

Challenge

Edward De Bono introduces the creative technique "Challenge" (De Bono, 1992). The creative challenge is a technique to never be satisfied with any solution no matter how excellent it satisfies its original goal. The creative challenge involves questions like

- Why is it done this way?
- Are there any other ways of doing it?
- Why does it have to be done this way?

Creative challenge is quite different from the critical challenge. The critical challenge sets out to assess wether the current way of doing it is adequate. The critical challenge is a judgement challenge. A product developer might set out to show that a solution is faulty or inadequate and then try to improve the solution. This is normal improvement behavior (De Bono, 1992).

The creative challenge does not set out to criticize, judge or find fault. The creative challenge operates outside of judgement. The creative challenge is sometimes referred to as “creative dissatisfaction”. A product developer likes to show that a solution is inadequate in order to find a reason for thinking of a better alternative. Without such a reason justification for looking for a better idea might feel absent. If something is working properly, why look for a better solution? This is the kind of negative thinking a creative dissatisfied person don’t accept. Creative dissatisfaction involves the constant search for better solutions, even though the present solution seems adequate (De Bono, 1992).

It is important to distance the creative challenge from the critical challenge. If the challenge was a criticism, the product developer might challenge only the elements of the solution which seemed inadequate. This would seriously limit the range of application of finding a creative solution satisfying the underlying problem (De Bono, 1992).

This is probably the reason behind the critique on the product development approach presented in chapter 3.10. The constant seeking for elements in the product structure that represent sources for environmental load, can be seen as a criticism to the present solution. The case study showed that the we automatically tried to find alternatives to this element of the product structure which is only a small detail in the overall structure. An alternative solution will certainly improve the solution detail, but may not contribute significantly to the overall solution at the higher levels of the function-means hierarchy.

Criticizing a solution might be a barrier to the solutions pace. If a product developer is not able to make a convincing case of inadequacy, he would be unable to suggest looking for ideas. Thus, the criticism creates a barrier around the elements being criticized making solutions outside the box invisible (De Bono, 1992).

Attacking the present solution makes the creator of this solution try to defend the perceived excellence of this solution. A lot of unnecessary time and effort is consumed in attack and defense. In addition, there will be a polarization within the company between the employees defending the status quo and the ones attacking the solution. De Bono (1992) argues that it is much wiser to avoid judgement and instead indicate that there is no attack on the present solution but just an exploration of other potential alternatives. Alternatives will never replace existing solutions unless the new idea clearly shows to be superior (De Bono, 1992).

De Bono (1992) offers several reasons why there is often a supposition in an organization that the current solution must be the best (De Bono, 1992)

- the current method has survived and been tested over time
- the current method has been in use for some time and so the faults have been removed

- The current method is the result of a process of evolution, which has eliminated competing methods
- the current method was selected from amongst many possibilities as the best method
- the current method would have been replaced if it had not been the best method

Consequently, there is some kind of tacit agreement that unless proved otherwise, the current solution is very likely to be the best solution.

Thus, using the creative challenge the product developer must simply refuse to accept that the current solution is necessarily the best way. The creative challenge assumes that the current way is just one way which happens to be there for a variety of reasons. This prevents the growth of barriers around solution details, and forces the product developer to stay in the open-minded mode where a holistic view is fostered. Here the product developer can view different alternatives to satisfy the overall function of the product system (De Bono, 1992).

The Ideal Final Result

"Begin with the end in mind" is argued by S. Covey, to be one of the key factors to success (Covey, 1992). Leonardo DaVinci expressed the same principle already in the 15th century, saying "create the end before the beginning". The final result of the process will become best when we start with the end result in mind. We have to establish a point of vision and direct our efforts to meet this ultimate scenario (Blankenburg and Wiik, 1998). Edward De Bono argues that this is an important technique to trigger creative ideas for solution (De Bono, 1992).

When studying escape techniques for establishing aggressive product development goals, the Ideal Final Result (IFR) of the theory of inventive problem solving (TRIZ) is vital. The Ideal Final Result contains the concept of (Altshuller, 1984):

- ideal machine (by which there is no machine, but the required effect is achieved)
- the ideal method (there is no expenditure of energy and time, but the necessary effect is obtained and in a self-regulating manner)
- the ideal substance (there is no substance, but its function is performed)

Characteristic of ordinary engineering thinking is the willingness to pay for the effect required - in terms of machine, expenditure of time, energy or substances. The need for payment seems evident, and the product developer is concerned only that the payment is not too excessive (Altshuller, 1984).

The inventive thought should be clearly oriented to the ideal solution (Altshuller, 1984):

> *We have a system with a damaging factor. This damaging factor must be fought. Ideally, this factor should go away by itself. Consequently, the goal must be to let it eliminate itself. Incidentally, it can be eliminated, by bringing*

it together with a different harmful factor. An even more ideal situation is where the harmful factor is turned into a beneficial factor.

The tendency toward the ideal by no means signifies moving away from the reality of the solution. In many instances the ideal solution can be fully implemented. The ideal nature of a method is not seldom achieved by the performance of the necessary effect in advance, thanks to which at the necessary moment there is no need to waste time or energy on this effect (Altshuller, 1984).

The transposition to an IFR cuts off all solutions at lower levels of the function-means tree, i.e. cuts them off immediately and indiscriminately leaving behind the IFR and those variants which are close to it and therefore can turn out to be powerful (Altshuller, 1984).

In mathematical terms the ideality concept can be expressed by:

$$I = \frac{U}{H}$$

where:

I = degree of ideality

U = sum of useful functions

H = sum of all harmful effects, including cost / pollution

The ideal final result should not be understood literally. The theory of inventive problem solving is often criticized for the concept of ideality. “Thinking that a technical system can become ideal is a communistic way of thinking”, the criticizers say. This may be true if we think of ideality in an absolute sense. An absolute ideal technical system is a system where the primary function is performed without the existence of the system itself. Obviously, a nonexisting product cannot perform a function.

However, if ideality is viewed in a relative sense, meaning that a redesigned technical system may become more ideal than the old design of the same system, the concept definitely has value. If the contrary was true, the redesigned system is less ideal than the previous version, we can conclude that the redesign activity has not achieved its objective. All redesign activities has the objective of creating a better product. “Better “in this sense can have several meanings, but every time the objective is to achieve some kind of increased efficiency of the product characteristics, e.g. a reduction in cost.

The evolution is a function of society’s judgment of what is useful and what is harmful. Though perhaps not every problem can be solved, every situation can be improved. Also, the perception of what is useful and what is harmful may change as place, time and circumstances change (Altshuller, 1984).

In connection with evolution towards ideality, the product developer need to consider the patterns for the supersystems and the subsystems that belong to our system. Having done this we can establish a fairly good picture of the most likely directions our system will move into. By looking far into the future the product developer can imagine what he may call IFR of his system. This is where he should be heading. Not necessarily in one step, but much better in small steps. But the product developer has to make sure that the path of gradual improvement is on the path to the ideal final result (Blankenburg and Wiik, 1998).

Kowalick (1996) argues that

> *The definition of the IFR is not dependent upon:*
>
> *(1) whether or not something is possible, or*
>
> *(2) how the IFR is to be accomplished.*
>
> *Knowing and defining IFR in advance is like having two pictures, the first picture is the "was" picture, and the second picture is the "become" picture. The "become"-picture is the ideal final result. Formulating the IFR gets the problem solver to think about solutions to the problem that are independent of technology, and that create the desired result using no resources, no energy, no space etc.*

Edward de Bono uses a similar technique to trigger creative ideas for solution. Wishful thinking is one of de Bono's techniques of lateral thinking. Wishful thinking is a tool for provocation. De Bono (1992) explains:

> *We put forward a fantasy wish knowing that it is impossible to achieve. It is important that the provocation be a fantasy. It is much too weak just to put forward a normal desire, objective or task.*
>
> *I would like to make this pencil for half the cost.*
>
> *That is an objective or task which you can work even if it may seem very difficult. But is not a provocation.*
>
> *Po, the pencil should write by itself*
>
> *This is more obviously a fantasy, and more obviously a provocation.*

The wishful thinking is a means for generating new concept ideas. The wishful thinking is a technique for generating all the ideas members of a brainstorming group never dares to say loud because they are too ridiculous. The ideal final result operator of TRIZ, must be viewed in the equivalent manner as provocation, escape and wishful thinking of de Bono.

The ideal final result cannot be understood literally. If the designer does not accept that there is an ideal situation, he simultaneously accepts the weaknesses of the technical system, which means in the worst case that the technical system cannot be improved, which is wrong.

The ideal final result is a thought experiment which is meant as a guide for directing the search for an acceptable solution. The Ideal Final Result is a guide in stepping aside and look at the useful and harmful functions of a system and by removing the psychological inertia of the designer to open up in an open-minded manner and use the creative toolbox to move the present solution closer to the ideal final result.

4.5.4 Movement

Movement is an extremely important mental operation. It is central to the whole of creativity (De Bono, 1992). De Bono argues that it is almost impossible to be creative without having some skill at movement. Simply paying attention to something and escaping current thinking about it is not always sufficient to generate creative ideas.

The brain acts as a self-organizing system which allows incoming information to organize itself as patterns, tracks, channels, sequences etc. Perception is the original formation and subsequent use of the patterns De Bono (1992). This involves recognizing the appropriate patterns and being sure that the pattern is followed (De Bono, 1992).

Judgement has two main roles in perception. The first role is to find, identify, match or recognize the appropriate pattern. The second role is to ensure that we do not wander off our identified track. Judgement points out the mistake, the deviation or the mismatch and guides us back to the established track. This aspect of judgement deals with the rejection of ideas that are wrong and contrary to experience. Judgment tend to reject new thoughts as not productive or too ridiculous to develop further (De Bono, 1992).

In movement, when an idea is developed, the product developer is totally uninterested in whether the idea is right or wrong or whether it fits his previous experience (De Bono, 1992). Movement calls for the product developer to keep exploring and connecting his thoughts (Plsek, 1997). The product developer is exclusively interested in where he can move to from the original idea. The use of movement with provocation is the most extreme form of movement. The question is how to move from an impossible provocation into a realistic and useful solution.

The general sense of movement means the willingness to move forward in a positive way rather than stopping to judge whether something is right or wrong. In creative product development the developer is indeed interested in arriving at practical, useful, valid ideas (De Bono, 1992).

Movement is a key principle behind the classic creative thinking technique of brainstorming. The ground rules of brainstorming are to generate as many ideas as possible, with no criticism and building on the ideas of others (Plsek, 1997).

Six Thinking Hats

The Six Thinking Hats method is a framework for thinking. The six hats represent six modes of thinking and are directions to think rather than labels for thinking. That is, the hats are used proactively rather than reactively. Valuable judgmental thinking has its place in the system but is not allowed to dominate as in normal thinking (De Bono, 1992).

The six thinking hats are normally used to structure a brainstorming event for generation and development of ideas. The thinker can put on or take off one of these six metaphorical hats to indicate the type of thinking being used. This putting on and taking off is essential. The hats must never be used to categorize individuals, even though their behavior may seem to invite this. When done in a brainstorming event, everybody wear the same hat at the same time. Table 4.2 shows a summary of the focus for thinking using the different hats.

Table 4.2 Summary of the Six Thinking Hats (De Bono, 1992)

Color of the hat	Summary of thinking focus
White Hat thinking	This covers facts, figures, information needs and gaps.
Red Hat thinking	This covers intuition, feelings and emotions. The red hat allows the thinker to put forward an intuition without any ned to justify it. Usually feelings and intuition can only be introduced into a discussion if they are supported by logic. Usually the feeling is genuine but the logic is spurious. The red hat gives full permission for a thinker to put forward his or her feelings on the subject at the moment.
Black Hat thinking	This is the hat of judgment and caution. It is a most valuable hat. It is not in any sense an inferior or negative hat. The black hat is used to point out why a suggestion does not fit the facts, the available experience, the system in use, or the policy that is being followed. The black hat must always be logical.
Yellow Hat thinking	This is the logical positive. Why something will work and why it will offer benefits. It can be used in looking forward to the results of some proposed action, but can also be used to find something of value in what has already happened.
Green Hat thinking	This is the hat of creativity, alternatives, proposals, what is interesting, provocations and changes.
Blue Hat thinking	This is the overview or process control hat. It looks not at the subject itself but at the ’thinking’ about the subject. In technical terms, the blue hat is concerned with meta-cognition.

The hat metaphor gives each mode of thinking its time and place. The hats guide a product development team to avoid premature negative thinking (De Bono, 1992). It also makes everyone equal; members with a negative attitude must think positively when wearing the Yellow hat and, both analytical and intuitive disposed members must practice the opposite mode of thinking when wearing the White and Red hats, etc. This is a useful task, as it stimulates mental pathways that might be otherwise under utilized or totally invisible.

The general attitude of movement is important (De Bono, 1992). During a product development project meeting, a member of the group makes a statement. A different member is quickly to judge whether what is said is correct and even searches for small aspects that is not correct. A third person might be interested in what the statement leads to. The second member uses the black hat at once. The third member uses the green hat searching for movement elements and only later uses the black hat to assess a conclusion. Using each idea as a stepping stone for generating further ideas contributes to further develop the original idea and to move forward.

4.6 Theory of inventive problem solving (TRIZ)

4.6.1 Introduction

The theory of inventive problem solving (TRIZ) is discussed separately although it is a creative problem solving methodology with all the elements of attention, escape and movement as described above (Altshuller, 1984, Altshuller, 1990, Arciszewski, 1988, Kowalick, 1996, Terninko et al., 1996, Tsurikov, 1993).

TRIZ is a theory with origin in former Soviet Union. The original literature is written in the russian language, and is therefore unavailable to the author of this dissertation. Consequently, this dissertation rely on that the work of other researchers and their understanding and perception through the translations of the references to the english language are correct. However, to start by acquiring sufficient knowledge of the russian language would involve to much time and effort, and would assumably result in the same conclusion.

The TRIZ methodology is a has its roots in the collection of available technological principles and solutions rather than psychology which is the basis for the methods and tools as described above.

With the increasing extent and complexity in recent times of our society's knowledge base, though, it has become impossible for inventors, great or small, to keep up fully with advances in many different fields. Thus, relevant inventions in one field may not be known to workers in another, with the result that much effort may be spent in reinventing an existing solution. The scope for developing TRIZ originated from Altshuller's search for a guide for solutions to inventive problems based on technical aspects giving a repeatable process. The objective behind the theory is to avoid the resource-intensive trial-and-error process which is commonly used during development of technical systems (Altshuller, 1984).

TRIZ research began with the hypothesis that there are universal principles of invention that are the basis for creative innovations that advance technology, and that if these principles could be identified and codified, they could be taught to people to make the process of invention more predictable. The research has proceeded in several stages over the last 50 years. Over 2 million patents have been examined, classified by level of inventiveness, and analyzed to look for principles of innovation. The three primary findings of this research are as follows (Domb and Dettmer, 1999):

1. Problems and solutions were repeated across industries and sciences
2. Patterns of technical evolution were repeated across industries and sciences
3. Innovations used scientific effects outside the field where they were developed

The results also showed that often the same problems had been solved in various technical fields using a set of solutions among only about forty fundamental inventive principles (Altshuller, 1984).

As stated above, creativity is also about combining previously uncombined elements. Thus, there is a great potential for generating beneficial ideas by understanding which problems have been solved in the past, in different domains and how these problems were solved. TRIZ deals with technical problems, i.e. it is based only on technical systems.

The TRIZ approach is to over-come the psychological barriers preventing the inventor to see outside his own field of experience. The TRIZ approach is not to try to reproduce the thinking process of past inventors, but rather to synthesize a methodology that would guide an inventor to the similar types of solutions (Altshuller, 1984).

4.6.2 Patents as an information source

Critiquers of TRIZ claims that great inventions and successful products are often kept out of the patent systems. Applying for a patent involves among other things a detailed description on how this technical system works. Furthermore, patent data are open to the public, giving competitors an opportunity to in detail study the invention. Consequently, a competitor can easily copy the invention, modify it sufficiently that the patent is not violated and present a competing product in the marketplace often at a reduced cost as development investments are kept at a minimum.

Iversen (1998) presents a critical discussion of the basis and background for using patent-statistics as an innovation indicator and reviewed some of its past and current applications. He has explored some of the advantages that have recommended the use of patent-data as a technology indicator and noted that the increasing ease of access to such data together with more recent analytical approaches (Systems theories of innovation) have given it new relevance and new currency (Iversen, 1998).

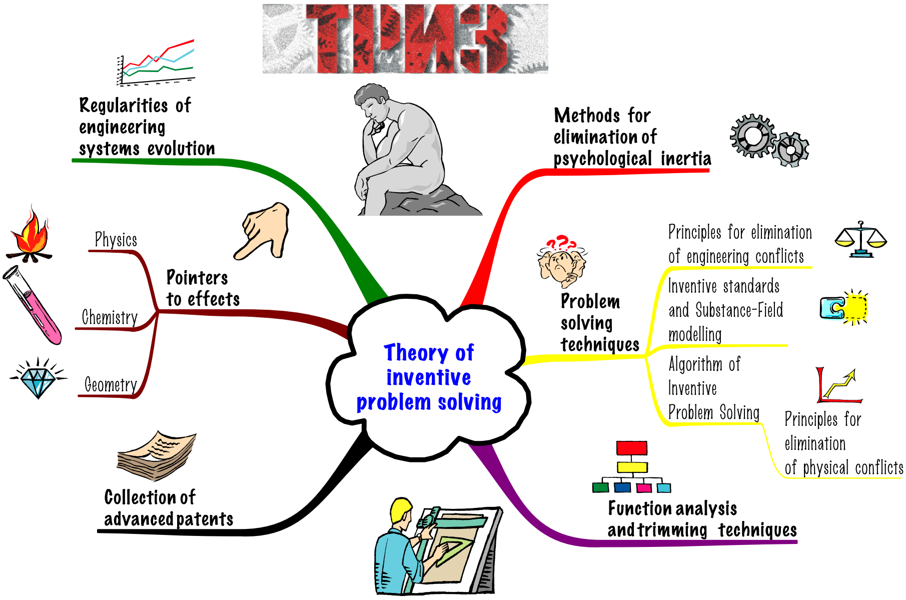
There are many considerations to keep in mind when using patent data in general and citation-data in particular. Patents are a ’tried’ indicator both of technology output of flows of inputs and intermediary innovative components. It is not a ’true’ indicator, in the sense that there are many difficulties with its use, but it remains a viable and certainly promising indicator for technological performance (Iversen, 1998).

4.6.3 Principles of TRIZ

TRIZ is based on three major principles (Altshuller, 1984):

1. The Resolution of Technical and Physical Contradictions
2. The Evolution of Systems
3. The Ideal System and Ideal Solution.

Figure 4.4 Elements of Theory of inventive problem solving



Resolution of Technical and Physical Contradictions

The functions of technical systems are realized by using physical, chemical and geometrical effects. It follows that knowledge of such effects is crucial in inventive situations. It is however difficult to directly apply the existing descriptions of natural laws and physical and chemical effects to generate alternative solutions (Altshuller, 1984). The effects need to be connected to functions through a set of means.

The basic concept of TRIZ is the resolution of a contradiction. Improvement of one of the system parameters will then lead to deterioration of others. To resolve the contradiction it is important to find the physical contradictions that are the hidden core of the technical problem.

TRIZ also features a collection of inventive principles for resolving technical and physical contradictions. The technical contradictions and principles are combined in a matrix, the rows and columns of which contain 39 generalized parameters, corresponding to the most common parameters the engineers try to improve. There are 40 different solution principles. It should be pointed out that the principles do not constitute final solutions to the problems, but rather high-level strategies for finding ideas.

In the context of proposing rational alternatives or starting points for the development of new ideas into concepts, Mann (1998) argues that there is probably no single technique in existence more powerful than the 40 Inventive Principles. This is a technique which says that actually there are only very few places where we might start development which might bring the product development activity into a profitable solution. And, further, if the product developer also use the Contradiction Matrix, he will find that for any given problem, the list of places to look further reduces to only three or four out of the original 40.

Of course, this is a naive view. Naive in that it assumes a) we are attempting to solve the right problem and b) the Contradiction Matrix is infallible. With respect to this second issue, despite the very large number of case studies used to derive the Matrix, Mann (1998) claims he has discovered several instances where a "better solution" has arisen through use of inventive principles other than those recommended by TRIZ for a given pair of contradicting design parameters. This indicates that relying on the contradiction matrix of TRIZ alone, may exclude valuable alternatives from consideration.

Standards in TRIZ are rules for solving commonly occurring inventive problems. To decide which standard to apply inventive problems are modelled by means of so-called S-Fields: models of the physical system consisting of substances (objects) and fields (e.g. mechanical and electromagnetic forces, heat fields, etc.) that act on the system. The interactions between the fields and the substances are indicated. The standards then suggest strategies for transforming the S-Field (physical system) in such a way that undesired, insufficient or missing interactions are eliminated without making the system more complex.

TRIZ recognizes the need to identify the core of a problem prior to start solving the problem. ARIZ is a recursive algorithm for identifying contradiction and system conflicts. This approach is beneficial for the redesign of a system in order to eliminate the system conflict. The stated aim is to eliminate the conflict while making minimal changes to the system. Mann (1998) argues that the need to search for the correct problem definition can never be overestimated. Some applied innovation researchers have suggested that problem definition should be given rather more of our attention than the comparatively simple tasks of location finding and solution searching.

TRIZ thus includes elements within the attention phase of creativity through the techniques for a fundamental problem formulation. Identifying contradictions within product structures and product systems is an important aspect of the attention phase of creativity. Identifying contradictory means on the function means level when generating product system concepts may give valuable contributions towards a leap improvement in reducing environmental load.

The Evolution of Systems

The characteristics of a given technological system change in a predictable manner as it evolves and matures over time. TRIZ states that the evolution of engineering systems is not a random process, but governed by certain objective laws. These laws are used to predict how a certain system will develop in the next phase. The laws can be a useful tool in product planning by providing support for technological forecasting (Altshuller, 1984).

Altshuller recognized that the evolution of any technical system has a characteristic bell-shaped curve when the rate of patent production is plotted as a function of time. Technology follows a life span of birth, growth, maturity, and decline as described by the S-curve (Fisher and Pry, 1971).

Eight laws of evolution of technical systems have been identified: The most fundamental law is that of the “Ideal System”, one in which the given function is realized but no resources are consumed. This ideal solution may never be found but the ratio function divided by resources is likely to increase over time (Altshuller, 1984).

The eight laws of evolution represent a valuable contribution for movement based on generated ideas.

The Ideal Final Result and the ideality concept

As a system evolves, it should become more nearly perfect, so that its ability to satisfy human needs increases while its cost decreases. The Ideal System, according to the TRIZ methodology, is a non-existent system with all of its functions still being executed. This Ideal System, analogous to the definition of limit in mathematics, is unrealizable in practice. Nevertheless actual systems approach the ideal by increasing their beneficial functions and eliminating harmful factors.

Most technical systems evolve to satisfy customer requirements and needs. The customer wants a design with more functionality and quality but with a reduced price and fewer harmful effects. This means that the natural evolution of a system increases ideality.

The ideal final result and its interpretation is described in detail above in chapter 4.5.3, Escape.

Utilizing TRIZ in the context of environmental improvements

If TRIZ can contribute to developing technical systems with higher efficiency, a relevant question to ask is why this methodology which until the last decade, mainly has been used in the former Soviet Union, has resulted in dramatic environmental damage to certain geographic areas within this country like the Kola peninsula. The author believes that this has nothing to do with the methodology in itself, but rather the normal belief that nature holds natural resources which can be fully extracted and nature can receive any by-product in any volume from industrial production. The technical system was not seen in relationships with its interfacing systems. Thus, optimizing technical systems in isolation, may result in a high improvement in the efficiency and capacity of the solution, but without seeing the interrelationships between different systems, damaging side-effects will occur.

Jones and Harrison (2000) compared the TRIZ principles with Eco-innovation by using the Ecocompass. They compared the engineering parameters of the contradiction matrix with the six axes of the Ecocompass tool.

Jones and Harrison report that there are engineering parameters covering several of the Eco-compass axes, as illustrated in Table 4.3. However, it also revealed that the non-technical Eco-innovation issues: Health and environmental Risk, Revalorization and Resource Conservation, are only blanket covered under the engineering parameter “harmful-side effects”.

Table 4.3 Comparing the axes of ecocompass with engineering parameters of TRIZ (From Jones and Harrison, 2000)

Ecocompass axes	Engineering parameters of the contradiction matrix
Mass Intensity The quantity of material used per unit service	Weight of moving object Weight of non-moving object Waste of substance Amount of substance Productivity
Energy Intensity Quantity energy used per unit service	Energy spent by moving object Energy spent by non-moving object Waste of energy Productivity
Extending Service and Function Increasing quantity of functional units in the product	Durability of moving object Durability of non-moving object Reliability Repairability Adaptability Productivity
Health and Environmental Risk Quantity of hazardous substances emitted to air soil and water	Harmful side-effects
Resource Conservation Quantity of scarce or depleting resources used	Harmful side-effects
Revalorization Quantity of waste not ecoefficiently recycled	Harmful side-effects

Studying the technical evolution of a fluorescent tube lighting through patents revealed several environmental innovations in fluorescent tube lighting related to a contradiction between mercury content and lamp-life. In addition, several inventions are brought together through a novel manufacturing process (Jones and Harrison, 2000).

Jones and Harrison point out that the environmental issues are present at the systems level of the problem hierarchy. This supports other sources in Eco-innovation that emphasize the need for top-down management commitment for Eco-innovation (Bhamra et al., 1997).

On the detailed level of the problem hierarchy the environmental element disappears. The problems are ordinary technical problems that could be defined as conventional technical or physical contradictions.

The innovations described in the patents all concern redesign or optimization of existing lighting products and therefore should only have been be defined as 'Eco-design exemplars'. Jones and Harrison claim that it will be much more difficult to find patented products which would be true 'Eco-innovation exemplars' (Jones and Harrison, 2000). Jones and Harrison seem to forget that the basic innovation is the energy consumption during use and lamp life when compared to a conventional light bulb.

Jones and Harrison conclude that technical or physical contradiction solving through the use of Existing TRIZ tools could help generate new solutions to problems encountered in sustainable design. The TRIZ principle of ideality and the 20 defined trends of evolution for technical systems could help existing technical systems evolve towards ideality, where the functions of that system are delivered without the environmental impacts currently associated. The TRIZ principle of ideality also supports sustainable design. TRIZ identifies the 'core' problems through the definition of contradictions that are to be solved.

Non-technical systems

TRIZ was established based on patent research, and thus is based on technical innovation. Social and organizational innovation is not part of this basis, and this could be the critique needed to neglect TRIZ tools by claiming it is not applicable to organizational problems concerning both technical and social innovation.

Mann investigated the use of TRIZ in business applications (Mann, 2000). Although the reporting must not be viewed as deep analyses, but rather observations, his work gives indications that systems containing both a technical and social components are systems where TRIZ can contribute to successful solutions. Mann studied the different TRIZ tools' applicability to business applications such as organizational structures, mass customization in manufacturing, organizational communication, trend development in marketing and product development, etc. (Mann, 2000).

Mann (2000) supports his observations on different cases concerning conflicting requirements regarding economic batch quantities in a production manufacture environment, a conflict resulting from the ideality equation in which the desire to increase customer benefit contradicts with the desire to minimize costs and harms, using the ideality approach for generating solutions to a car delivery problem and product customization, etc.

Common for all the cases Mann (2000) presents is that they are seen in a systems view, and it could be argued that they are all technical systems. A manufacturing facility is indeed a technical system, but a manufacturing organization is also a social system. Both are mutually interdependent to make the total system perform properly.

Mann concludes that TRIZ provides a powerful framework from which to systematically define and solve business, organizational management and human relations type problems. Mann claims that several of the TRIZ tools, methods and strategies originally configured for use in solving technical problems have direct or analogous application in a non-technical context. In combination with other management problem definition and solving methods, TRIZ can contribute to systematic creativity and innovation on the organizational level of a business.

Conclusion

The theory of inventive problem solving is different from other creativity enhancing methodology, not only by its basis, but also based on enhancing the tacit requirement for holistic thinking. TRIZ emphasizes the need to find the core of the problem in a problem solving situation. Identifying the problem is often the most important part. If the problem which may be a contradiction between parameters, is not solved, there is reason to believe that the product developer focuses on the wrong problem. This is the situation where it is required to look into the hierarchy of systems. The solution may lie in the supersystem level, where the current product solution is a component. Thus, jumping between different system levels is also necessary to identify the correct problem. This represents a possibility to acquire a holistic view of the product structure and the relationships between functions and means, and to generate untraditional means to satisfy identified functions.

It is important to point out that TRIZ is a problem solving methodology, and not a complete design methodology. As a design process includes problem solving on both conceptual and detailed levels of the product design phases, there is reaseon to believe that the theory is complementary to other tools and methods which a designer utilizes during the design activities. Malmqvist et al. compared TRIZ with the systematic approach of Pahl and Beitz (SAPB) (Malmqvist et al., 1996). SAPB includes all phases of the design process from product planning to detailed design, while TRIZ focus on the aspect of the problem which is stated to be the most critical part, i.e. the system conflict. Malmqvist et al. proposes a new model unifying TRIZ upon SAPB where the powerful elements for solving “inventive” parts of a design of TRIZ are united with the systematic design steps of SAPB (Malmqvist et al., 1996).

4.7 Barriers to creativity

4.7.1 General

Barriers to creative thought can limit effectiveness of product development. The primary reason that children are so creative is that they are uninhibited in their thinking and are not influenced by past experiences that tend to inhibit older people with life experience (Harrington et al., 1997). Harrington et al. (1997) argue that a better understanding of the nature of these barriers can often help the product developer overcome this limitation to creative thought.

The human mind can store large amounts of information in its subconscious storage area but only a few concepts in the active use area simultansously. For this reason conceptual models in the form of equations, pictures, sketches, words, and objects are frequently used to expand and organize the creative process.

Harrington et al. (1997) argue that a modest amount of physiological stress enhances the effectiveness of creativity. However, too much stress has a severely negative effect on the output of creative thinking. Creativity is disturbed by the noise of a too-hectic environment that does not provide quiet time for reflection and introspection. At the Norwegian University of Science and Technology, Department of Product Design Engineering they have built a room for reflection, creative visualization and meditation, called *Vision Lab*. The Vision Lab is a room for silence where both staff and students can come and find rest and inspiration.

A designer should intuitively sense underlying needs others do not sense. In a hectic work environment, the ability to sense the underlying needs is reduced. Designers can regain and develop their sensibility through relaxation and meditation. True visualization and meditation is thus not a tool to run away from the real world, but rather a tool to help you to be more present. Besides, it is important to learn to fluctuate between an inner world of fantasy, images, concepts and an outer world of reality, concreteness and limitations. It is in the tension between the inner world of fantasy, images, concepts and an outer world of reality, concreteness and limitations that new form comes into being (Hermansen and Lerdahl, 1997).

When working on projects it is often during moments of relaxation that new solutions come to mind. Using techniques for deep concentration and creative visualization designers might actively evoke the creative process with new solutions.

Creativity is also disturbed by (Cave, 1999):

- a sterile environment that does not feed the senses
- demands for quick production of results.
- by rigid rules and barriers that prevent designers from gathering information and / or from connecting with others.

Thus, in a work environment it is important to provide just the right amounts of motivation and challenge for optimum creative effort.

The limitations and barriers for creative activity can disturb the basic mental process that is necessary for effective design. These limitations are built through a variety of mechanisms and can be classified as either intellectual barriers, emotional barriers or social and cultural barriers.

4.7.2 Intellectual Barriers

Mistree et. al. (1995) argue that intellectual barriers to creative thought arise from either experience directly attributable to the specific problem or from perceptions that are based on experiences that are not directly related to the problem. Both the practical life experiences of the product developer and the knowledge he has learned through his formal education can contribute to intellectual barriers (Mistree et. al., 1995). The human mind cannot maintain a large number of ideas for solutions in the active use area simultaneously. A single solution may dominate the mind and thereby exclude the emergence of other valuable ideas. One good way to overcome this barrier is to document the initial solution fully and saving it for later use, and make the product developer force himself to look for other alternatives (Mistree et. al., 1995).

All engineers suffer to some degree from psychological inertia (PI). The psychological meaning of the word “inertia” implies an indisposition to change. It represents the inevitability of behaving in a certain way - the pattern that has been thoroughly described somewhere in the brain (Mann, 1998).

Altshuller argues that the most important barrier to creativity is the intellectual barrier of psychological inertia. Presenting an ideal final result may represent a sacrifice of current visible and tacit knowledge. The TRIZ approach is not to try to reproduce the thinking process of past inventors, but rather to synthesize a methodology that would guide an inventor to the similar types of solutions (Altshuller, 1984).

Other factors that limit creative behavior include (Cave, 1999):

- *Self criticism*. Negative thinking and self criticism are also limiting factors of an individual's creativity.
- *Beliefs*. Having a strong belief in something not only limits our response options, but causes us to limit the way in which we perceive and process information from the outside world. We may “filter out” information which contradicts our belief, and end up in our own “reality tunnel”, in which we remain unaware of much that occurs in front of our very eyes.
- *Stress*. Stress is not only a distraction which drains energy which could otherwise be used creatively, it is bad for one's health.
- *Routines*. Routines or set ways of performing tasks have their uses, but allowing them to become too entrenched in one's life causes product developers to limit the range of available solutions.

4.7.3 Emotional Barriers

Mistree et. al. (1995) argue that the emotional barriers to creative thought come from the fears that are imprinted in our lives to enable us to avoid the feeling of injury or disappointment. The educational system teaches us that fantasy and reflection are a waste of time, and yet these are the very tools that creativity depends on for success. Engineers and professionals are taught that reason, logic, numbers and utility are useful tools in a product development enviornment, while feeling, intuition, qualitative judgments and pleasure are not applicable. However, these human qualities are quite useful in the creative process. In our educational system we are taught that problem solving is serious business and that there is no room for humor. On the contrary, a playful, humorous environment is often very useful to creative thought and idea generation (Mistree et. al., 1995). It is in the tension between the inner world of fantasy, images, concepts and an outer world of reality, concreteness and limitations that new form comes into being (Hermansen and Lerdahl, 1997).

4.7.4 Social and Cultural Barriers

Cultural blocks are acquired by exposure to a given set of cultural patterns. These rules and norms of behavior guide us within our social setting. Unfortunately, cultural blocks may contribute to removal of entire families of solutions from consideration and evaluation (Mistree et. al., 1995). Society often rewards conformity. However, the most creative persons are often the nonconformists who identify and change unsatisfying situationsare willing to make changes from the status quo. To create an environment in which creativity is to fluorish, a situation must be establshed and built into the organisation, where the creators of ideas are not persecuted, ridiculed or laughed at for their efforts (Mistree et. al., 1995).

Competition in the present environment can disturbe motives for creative output of solutions. Cave (1999) argue that concerns with job advancement or opportunities as opposed to job stability or security may affect motives to be creative at work. Therefore, business organisations have identified that the creativeness of their employees are promoted when the structure of their organization is less hierarchical and more democratic and free flowing (Cave, 1999).

Cross-disciplinary problems are often attacked by establishing cross-disciplinary project teams to solve them. Research culture, the scientific language and theory base of each discipline may become a barrier to creativity. The main intention of establishing such a team was probably to draw positive effects from the complementary competence of each member of the team. Every discipline of science has its own language which makes communication difficult through discipline interfaces. People are generally reluctant to give up their investment in the current solution to a new one even if it an obviously better solution, especially if the current solution is interpreted as an ingenious use of existing resources, and which they discovered for themselves after much effort and thereby won recognition. The new solution may also act as a closed system which the users do not fully understand, either because they never had the opportunity or because it is beyond their competence. Given a choice between using the new solution or something that may not work as well but which they understand, they will almost always choose the latter.

Both these situations are part of the socalled “not invented here” syndrome and may become the result if members of a project team communicate through different scientific languages based on different research cultures. Ideas and results initiated by one party may be presented in a language the others do not understand, and thereby rejected by other members of the group. This situation can occur at all levels of an organisation, not only within a project team.

The clearest example of environmental influence is when one is creative in virtue of serendipity. These are instances when the environment facilitates creativity by affording stimulating observations (Cave, 1999).

Cave (1999) argue that most of the obstacles to creativity can be found within person trying to be creative. The main thing that hinders creative thinking is a belief that oneself is not creative. Cave (1999) argues that when a product developer says ”I am a creative person”, he has to have beliefs about himself that support that identity. Once the product developer has a particular identity and set of beliefs about himself, he will become interested in seeking out the skills needed to express his identity and beliefs (Cave, 1999).

4.7.5 Overcoming the barriers to creativity

Overcoming the barriers to creativity and innovative renewal is critical to the success of any organization.

Harrington et.al. (1997) argue that it is important to match the method and tools to be used with the expected outcome. Ideas fluorish when the correct surrounding environment is established with balanced boundary conditions as guidelines for expected outcome.

Without guidelines for the expected outcome of a ideageneration event, the results may turn out invaluable. However, guidelines should not be too strict, as this may obstruct the creative thought. Furthermore, the styles and methods for all members of a product development team will not be consistent with either the circumstances or the available skills of each member. Thus, different tools are appropriate for addressing different kinds of issues using different styles of creativity.

Time and setting for an ideageneration event is also important. “Creativity on demand” may work, and may not. The assumption that to tell employees to be creative is enough to generate a number of better solutions is not going to work every time. Without any understanding of creativity and its nature, and no training or practice in being creative inhibits employees creative abilities.

Furthermore, creativity and ideageneration alone is never sufficient to ensure success in the marketplace. Understanding the frame of reference can help optimize a company’s allocation of resources toward efficiency, effectiveness, creativity and adaptability into successful exploitation of products and services in the marketplace. However, the frame of reference is dynamic and changes continually, making the new creative challenge to understand the new frame of reference to comply with.

Thus, to support a creative environment in an organisation and conquer barriers, there must be room for creative outbrakes during daily work, and not only thorugh enforced creativity through strategy meetings. Creativity and the attitude towards persistent search for new and improved solutions must be built into the organisations through organisational structure and project team composition.

4.8 Knowledge Creation

Nonaka and Takeuchi (1995) focus on knowledge development and organizations ability to produce new knowledge. In stead of organizational learning, they focus on knowledge development and define this as the ability for a company as a whole to create knowledge, distribute it throughout the organization and incorporate it into products, services and systems.

Central to Nonaka and Takeuchi’s view of knowledge is the division between tacit and explicit knowledge.

Explicit knowledge is formal and systematic. For this reason it can be easily communicated and shared, in product specifications, a scientific formula or a computer programme.

The starting point of any innovation is a kind of knowledge that is not so easily expressible: "tacit" knowledge. Tacit knowledge is not formalized and therefore difficult to communicate. Tacit knowledge is also deeply rooted in action and in an individual's commitment to a specific context - a craft or profession, a particular technology or product market. Nonaka and Takeuchi argue that the most important learning is related to first hand experience, and that this knowledge is neglected as a critical component for human behavior within organizations.

The core knowledge development within an organization lie in the mobilization and transformation of tacit knowledge. New knowledge always begins with the individual. New knowledge is created when an individual finds a new idea or solution. This knowledge is personal. A researcher has an insight which solves a problem through the creation of a new idea. This idea may be developed into a patent. A middle manager's intuitive sense of market trends becomes the catalyst for an important new product concept. A shop floor worker draws on years of experience to come up with a new process innovation. Each individual's personal knowledge is transformed into organizational knowledge valuable to the company as a whole. Making personal knowledge available to others is the central activity of a knowledge-creating company. It takes place continuously and at all levels of the organization.

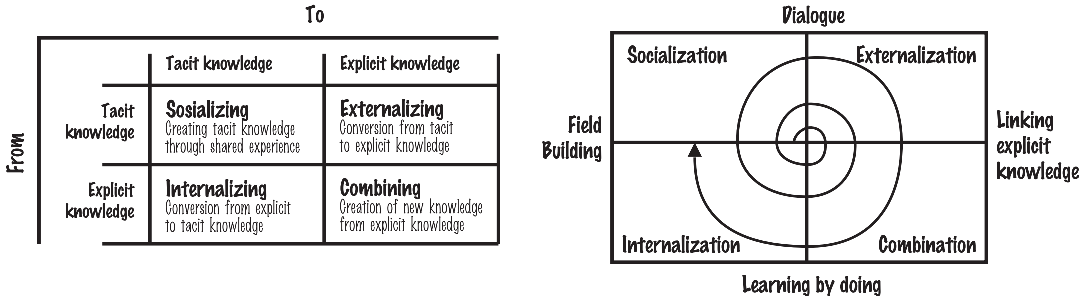
Tacit knowledge consists partly of technical skills - the kind of informal, hard to express skills captured in the term "know-how". A master craftsman after years of experience develops a wealth of expertise "at his fingertips". but he is often unable to articulate the scientific or technical principles behind what he knows. At the same time, tacit knowledge has an important cognitive dimension. It consists of mental models, beliefs and perspectives so ingrained that we cannot easily articulate them. For this very reason, these implicit models profoundly shape how we perceive the world around us.

The theory of dynamic knowledge creation is based on two dimensions (Nonaka and Takeuchi, 1995):

1. The *epistemological dimension*, which embraces the continued dialog between explicit and tacit knowledge, and
2. The *ontological dimension*, which is associated with the extent of social interaction between individuals developing and sharing knowledge, from small groups to extend whole organizations and societies.

Nonaka and Takeuchi identify four patterns of interaction between tacit and explicit knowledge, commonly called modes of knowledge conversion, as depicted in Figure 4.5a.

Figure 4.5 a) Knowledge creation modes and b) Knowledge spiral (Nonaka and Takeuchi, 1995)



Nonaka and Takeuchi argue that a double-loop learning ability implicitly is built into the knowledge creation model, since organizations continuously make new knowledge by reconstructing existing perspectives, frameworks or premises on a day-to-day basis (Jørgensen et al., 1999). It is this very dynamic view of knowledge, as something continuously being created, refined and reformed based on available information, that makes their theory unique.

Metaphors play an important role. Tacit knowledge may be transformed into explicit knowledge by recognizing contradictions through metaphor and resolving them through analogy (Jørgensen et al., 1999). When tacit and explicit knowledge interacts in this way, innovation emerges. This argument is in line with the intention of TRIZ, where the breakdown of the problem is very important to find the core of the problem. The real problem is then formulated into a contradiction, and compared with the patent database to find analogous solutions to similar problems.

The similarities between this double-loop learning ability and the Model of the creative process in Figure 4.2, is also interesting. From Figure 4.5b, we have socialization mode starting with building a field of interaction facilitating the sharing of experience and mental models. This sharing experience can seem valuable in the beginning, but can be transformed into a feeling of dissatisfaction when sharing experiences don’t result in progress. Staying within this situation too long may develop a feeling of stagnation. Here, there is a feeling of no development and general dissatisfaction with the situation. As analyses indicates that the situation is dissatisfying, a feeling of breaking up becomes present where the product developer searches to break with the existing, and forces him into new paths. Finding this new and better way involves thoughtful analysis of how things work and fail. These mental processes create a store of concepts in a product developer’s memory. The socialization mode primarily yields what is coined sympathized knowledge consisting of shared mental models and technical skills.

Furthermore, this triggers the externalisation mode by meaningful dialogue and collective reflection where the use of metaphors or analogies help articulate tacit knowledge hard to communicate. This process is the diverging process towards a chaotic situation where the product developer distances himself more and more from the existing situation. Meaningful dialogue and collective reflection are tools to organize an otherwise rather chaotic situation where tacit knowledge is transformed into explicit knowledge, but still in bits and pieces. Each knowledge element is however, well organized and easy to communicate. The externalisation mode results in conceptual knowledge.

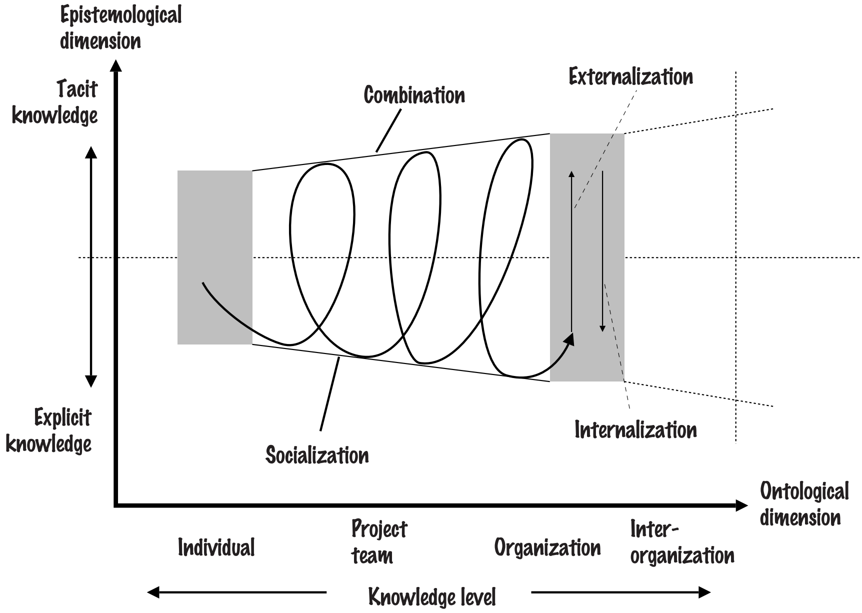
Combination mode is triggered by networking newly created knowledge with existing organizational knowledge. This phase is described as a converging process towards a crystallizing situation where all the loose ends are linked together and a new structure slowly is formed. In a product development situation, this is the phase where the he/she uses the store of mental concepts to generate novel ideas to meet specific needs by actively searching for associations among concepts. Here the explicit knowledge elements are structured and organized into new explicit knowledge. The combination mode gives rise to systemic knowledge.

Finally, learning by doing triggers internalization. Here the new organized and structured knowledge is distributed throughout the organization or product development team, making the new explicit knowledge tacit knowledge with all members. The internalization mode produces operational knowledge.

These contents of knowledge interact with each other in the spiral of Figure 4.5b and Figure 4.2. When we in addition to this epistemological dimension consider Nonaka and Takeuchi's ontological dimension of knowledge creation, we end up with the spiral of organizational knowledge creation depicted in Figure 4.6. This model shows how the organization mobilizes tacit knowledge created and accumulated at the individual level, organizationally amplified through the four modes of knowledge conversion and crystallized at higher ontological levels. Thus, it is proposed that interaction between tacit and explicit knowledge becomes larger in scale as the knowledge creation process proceeds up the ontological levels. The spiral process of knowledge creation starts at the individual level and moves upwards through expanding interaction communities, crossing sectional, departmental, divisional and possibly organizational boundaries.

Knowledge creation within an organization is a continuos and dynamic interaction between tacit and explicit knowledge, where tacit knowledge on the individual level forms the basis of the process. Nonaka and Takeuchi argue that the interaction between tacit and explicit knowledge is the basis for knowledge creation and innovation, and believes that the division between tacit and explicit knowledge is the key to understand the difference between knowledge approaches in Japan vs. USA/Europe. Nonaka and Takeuchi points at the disposition in USA/Europe to think through dichotomies such as tacit/explicit, theory/practice, operation/design, east/west - while the basis for the creation of new knowledge is recognizing the need to rise above these contradictory statements. Nonaka and Takeuchi do not see these as contradictory statements, but rather as mutual complementary entities which dynamically affect each other and alternate each other to create something new.

Figure 4.6 Spiral of organizational knowledge creation (Jørgensen et al., 1999)



This model also has its similarities with the models for innovation and product development described in Chapter 3.

Product development is totally dependant on the individual skills of each member of the product development team, i.e. the tacit knowledge of each individual. The product development team is normally composed with individuals holding different knowledge and experience. Normally, there should be little overlap between the knowledge each individual brings into the team. Organizations mobilize tacit knowledge created and accumulated at the individual level into a product development team to create new knowledge.

Companies try during the product development project, and through organizing the product development team, to amplify the individual tacit knowledge through the four modes of knowledge conversion and crystallized at higher ontological levels, i.e. into new industrial products or services, and thus new business opportunities.

Thus, it is proposed that interaction between tacit and explicit knowledge becomes larger in scale as the knowledge creation process proceeds up the ontological levels (Jørgensen et al., 1999). The spiral process of knowledge creation starts at the individual level and moves upwards through expanding interaction communities, crossing sectional, departmental, divisional and possibly organizational boundaries.

One of the deficiencies with the innovation and product development models described in Chapter 3, was the lack of life phase approach and a holistic view point.

This is where the theory of knowledge creation can aid us into externalizing this tacit knowledge into explicit knowledge and furthermore, internalizing this explicit knowledge to all members of the product development team and enhance knowledge and skills of all member of the organization. The element of life phase approach and holistic viewpoint must be introduced and pervade the attitude of the product development team. This tacit knowledge is not in contradiction to, but complementary to all experience and skills of product developers. This is why an individual holding environmental specialist knowledge should be part of a product development team where focus is improving environmental performance. Companies which are newcomers in viewing their products and services through the eyes of environmental performance, would have great benefit from starting a project focusing on environment, and benefit from the accomplish the mechanisms of knowledge creation.

The theories of Nonaka and Takeuchi explain the link between creativity, innovation and product development, and explains how environmental awareness and consciousness, can be distributed throughout an organization.

4.9 Discussion and concluding remarks on creativity in product development

De Bono argues that many executives, scientists and almost all business school graduates believe that if you analyze data, this will give you new ideas. Unfortunately, this is totally wrong (De Bono, 1992). Simply analyzing data will not lead to new ideas. Analyzing data may set focus on the source of a problem, and thus contribute to the attention dimension of creativity. However, escape and movement are absent, and thus creative ideas will not come into being by itself. Relying on serendipity may not work all times as the circumstances may not be satisfying.

Simply analyzing data will certainly lead to insight into what is wrong with the current situation. However, the utilization of this insight for generating new solutions requires more than being aware of that something is not satisfying. Considering the model of the process of creating (Hermansen and Lerdahl, 1997, Lerdahl, 1997, Plsek, 1997) simply analyzing data will at its best contribute to the phase of dissatisfaction. The dissatisfaction may be valuable if it is used in a creative way, i.e. a creative dissatisfying way.

Considering the area of sustainable development, researchers presently seem to be diverging into chaos, i.e. they have accepted that there is a dissatisfying situation where improvement of present solutions are required in the short term and new creative solutions are needed in the long term. Researchers around the world still have not united around a definition on the term sustainable. A lot of creative approaches are proposed trying to break with existing patterns creating pieces of valuable research results contributing to a broader understanding. However, the overall process of creating a sustainable society remains unsolved. All the bits and pieces within this chaotic phase will eventually lead into a converging phase where piece of research work fits together into an overall solution.

The situation seems to be too much focused on analyzing data and generating alternatives to the details found to be the source. This approach automatically leads to incremental improvements of environmental performance. The reason for this approach may lie in the phenomena of technological lock-in where companies and industries try to defend large investments in production capacity etc. which totally rely on present technological solutions, and which are not flexible enough to handle a totally different solution approach.

When there is willingness to develop really new products, there is a huge need for conceptual creativity. New products are going to work only if they integrate fully into the complex values of the customer and other stakeholders. Being aware of these complex values and finding ways to integrate with them is a creative exercise. Once the concept is in place, there is the need to create ideas for the carrying out of that concept. Finally, creativity is needed to devise ways of pretesting the product. Creativity is also needed to shorten production time and to reduce the cost of product development (De Bono, 1992).

There is a need for creativity in looking at possible future scenarios. There is a need to conceive of discontinuities that may provide problems or opportunities. There is a need to devise concepts that will be sufficiently adaptable to changing conditions or imperfect forecasts (De Bono, 1992).

Hermansen and Lerdahl links the model of creativity to ecology using similar notation as for soft-, hard- and practical ecology: soft-, hard- and practical creativity (Hermansen and Lerdahl, 1997).

Soft creativity is based on emotions and feelings, and relies on the free will and thought. The product developer utilizing this approach is driven by the need to create, not based on necessity, but based on an inner need and want to participate. He will participate in contributing to improving environmental performance, although he cannot prove that environmental problems will arise in the future.

The hard creativity approach relies on facts, science and rational argumentation when creating products.The product developer wants to use concrete rules, accepted methods and is very upset by scientific reasoning prior to implementing actions for improving environmental performance. With such an approach, the product developer has little room for fantasy, assumptions and intuition. In this approach the hard facts are needed to hold on to, and that the developer is conscious about the limitations of reality.

To be able to cope with present and future environmental effects Hermansen and Lerdahl asks for the practical creative product developer, which is an approach between the extremes of soft and hard creativity. Personal involvement and liability, idealism, holistic understanding and improvisation is needed from the soft creativity approach. This will contribute to that the product developer grasps the intention and feels a personal participation in the creation process, and not the feeling to be frozen by the a framework with too strict guidelines, criteria and barriers (Hermansen and Lerdahl, 1997).

Simultaneously, the systematics, detail work, clarity, the science based and the concrete from the hard creativity approach is needed to be able to solve the large ecological challenges. This will give the product developer robust tools to use as a starting point. The product developer must however, not be caught by the tools and always search for scientific evidence prior to implementing action. Creativity is characterized precisely by that it links and connects different and often unexpected viewpoints together.

The practical creative product developer can support satisfying the need for creative results on the function-means level. Untraditional means to satisfy functions requires elements of the soft creative product developer to represent a leap improvement in environmental efficiency. It simultaneously requires sufficient elements of the hard creative product developer to keep the means proposed on a realistic level.

The modifications and redesigning products into new artefacts which makes a real difference in improvement in environmental efficiency, requires a fundamental analysis and understanding of the primary and secondary functions of the product. The tools and techniques presented in 4.5.2, Attention can contribute to this goal. This activity requires more of a hard creativity rather than the soft type as the scientific analytical skills, becomes more important than emotions and fantasy. The tools and techniques presented in 4.5.3, Escape can contribute to generating ideas which can represent a true mental process of escape through identifying the ultimate scenario utilizing different means satisfying the defined function. Here, there is a transformation in the use of skills from the analytical to the emotional and fantasy related skills. The need to generate ideas without immediate judgment can contribute to identifying ideas with potential for improving environmental efficiency. Furthermore, the tools and techniques presented in 4.5.4, Movement an contribute to moving the ideas into beneficial concepts which can be developed into profitable products and services.

The theory of knowledge creation can aid company employees to externalize their tacit knowledge into explicit knowledge and furthermore, internalize this explicit knowledge to all members of the product development team and enhance knowledge and skills of all member of the organization. The element of product life phase approach and holistic perspective must be introduced into the product development team and pervade their attitude. This tacit knowledge is not in contradiction to, but complementary to all experience and skills of product developers. This is why an individual holding environmental specialist knowledge should be part of a product development team where focus is improving environmental performance. Companies which are newcomers in viewing their products and services with environmental performance in focus, would have great benefit from starting a project focusing on environment, and benefit from the mechanisms of knowledge creation.

As argued in chapter 3.8, Discussion on innovation- and general product development models and 3.11, Concluding remarks on innovation and product development, product development models focus too much attention to existing mind patterns. The demands of time to market makes using existing information and redesigning existing product systems important elements to reach milestones on the time schedule. This finding support hypothesis C *Traditional product development models lack the support* *systems to conquer barriers and break out of existing mind patterns of technological lock-ins to create completely new systems with significantly improved environmental performance for delivering customer needs.*

However, market forces sustaining present business practices are still strong enough to keep supporting consumption growth without improvements in material and energy use. Customers are simply not ready for integrating reduction thinking into their criteria for selection. This lack of positive market response of truly innovative products and services, is also a barrier for further development of ideas which can break out of technological lock-ins and create completely new systems with a true benefit in material and energy consumption and significantly improved environmental performance for delivering customer needs. This is also a barrier to using environmental criteria as guidelines for creative thinking. The market forces are however, the leading guidelines for product development, and naturally cannot be neglected.

The lack of positive market response can also explain why industry is evasive to establish long term visions of their environmental perspective, and develop strategies to reach these visions. The vision and goals for environmental performance defines the boundary conditions for product development projects in a company. This seems to be the main cause why exploring results of unbiased creative exercises, which may lay outside current business practice, are often rejected and further development is omitted.

Thus, hypothesis D *it is possible to overcome the barriers of renewal due to technological lock-in by stimulating internal players and resources within a company* is supported. Establishing a vision with the company's environmental perspective and goals has been identified as vital to stimulate for finding solutions for leap improvement in environmental performance. The vision becomes incentives to establish strategies for leap improvement. Establishing outrageous goals will stimulate for finding solutions which differ from current procedures and thus break out of technological lock-ins which form barriers to leap improvement.

This also supports hypothesis E *innovation and product development are the only activities where companies themselves can stay in control, and combine internal interests with the external interests of customers and nature, i.e. to develop technical systems where their interactions with social systems and natural ecosystems are optimized based on sustainability criteria.*

Boundary conditions which form the framework in which a company has to operate, changes continuously. Customer attitudes in the market, legislation, suppliers and competitors are all dynamic in their behavior, although a static environment would be appreciated. A company is not able to control these interfacing elements of the system network where it operates. They are controlled by other stakeholders, and can only in a limited sense influence decisions to comply with their own goals. The product development task is therefore the only activity where the company itself can stay in control and approach the market based on their own vision and goals.

Creativity as a vital element of the early phases of product development, is essential in developing ideas and new solutions to develop further into products and product systems to approach the market. The product is expressing to the market the creative abilities and tacit knowledge of the members of the product development team. Creativity and product development is thus visualizing the tacit knowledge of the individuals of the organization.

The theories of Nonaka and Takeuchi explain the link between creativity, innovation and product development, and explains how environmental awareness and consciousness, can be distributed throughout an organization.

CHAPTER 5

LEAP IMPROVEMENT IN ENVIRONMENTAL PERFORMANCE

This chapter describes leap improvements in environmental performance. Based on the findings in chapter 3 and 4, some of the identified tools are utilized to find solutions to the basic physical contradiction identified in chapter 1. These solutions are coinciding with the three dimensions of efficiency described in chapter 2. The intention of the chapter is to unify the findings of the preceding chapters into a strategy for leap improvement in environmental performance.

5.1 Introduction

The two preceding chapters explain two important aspects of creating innovative and environmentally friendly industrial products, i.e. following a structured methodology, and using techniques to trigger new ideas and concepts. The question now is how to use these aspects as input for the creation of products which do not merely represent an incremental reduction in environmental load, but to significantly contribute by a leap improvement. The product development models presented are all based on present industry infrastructure and industrial habits. There is a general agreement that to achieve a sustainable society, there is a need not only to design different products, but also to do it in a different way. The holistic thinking and systems view which is very important in light of environmental properties, which is partly lacking in present methodologies is needed as a guidance for the high level decision making within industry. However, the holistic thinking and systems view is not only beneficial for improving environmental properties. The relations between early design decisions and consequences later during the product life span, becomes visible using the holistic systems view and appropriate action can be taken prior to the actual meeting between the product and product system.

5.2 Factor x improvement

The Brundtland report (WCED, 1987) which triggered world attention, seems clear in their global goals, but no direct quantitative consequences are given. The report does not give any specific contributions on what we have to do if we want to preserve natural resources for future generations.

The background for the factor X concept, where X is a number somewhere between 1 and ∞, is illustrated by the PAT formula (Ehrlich and Holdren, 1972), i.e. a simplified formula to show at which level the environmental goals industry have to meet. The original Ehrlich-formula :

$$I = P \cdot A \cdot T$$

(environmental) impact (I)=
population (P)
x consumption per person (affluence, A)
x impact per consumption (technology, T)

Holdren and Ehrlich (1972) argue that, a bit of further disaggregation seems useful, for preventing to confuse affluence with resource use (separable by means of the inverse efficiency factor, resource use per economic activity) and to separate what technology does to the environment (stress or load) from the actual damage or impact that also depends on recipient susceptibility (Holdren et al., 1995). Thus:

$$D = P \cdot A \cdot R \cdot T \cdot S$$

Damage (D) =
population (P)
x economic activity per person (affluence, A)
x resource use per economic activity (resources, R).
x stress on the environment per resource use (technology, T)
x damage per stress (susceptibility, S)

Holdren et al. (1995) note that the original and also the expanded relation is no more and no less than an identity. It is true by definition. They believe that this relation is both informative and useful on a global level.

Identities of this sort are instructive because they remind us that increases in population, affluence, and the ratio of environmental stress to economic activity are multiplicative in their effect on damage. They are clearly a function of the composition of economic activity and the technology with which it is accomplished. Thus, the impact of each factor is a matter not only of its own magnitude, but also of the magnitudes of the others (Holdren et al., 1995).

To reduce the environmental load due to human activity every individual actor within the economy has to optimize their use of resources from the national (macro) level, over sector and regional (meso) levels on to the single firm and the household (micro level). The long time span is needed to allow the technical, social and economic dynamics to adapt and adjust without major conflicts with the requirements of economic sustainability (Kuhndt and Liedtke, 1999).

However, nothing seems to indicate that neither population growth nor level of prosperity will undergo significant reductions. On the contrary, statistical observations indicate that both will increase significantly during the next decades.

World population is expected to rises from 5.7 billion persons in 1995 to 9.4 billion persons in 2050 according to the medium scenario, i.e a factor 1.7 (Economist, 1998). The medium scenario assumes that fertility in all major areas stabilizes at replacement level around 2050. During the same time period economic growth (approx. 2-3% per year) will result in an increase of consumption of a factor 4 to 8 in the same period (Von Weizsäcker et al., 1997).

Assuming that fertility remains at replacement level also after 2050, world population nearly stabilizes at a level just above 10 billion after 2200 (Economist, 1998, United Nations, 2000). Environmental damages can affect fertility rates. As the UN population predictions shows, only a small reduction in fertility rate affects population growth. One could therefore argue that pollution problems would solve the population growth problem. However, such a thought is rather cynical, and does not solve any population growth problem, but will at the utmost consequence, remove the basis of existence for mankind.

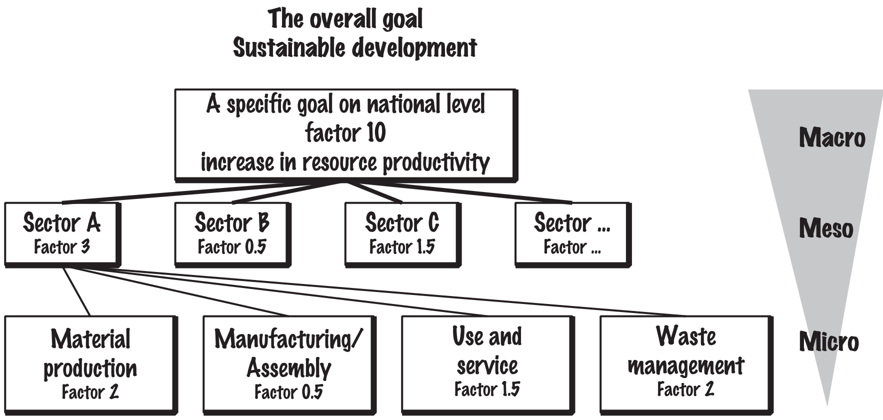
If the environmental load is to be kept at present level or even reduced, the remaining solution is to create economic activities and technologies with significantly lower environmental load. Using the above equation, our current resource- and technology use will have to be reduced by a factor 7-14 globally (D=1.7P4AT/x and D=1.7P8AT/x), in order to keep current prosperity unchanged. Similar results report the range of factor 4-20 (Factor Ten Club, 1997). As the prosperity of the world is unevenly spread, the improvement would need to be as high as 20 within the industrialized world. This affects all areas of human activity. This serves as a starting point for the long-term horizon (50 years). It is expected it is required to achieve a factor 4 increase in efficiency related to environmental load within the mid long term (10years).

Reijnders (1998) argues that there is no agreement on the environmental impact that the factor X relates to. The factor X may be considered to give a quantified edge to the concepts of natural resource productivity, dematerialization, and ecoefficiency. Natural resource productivity relates to the natural resources that are inputs for the economy, i.e. the quantification of the link between the ultimate- and intermediate means in Figure 2.3. Dematerialization also relates to these inputs, but includes material flows that are side effects of economic activities, such as those generated by erosion (Adriaanse et al., 1997).

Other contributors have referred to (natural) resource and energy productivity use varying parameters in determining the factor 4 referring to either transport, energy, or non fuel materials. Such parameters clearly do not reflect overall environmental impact (Factor Ten Club, 1997, Schmidt-Bleek, 1994a, Von Weizsäcker et al., 1997).

Kuhndt and Liedtke (1999) argue that the Factor of 10 refers to total material flows (that include also material flows for energy production) within the economy and can be set e.g. in the national policy plan as quantitative goal. For the industrial production of goods and services within this national economy, this does not mean that the resource productivity of every single process or every individual phase of the life cycle must be drastically increased. Rather those whole industry sectors contribute with different factors to the Factor 10 goal according to their life span wide potential to reduce resource consumption (Kuhndt and Liedtke, 1999).

Figure 5.1 The setting of Factor X goals on different levels (modified from (Kuhndt and Liedtke, 1999))



The factor X debate fits in a wider discussion on the importance of technological change in improving the environmental performance, and lowering the materials intensity of economies and can be visualized through the transition to the next technological s-curve (Fussler and James, 1996, Von Weizsäcker et al., 1997).

Fussler and James (1996) and Von Weizsäcker et al. (1997) document 50 examples of economic activity where a factor 4 improvement over traditional activities is said to be implemented by technical means. These examples vary from tomatoes and strawberry yogurt to office buildings and refrigerators. They mainly refer to products and services current in western industrialized societies and come in essentially three groups said to illustrate, respectively, a fourfold increase in energy, (non fuel) materials, and transport productivity.

Consequently, the factor 4 improvement means improving the resource use in all areas of our society, i.e. improving

- eco-efficiency, i.e. improving technical solutions
- eco-effectiveness, i.e. improving infrastructural solutions
- eco-sufficiency, i.e. social innovation reducing overall need for artefacts with makeshift functionality compensating for human imperfections.

giving a product of a factor 4. The figure here is of minor importance. Wether it is 4, 10 or even 50 makes no different to the fact that business as usual will not succeed. Fundamentally different business practices are needed to achieve such ambitious goals.

As described in 1.7.3, a function economy represents a fundamental shift in the relationship between producer and consumer, i.e. an economic change from procuring products to procuring services or functions.

In principal, producers/suppliers sell services in a function economy, in preference to products. Producers/suppliers offer services based on products, and customers buy the function these products can perform. A function economy is an economy which is needs oriented and service/function oriented instead of product oriented. Ownership of product stays on the producer/supplier's hand. Customers buys the results these products perform. When producers keep ownership of products, they are incorporated into the producer's assets, i.e. they become part of the producer's real capital. Being part of a company's real capital, is an incentive to maintain these products. The opposite means depreciation of capital, which means expenses for the company. Producers will no longer benefit from customers for some reason replacing old products. Under these circumstances, a producer/supplier may benefit from increasing product lives, maintenance and repair, disassembly and recycling of products, components and materials.

In a function economy one does not perceive natural resources and human made capital primarily as substitutable, rather complementary. The intention is to contribute to increased quality of life and just distribution through an ecological closed loop economy without pollution and lavishment and where waste from one value chain is input for other value chains.

The most important difference between a function economy and a more traditional service economy, however, is that the function economy is system oriented while a service economy is product oriented. External social/systemic conditions which makes a function economy profitable for business in preference to a consumption oriented economy. This is a condition so that supplying services/functions will result in a drastic reduction in resource extraction and environmental load, and become superior to traditional business practice.

5.3 The three dimensions of environmental performance

The O_2 network (Opschoor, 1998), argue that the factor 4 concept presents an optimistic vision of the future with attractive and relatively simple solutions to environmental problems. Furthermore, they argue that the most attractive thing about the Factor 4 concept is that instead of costing more money, increased environmental performance costs less.

This has been true for the incremental improvements presently implemented in industry. The strategy of using less also leads to saving costs. However, the strategies for incremental improvements, i.e. strategy 1 through 5 and partly 6 and 7 in the ecodesign strategy wheel (see Figure 3.16), do not conquer the fundamental idea behind any product. A completely redefinition of the product (or even if there should be a product at all) starting with the basic need, wants and function-means combinations, is rarely questioned. However, strategy 8 can also be interpreted as to define a new vision for the product in a larger holistic systems view, and utilize strategy 1 through 7 as tools for incremental improvements to reach this vision.

The reason for this may be that environmental friendliness of industrial products is still in its infancy as a criteria for product development activities. Industry therefore look for solutions which are easy to implement and which clearly shows a win-win situation with economic benefits.

Porter and Van Der Linde (1995) deny the possible contradiction between environment and economy, and claims that regulation trying to contribute solving environmental problems, is just a new wall in the framework governing competition:

> *Successful environmentalists, regulatory agencies and companies will reject old trade-offs and build on the underlying economic logic that links the environment, resource productivity, innovation and competitiveness. (Porter and Van Der Linde, 1995).*

Porter and Van Der Linde (1995 argue that resource productivity due to changes in the world economy is a critical parameter for competitiveness in combination with rapid means for change. Larssæther and Eik (1998) and Walley et al. (1996) however, argue that Porter and Van Der Linde (1995) underestimate the complexity of environmental problems and the increasing pressure from environmental legislators, claiming that it becomes too easy to deny what Walley et al. (1996) argue is a concrete contradiction between environmental- and economic considerations during day-to-day business claiming that the win-win situation is always present (Larssæther and Eik, 1998):

> *As environmental challenges become more complex and costs continue to sky-rocket, win-win solutions will become increasingly scarce. Environmental costs have stubbornly continued to outpace both inflation and economic growth for the past two decades. (Walley et al., 1996).*

The situation which Walley et al. (1996) describe is the cost of technological lock-in. Innovation driven environmental legislation shall promote innovative ideas and redesign of polluting products, processes and organizations (Porter and Van Der Linde, 1995). This may very well turn out to include introduction of new (to the company) technology and even lay down of production facilities. This situation in turn leads to loss of production and loss of investments, which is what the barriers locking in a technology is trying to defend, but are torn down by legislation and customer requirements.

Van Hemel (1998) reports from a study among 77 small and medium sized companies in the Netherlands, that customer pressure and criteria are stronger incentives for these companies to implement environmentally focused redesign projects, than governmental legislation (Van Hemel, 1998). Alteration of market focus is like legislation partly outside of normal company control, and may consequently lead to uncontrollable financial losses.

Slocum (1998) argues that the resistance to change, the current paradigm, must be understood if it is to be defeated. In order to increase our understanding of paradigms some discourse on this topic is necessary. Kuhn (1970) states that every scientist (or engineer), just like the rest of humanity, carries out their day-to-day affairs within a framework of presuppositions about what constitutes a problem, a solution, and a method (Casti, 1989). Such a background comprises a paradigm, and at any given time a particular scientific community will have a prevailing paradigm that shapes and directs work in the field. Kuhn further claims that scientific revolutions involve that companies that cannot resist the competition and supply markets with products satisfying customers, will go down (Slocum, 1998).

The focus here is on a company's ability to escape from a technological lock-in situation, while still staying in control of the situation. There is reason to believe that the cost of change due to environmental regulation will be higher than using innovation to replace environmentally unfriendly technology. There is also reason to believe that to cope with the complex environmental problems, it is necessary that businesses must do things differently to achieve factor 4 improvement in particularly the efficiency of their choice of technical solutions. Businesses must also have in mind the consequences for and changes in infrastructural effectiveness and social innovation driven by the sufficiency principle.

The use of suitable technologies and products enables a much more efficient use of energy and materials. Increase in wealth is especially important for the developing countries, as it is important that these countries not to perform the same mistakes as the industrialized countries which created the problems in the first place. Increasing the environmental performance of products and services will reduce pressure on the environment while the economy continues growing (Opschoor, 1998). This can also contribute to strengthen the international competitiveness of enterprises. Obtaining greater earnings from less energy and less raw materials is an attractive prospect for companies of all kinds. This is true in the industrialized countries of the West, but even more true for the developing countries, which could 'leapfrog' several stages of development by implementing environmentally efficient factor 4 technologies (Opschoor, 1998). However, by focusing on wealth, it is important to avoid the rebound effect where the benefit regarding environmental issues is consumed by increasing consumption. Furthermore, the factor 4 scenarios in the literature fails to consider questions of consumer behavior and the quality of life. The acceptance of existing patterns of consumption gets in the way of clear thinking about socially and culturally desirable behavior (Opschoor, 1998). Innovation is environment-friendly only if it delivers ecoefficient products and simultaneously the intended beneficial effects are preserved by sustainable use of these products.

Opschoor (1998) furthermore argues that the end should justify the means, i.e. a product does not have to be manufactured in a sustainable way as long as it elicits sustainable behavior.

This illustrates the growing importance of the three measuring parameters: ecoefficiency, ecoeffectiveness and ecosufficiency respectively. Increasing ecoefficiency is normally a challenge related to improving the technical system (here: a product), while increasing ecoeffectiveness is related to the technical/infrastructural system where the product is a component. Finally, increasing ecosufficiency is related to the social system governed by individuals and social needs. Thus, as explained above, it may not matter how ecoefficient the product is designed and manufactured if customers prefer a product using obsolete and environmentally unfriendly technology. Thus, the ecosufficiency parameters has the highest potential for improvement in environmental friendliness within the global economy.

Opschoor (1998) argues that we should insist that governments develop a long-term policy based on insights into behavioral science. A better environment does not start with the consumer or with industry. He claims that it is naive to believe that industry, customers and market forces alone are able to introduce incentives for reduction in customer and industry resource consumption. This author will claim that it is even more naive to believe that government can stimulate people to start behaving in a way that is less damaging to the environment. Companies have a large responsibility in this sense. Many observants indicate (Randers, 2000) that it is likely that companies and NGOs are the groups which can make a difference, and achieve positive results in the short term. Fortunately, there exists highly proactive companies that surpasses legislation, and sees environmental issues as a key to competitive advantage.

In this sense it is important to emphasize the need for incentives rather than punishment. To stimulate environmentally friendlier activities, all environmental regulation must contain an element of ways for innovative solutions to get around it. Like Porter's view, regulation must be innovation driven (Porter and Van Der Linde, 1995).

5.4 A step further

5.4.1 Challenging the Laws of Physics

When developing products, the main objectives is to create an artefact which can produce a desired effect supporting the defined primary function. This function is achieved by the means of combining different human, natural, social and technical processes. When the need is solved by technical means, we rely on our knowledge of the physical world around us. This knowledge is explained through the basic laws in physics such as the laws of thermodynamics, mechanics, chemistry, etc.

As explained in chapter 4.5.3, de Bono argues that a creative escape must be provoked, e.g. by wishful thinking, and Ottman asks for outrageous goals.

The ultimate goal in an environmental sense is to perform the primary function of the artefact

- without the use of materials,
- without the use of energy, and
- without toxic side effects.

This goal is challenging the laws of physics described above. The second law of thermodynamics states that no work can be performed without the transformation of energy. Similarly, the existence of a product without its materialization is illogic. Consequently, the ultimate goal as described above in the logical sense remains as an un achievable option. It is certainly an outrageous goal.

Why are these questions discussed? Operating in the field of engineering obviously generates objections against such an expression. Naturally, we cannot challenge the laws of physics based on our present knowledge of how nature works. The laws of thermodynamics is one of the fundamental laws of one of the basic pillars our industrial world is built upon.

However, if we use the concept of lateral thinking and the tools of provocation, escape and wishful thinking, anything is allowed. Lateral thinking is about moving sideways when working on a problem to try different perceptions, different concepts and different points of entry.

The experiment of challenging these laws is a situation of escaping the present paradigm and watching what is behind this “barrier”. It is a situation of wishful thinking as when it comes to the bottom line, we know that this is impossible. Besides, the concept of making product without the use of materials, without the use of energy and without toxic side effects, is identical to the ideal final result operator of TRIZ, and makes it not such an illogic concept for idea generation.

5.4.2 The separation principles

TRIZ explains that an invention appears when contradictions are solved (Altshuller, 1984). Contradictions can be either technical or physical. A physical contradiction is a situation where a parameter of the technical system is given two different values simultaneously. An example illustrating such a situation is the pointing device used for presentations. One criteria for the pointing device is that we want it to be long to be able to point on the wall. At the same time we want it to be short to put it in the shirt pocket.

Physical contradictions are solved by the separation principles (Altshuller, 1984):

- Separate in time
- Separate in space
- Separate in structure or between parts

Applying these principles to the pointing device give a solution: A telescopic assembly makes it long for the pointing function, and short to put it in our pocket. Here, both separation in time and separation in structure are used.

When trying to solve a physical contradiction, we try to challenge some physical law. Using the pointing device again, trying to make something long and short simultaneously requires challenging the laws of material consistency. Making this pointing device long and at the same time short requires some parts of the material of the device to disappear and come back again, which does not make logical sense.

Similarly, there seems to be no logical sense trying to make products without using materials. Consequently, solving physical contradictions includes walking around some fundamental law of physics.

The solution to ultimate goal to

- perform work without the use of energy
- make products without the use of materials
- make products and perform work without toxic side effects.

is to use the separation principles, separate in time, space and structure and between parts (Altshuller, 1984).

5.4.3 Applying the separation principle

Applying the separation principles should be in line with the lines of evolution drawn by (Altshuller, 1984). The original wording of the eighth line of evolution proposed by (Altshuller, 1984) states that

> *the development of technical systems proceeds in the direction of increasing the S-field involvement*

This line of evolution is interpreted by (Terninko et al., 1996) to be

> *evolution towards decreased human involvement*

The S-Field is what Altshuller calls the minimal technical system. The S-field analysis is an analytical tool for problem modelling related to existing technical systems. The desired function of a system is the output from an object or substance S1, caused by a different object S2 with the help of some means or types of energy, F. Substances are objects of any level of complexity, i.e. single items or complex systems. The action or means of accomplishing the action is called a field (Terninko et al., 1996).

Every technical system includes four basic parts. The system will not work if one of these parts is missing, or does not perform well.These parts are an engine, a transmission, a working organ and an organ of control. The engine is the source of energy. The transmission carries the energy from the engine to the part that does the work: the working organ. Finally the system contains an organ controlling the system. The control function is normally performed by humans who also often are the recipient of the desired function of the technical system. The interpretation of the original wording of the eighth line is that technical systems evolve in a direction where the technical system is controlled by others than the recipient of the function. That is: the human control function is replaced by a different technical system.

This is in line with the work of Hubka and Eder (1992) who argue that technical systems follow a trend of :

- instrumentation,
- mechanization,
- automation
- and computerization

We can find evidence of this line of evolution everywhere in society where technical systems are involved. Human work is replaced by technical system through automatization. This line of evolution indicates that development of services is central, which will be discussed below.

Consequently, the separation principles should be applied to

- the technical system from the social system throughout the utilization phase of the product system, i.e. ownership of the product
- the structure and architecture of the product system
- structure of the supersystem where the product has the role of a system component

The goal is to reduce resource use and toxic emissions based on the environmental mind set.

5.4.4 Separation in time: Developing product-service combinations

In the example about the pointing device given above, the solution to the use of the separation principle was given by the question: Do I need the characteristic "long" at the same point in time as the characteristic "short? The answer is no. The pointing device did not need to have both characteristics simultaneously. They needed to be present only when needed. The solution involves separation in product structure, through the telescopic design.

This situation is often present in our daily life. We gather a lot of products which we seem to need, but we do not use them. One example is the personal car. The personal car is use to and from work, and probably every weekend for leisure.

Car sharing is an example where the product is used when the consumer needs it and reserves it, while someone else make use of it when left. Instead of having ownership to a car, the user has a subscription on a car rental system, together with people in the neighborhood: therefore, cars will ideally be available for everyone in the neighborhood. Car sharing is especially popular for people needing a car once in a while. The car sharing systems are set up by small entrepreneurs, providing evidence that sustainable concepts are not only developed by large companies

Another example is the launderette service found in many apartment blocks throughout the world. The wash service is exemplary for fulfilling the need for clean clothes (and free time) for consumers instead of selling products (washing machines).

Both the car sharing- and the launderette service are examples of product service combination where a service is added to a product and where the service is the function utilized by the means of a product.

Another example (of a stationary product) is the US carpet manufacturer Interface through the company's Evergreen Lease flooring system, in which customers do not make a one-time purchase of a carpet, but instead continuously lease carpet tiles from Interface. Eventually, old carpet tiles will be broken down and remanufactured.

This is actually the principle of separation in time where an activity seeking to fulfill some need or want, is done by someone else. These are three examples where a service provider has a product, a means, to utilize this need or want. The service provider organizes the service by taking into account that all his customers do not need his function at the same time. Thus, there is an efficiency gain through a reduced need for the means, i.e. the product. The purpose of utilizing a service may be due to lack of skills or lack of time to perform the activity.

The lack of time is the basis for the growing service economy making time for other activities. This principle is also utilized in communities and organizations sharing personal time and skills on a voluntary basis. G. Gardner presents the sharing of time and skills in the article "Why share?" (Gardner, 1999). Time, like material possessions can be shared, typically through tutoring, coaching or some other form of volunteer work. Here, time spent utilizing personal skills represent a unique monetary value e.g. one hour spent equals one service credit. Service credit programs are monetary systems developing in several communities in the western world in parallel with the official monetary system, where the currency is time doing what each participant is good at (Gardner, 1999). However, service credit programs have one important difference: most participants see themselves primarily as volunteers rather than paid workers. Volunteering of time is a great community builder and may serve as a starting point to develop the issue of ecosufficiency.

Interpretation of the separation in time-principle

The ultimate goal of designing product as described in chapter 5.4, was to develop products without the use of materials, etc. The separation in time must here be understood as once the product is manufactured, it will not disappear unless it is deteriorated by wear, natural processes like corrosion, or scrapped by action. As it does not disappear, the product can be utilized continuously as long as service and maintenance is taken care of. Continuos use means under normal conditions that several users will have access to the product, which increases the degree of utilization of the product up to nearly continuos use.

This is a lacking attitude in today's society where the need of ownership is very important for groups of customers. The need for ownership of artefacts is a way of expressing to other people the values which the owner appreciates. This may represent a significant barrier to the need for increased focus on the functions supported by products and which must be surpassed to give room for the delivery of services instead of artefacts.

When utilizing the separation in time principle, it is important to understand that the design activity is still a synthesis activity. The separation in time principle therefore means that the separated elements of the product life structure must be synthesised into a new whole, but in a different way which provides a significant improvement in environmental performance.

5.4.5 Separation in space

Transportation is a heavy contributor of environmental load around the world. Traffic congestion is a major problem in daily life in addition to its major contribution to the environment effects in terms of emissions during community travel. Business meetings out of town involves technical means like airplane, train or personal car for transportation thereby to obtain the need. Similarly, the day-to-day travel between home and office involves utilization of transportation systems. The need here is "participant being present at the meeting" or "show up or be present at work". Applying the separation principle to this need involves either separation of the participant, which is not an option, or separating the meeting or the office which is a fully obtainable option today.

The virtual office and -meeting are examples of separation in space. Here the functions are present, but are placed geographically in different locations and makes the user or customer of the functions able to be virtually present at different locations simultaneously. The user is apparently present at several locations at the same time.

Teleworking and virtual meetings are options utilizing telecommunication connecting computer hardware and video conferencing for reducing business related travel, and reduces travel related environmental effects.

Reducing traffic by stimulating (part-time) teleworking, requires new concepts at home (telework-places and connectivity with the home office), as well as at the office itself (flexible workplaces). Several companies are working hard to make this possible, not only in order to reduce environmental effects, but also because there is an economic benefit (Niles, 1994).

Teleworking is a solution where a product-service combination is utilized to obtain the need. A product-service combination is a technical system where both the product and the service are mutual dependant of each other to perform the need of the customer (Niles, 1994).

Studies from USA shows that telecommuting accounts for 7.6 million U.S. workers as of early 1993, up 15% from 6.6 million in 1992 (Niles, 1994). The U.S. Department of Transportation estimates that telecommuting by the year 2002 will reduce the annual total vehicle miles traveled by only 1% below the level expected to be seen if there were no telecommuting. A follow-up study by the U.S. Department of Energy calculates that the reduction in mileage from telecommuting by 2002 is likely to be even less because of (Niles, 1994)

- commuters living further from work, and

- other travelers taking the road space vacated by telecommuters.

However, telecommuting is not the only way that telecommunications can act as a substitute for transportation. Other examples of telecommunications substituting for travel include (Niles, 1994):

- Sporting, entertainment and other live events broadcast to a dispersed audience, rather than requiring that the audience travel to the event.
- Observations from scattered sites collected via remote sensing and transmitted to a central point, rather than sending a human observer.
- People initiating travel to a needed destination only after using telecommunications to find that the trip will be necessary or productive.
- Service transactions carried out by electronic means that require less travel.
- Dedicated telecommunications applications that increase vehicle loads and save trips by consolidating freight loads and expanding traveler ride sharing.
- Interactive educational, shopping, and entertainment services, and more television channels with movies on demand, that may convince more consumers to stay home rather than traveling to the mall or theater.

Telecommuting is only a small part of a large and expanding set of processes that govern how the telecommunication infrastructure makes an impact on transportation. Present and future telecom applications in health care, public education, government, and manufacturing offer opportunities for general societal benefits that are more significant than travel savings, while keeping or enhancing quality of life compared to without this specific application.

In public education, local teaching and learning can be enhanced by telecommunications providing access to people and information in the next county or on the other side of the world. Telecommunications is also a key resource for extending learning environments into homes, offices, libraries, and community centers.

Modern manufacturing processes increase the responsiveness of production to the immediate needs of purchasers. Raw materials and finished products are put into computer-coordinated shipments monitored by telecom-enabled location tracking systems, reducing dependence on large inventories in warehouses and storerooms.

A closer examination of the U.S. experience over the last few decades does not reveal a natural evolution of telecommunications substituting for travel (Niles, 1994). As telecommunications volumes build independently of direct substitution for transportation, an opposite effect occurs, i.e. travel stimulation. A number of distinct stimulation effects can be identified (Niles, 1994):

- Telecommunications causes economic growth, productivity improvement, and income growth at the individual, organizational, and societal level.

- As the economy grows, the use of telecommunications expands the number and geographic scope of economic and social relationships in which people and organizations engage.
- Telecommunications permits geographic decentralization of residential settlement, and of organizational activity locations and thereby leads to higher travel consumption.
- Telecommunications enables rapid response systems that dispatch customized vehicle trips to meet personal and organizational needs, e.g. just-in-time logistics, home delivery of fast food, overnight package delivery, etc.

The different telecom applications illustrates the ecoeffectiveness dimension of environmental performance. Recent achievements in technological development makes it possible to increase the capacity of the telecommunication infrastructure. This in turn give room for new innovative products and applications which utilizes this capacity for the delivery of new and redesigned services. However, as the demand for services increases, and makes room for other activities which increases environmental load, the overall environmental benefit becomes marginal.

Interpretation of the separation in space-principle

The ultimate goal of designing product as described in chapter 5.4, was to develop products without the use of materials, etc. The separation in space must here be understood as although one object cannot have two different or opposite properties simultaneously, the introduction of technical means can contribute with functions which apparently satisfies both properties. This involves the purchase of a function or service from outside the organization. The function is delivered without the use of the means of the organization's own resources.

As for the separation in time principle explained above, when utilizing the separation in space principle, it is important to understand that the design activity is still a synthesis activity and the separated elements of the product life structure must be synthesised into a new whole, but in a different way which provides a significant improvement in environmental performance.

5.4.6 Separation in structure and between parts

Separation in structure involves breaking up the structure of the product system, and putting it back together differently.

Car sharing is an example of using the separation in structure principle in addition to the description above. The separation here involves separating the link between the technical- and the social system. Separating ownership of the product from the customer is the essential principle for introducing the transition from a product based business to a service based business. This strategy can be used on the variety of products which are present in each household and which are not in continuos use.

Separation in structure on the product structure and component level is through modularization. Modularization and the development of product programs are essential elements in design for environment keeping in mind issues such as recyclability, serviceability, ease of disassembly, refurbishing, etc. Separation of structure involves separating components of the whole products into a modularized design. Ishii (1998) describes the importance of modularity in product life-cycle engineering. Modularity is important due to customer demand for variety and need to respond to technology changes and other flexibility requirements.

The product development activity at the bottom line, measured by its ability to meet all customer needs. Olesen argues that the performance of product development activity is measured by the universal virtues as described in chapter 3.9.2 (Olesen, 1996). The dilemma for industry is that customer needs and wants are not uniform, but vary independently of each customer. Thus companies try to achieve competitive advantage by satisfying these varying customer criteria through offering a spectrum of models and variants of products. Variants may in some cases differ only cosmetically, but may also have completely different qualities in functional areas (Aasland et al., 2000).

Companies keep themselves alive by satisfying customer needs and wants. However, offering product variants also has some consequences for manufacturing where the streamlined series production is affected. Furthermore, they want to reuse designs, documents process plans, spare parts catalogs, etc. This strategy also offer other favorable effects, such as reduction in storage, administration, and thereby reduction of cost. The production of a mixture of models and variants makes efficient production difficult. From a production point of view, variants are unwanted, fostering efficient series production of as few as possible products. However, this may affect customer satisfaction (Aasland et al., 2000).

One solution to this contradiction is the is the creation of production friendly product programs where the structure of the product appears as one single product from a production point of view, but as a variety of models in the market. The essential property of a efficient product program is reuse. This involves reuse of components and modules between different variants, but may also include reuse on other levels such as design specifications and other documents, calculations, solution principles, maintenance procedures or transport solutions including packaging (Aasland et al., 2000).

Modularization of a product increases its ability to be manufactured and assembled in steps in smaller parts. Increased use of modules in a product family strengthens this effect due to the fact that modules are used in several variants. In addition to these advantages, increased use of modules opens up for a great increase in the degree of reuse. Reuse means that something repeats itself within the structure of a product and in different variants and models of a product. This can be

- complete units, i.e. function and assembly modules
- groups of parts, i.e. part modules
- solutions, i.e. scale modules
- steps of the production process, i.e. process modules
- design elements
- user interface

When a product has been modularized, it is natural to expand the standardization of elements to not only include components, but standard modules as well. Extensive use of standard modules represents a compromise between the market's demand for one-of-a-kind products and the manufacturer's demand for one standard product manufactured in large numbers. Modularisation thus is a means for developing product variety without manufacturing complexity.

The different classes of modules above, are identified from a design and manufacturing point of view. Modularisation based on these principles may also be beneficial from the view of service and maintenance and the view of de-manufacturing which involves disassembly. This pushes the utilization of reuse even further. Reuse in this sense also means

- reuse / refurbishing of modules,
- reuse / refurbishing of components
- reuse / refurbishing of parts
- recycling of materials

Developing a completely new car model is a very expensive project. Motivated by cost savings, car manufacturers today develop models based on the same platform, either within the company or through alliances with competitors. The platform consist here of a physical building group, often the frame combined with suspension and transmission modules.

A product platform is the collection of assets that are shared by a set of products. These assets can be divided into four categories (Robertson and Ulrich, 1998):

- *Components:* the part designs of a product, the fixtures and tools needed to make them, the circuit designs, and the programs burned into programmable chips or stored on disks.
- *Processes:* the equipment used to make components or to assemble components into products, and the design of the associated production process and supply chain.
- *Knowledge:* design know-how, technology applications and limitations, production techniques, mathematical models, and testing methods
- *People and relationships:* teams, relationships among team members, relationships between the team and the larger organization, and relations with a network of suppliers.

Taken together, these shared assets constitute the product platform. Generally platform products share a significant if not majority portion of development and production assets. In contrast, parts standardization efforts across a set of products may lead to the sharing of a modest set of, but such a collection of shared components is generally not considered a product platform (Robertson and Ulrich, 1998).

Successful platform planning offers the following potential benefits (Robertson and Ulrich, 1998):

- *Greater ability to tailor products to the needs of different market segments or customers*. The incremental cost of addressing the specific needs of a market segment or of an individual customer may be reduced through the platform approach, enabling market needs to be more closely met.

- *Reduced development cost and time.* Parts and assembly processes developed for one model do not have to be developed and tested for the others. This benefit applies to new products developed from the platform as well as to subsequent updates.
- *Reduced manufacturing cost.* Economies of scale may be achieved when producing larger volumes of common parts.
- *Reduced disassembly cost.* Product programs that share the basic components, manufacturing processes and hold the knowledge required for manufacturing and assembly, will have the same benefits when these products are returned for recycling. They can be treated in a similar manner, and return for reuse of components and parts, remanufacturing of subsystems or recycle materials. Economies of scale may be achieved at high volumes.
- *Reduced production investment.* Machinery, equipment, and tooling, and the engineering time to create them, can be shared across higher production volumes.
- *Reduced systemic complexity.* Cutting the number of parts and processes can cut costs in materials management, logistics, distribution, inventory management, sales and service, and purchasing.
- *Lower risk.* The lower investment required for each different product developed from a platform results in decreased risk for each new product.
- *Improved service.* Sharing components across products allows companies to stock fewer parts in their production and service parts inventories. This translates into better service levels and/or lower service costs.

The standard for minimum acceptable product development performance is high and rising fast in many industries. It is no longer possible to dominate large markets by developing one product at a time. Increasingly, good product development means good platform development.

To do platform development well, a company must carefully align its product plan, its differentiation plan, and its commonality plan through an iterative planning process (Robertson and Ulrich, 1998). The planning must be a cooperative process involving all groups and guided by top management. Just as good product engineering involves up-front consideration of manufacturing issues, good platform planning requires up-front consideration of design and manufacturing issues. Platform planning is difficult: teams may achieve high commonality but fail to differentiate the products; teams may differentiate the products, but create products with excessive costs; or teams may create viable platform plans that are subsequently never realized.

Ishii (1998) presents a design approach to analyze and implement a modularization of the product structure. Modularity in product design affects every stage of the product life span. Supply chain factors influencing modularity include outsourcing strategies and postponed differentiation.

Integrating manufacturing considerations in the product development phase address assembly efficiency and component complexity. The degree of modularity of a product also affects serviceability and recyclability in terms of disassembly, separation, repair, reprocessing in addition to component / module replacement or upgrading.

Ishii presents a methodology for analyzing modular product architecture for overall life span efficiency. He introduces a set of metrics and design charts that aid in enhancing life span modularity of product families and programs. The charts can aid designers in grouping subassemblies by identifying (Ishii, 1998):

- core platforms,
- flexible modules
- mating interfaces.

Ishii argues that designers should keep the features that require flexibility in small chunks and standardize other core functions (Ishii, 1998). Here the consumer and the manufacturer would benefit from differentiation in component design life. This may involve developing ling-lived core platforms with wear parts or modules with shorter design life. This give room for replacement of wear parts etc., without replacing the complete product.

Designers should furthermore measure and analyze the modular architecture against three evaluation charts that relate design attributes with life span complexities (Ishii, 1998):

1. The modularity evaluation for manufacturing plots part commonality against lead time.
2. Service modularity measures service complexity vs. frequency of service and maintenance.
3. Recyclability chart plots sort complexity against material recovery.

The modularization charts visualizes the relationships between product characteristics and their consequence on the future meeting between the product and product life system.

Designing a product architecture through modularity is especially important for products that have their main contribution to environmental load during the use phase through the consumption of energy. Here there can be a large benefit potential where an upgrading of e.g. the electric compressor of a refrigerator, the heating element of a heating device or even the engine of an automobile. This replacement can contribute to replacing old- with state-of-the-art technology. This will thus secure that the highest available efficiency is utilized in the energy consuming elements of the product.

A company which have made extensive use of the modularization philosophy to manufacture product with a high environmental profile is Xerox with their ecoserie copier. The platform here are vital elements of the product with a design lifetime of up to 100 years. Rank Xerox started in 1968 with dismantling of their copying machines and recycling parts. This approach developed into a system for chain management, in which the total logistic and technical process is aimed at recycling of the copying equipment and supplies. Up to three quarters of the components can be reused and some parts can be recycled up to 98%. All existing and reusable components are tested and if they meet the same criteria as those for new components, they are used again in the Xerox ecoserie copier.

These products are covered by a guarantee if the user takes a full service maintenance agreement. This commits Xerox to replace the product with an identical or similar model free of charge if the user is not fully satisfied with it. Used copiers are dismantled at a disassembly plant. Parts are tested and selected for re-use. Worn out parts are turned into scrap and used as raw material for producing new parts. A new copier is assembled from reused parts, (partly) recycled parts and new parts. The resulting ecoserie copier is according to Xerox, completely equivalent to other new copiers, as it meets the same specifications and it is tested in the same way. The copier is delivered to the customer in reusable or recyclable packaging. The packaging material is taken back by the service field engineer.

On top of this system customers can take part in the chain management for supplies. This additional customer relationship ensures improved reuse and recycling of supplies and used machine parts. Used toner cartridges are taken back by Xerox, where they are thoroughly cleaned and reloaded with consumables. Parts are replaced where necessary. As a result, the reproduced cartridges have exactly the same quality as a new one (Hegeman, 1997).

This system shows that it is possible to design complicated products in a way where a large part can be reused or recycled. The take back of a large number of machines is furthered by leasing the machines in stead of selling them. The additional maintenance service improves the reuse and recycling rate of supplies and used parts. The guarantee agreements ensures the user the quality of the output of the machines. Besides, such an modularized product structure ensures that the different modules and components containing old technological solutions can be replaced when improved solutions are found, i.e. solutions for energy utilization, paper handling etc.

The Xerox example illustrates that such a shift towards integrated chain management (including suppliers and consumers) and more service in stead of just selling a product can also be applied to other complicated products.

Interpretation of the separation in structure and between parts-principle

The ultimate goal of designing product as described in chapter 5.4, was to develop products without the use of materials, etc. The separation in structure and between parts can here be understood as once the product is manufactured, it will not disappear unless it is deteriorated by wear, natural processes like corrosion, or scrapped by action. As it does not disappear, the materials and their shape (parts and components) can actually be utilized again.

It can also be interpreted as separating a whole into an organized subdivision of this whole, i.e. into a product structure through modularization and product platform planning. Modularisation and product planning plays an extremely important role in preparing products for disassembly, reassembly and reuse.

This is an important finding for the development of loops for component reuse. Resources for recycling of materials can thus be utilized for other means. However, reuse of components and modules, require comprehensive testing to meet the required specifications as for virgin components.

This is a lacking attitude in our today's throw-away society. Reusing and recycling of parts, components, modules apart from recycling materials represent a psychological inertia which must be surpassed to give room for a market for reused parts and components in addition to recycled materials.

The design activity is still a synthesis activity. The separation principle and the separated elements of the product life structure must be synthesised into a new whole which provides a significant improvement in environmental performance.

5.5 Developing product-service combinations

5.5.1 Introduction

To achieve global environmental goals, the efficiency of the production system must rise substantially. However, since all gains from efficiency can be overcompensated by unlimited growth of consumption, sufficiency strategies should be pursued: people and service providers alike can learn to generate more satisfaction from each service unit so that people more enjoy a less material way of life.

The idea behind the rise of the service efficiency is to reduce the material throughput of the economy without losses in the overall availability of service units in the domain of consumption by utilizing the service capacity of material stocks to a higher degree. This can be achieved by the substitution of short-lived by long-lived goods and the substitution of the purchase of material goods by eco-efficient services (Wuppertal Institute, 1996). In these cases one service unit requires regularly less energy and material than in the conventional way of use. This means that here the use pattern will change over time.

Services can help to decrease the use of material and energy resources, depending on how product/service alternatives are designed, implemented and delivered. Only services which reduce the environmental impact of (part of) the entire system and improve the quality of living are desirable. The objective of the service should be sustainable in itself or clearly contribute to sustainable development. Special emphasis should be given to customer response and repeated satisfaction.

It is difficult to go around a tradition of ownership, security, aesthetics and self control. A service economy will only be feasible if virtual possessions/services are made more attractive. However the various risks associated should be taken into account such as (Hoogerwerf, 1996):

- people tend to care less for products they do not possess;
- the increased disassociation from the physical, natural world;

- rebound effect (money saved may be spent on non-sustainable goods).

Verbeek (Hoogerwerf, 1996) find it useful to define products or 'devices' as objects consisting of part machinery -the technical components that are responsible for its functionality-, and part commodity, the service they provide to users. Over recent times there has been a gradual shift towards the commodity aspect (Ethernally Yours, 1996).

Verbeek claims that the machinery-part gradually disappears into the background and the abstract functionality becomes the primary issue. Verbeek claims the shift towards 'commoditiness' causes a decrease in user engagement and weakens the bond between users and products (Hoogerwerf, 1996). This is supported by Michl who argues that a focus on the basic needs, wants and functions are potentials for solving the problems of environmental effects (Michl, 1991).

As competition between companies within all industrial areas, which often provokes a continuos price cut and continuos efficiency improvements, companies try to find alternative ways to keep customers linked to the company by bringing other values than merely the price factor (Hoogerwerf, 1996).

Strategies to develop life-long customer relationships which brings a loyalty feeling are becoming common within more and more industrial areas. In this sense, the service approach fits neatly, and is getting more and more important.

5.5.2 Service characteristics

To be able to explain different aspects of services it is important to define the core issues of services. The diversity of both activities and businesses encompassed under the service sector makes an all embracing definition of what a service is difficult. For example, some services are consumed at the point of production (i.e. restaurant meal) and that the item takes a non-material form (i.e. live theatre) whilst others are not consumed at the point of production (i.e. take away meals) and take a non-material form (i.e. software). However, a practical definition of a service is

> *a service is what you can buy or sell, but you can't drop it on your feet*

described by (Hoogerwerf, 1996, Te Riele et al., 1998).

This definition is also in line with the discussion above on the line of evolution where the recipient of the desired function is distanced from the technical system, i.e. his meetings with the product system is reduced to merely procurement and utilization of the product whereas the normal meeting points for a customer involves sale, utilization, maintenance and repair and collection (See Figure 3.13).

Kotler (1991) proposes the following definition of a service:

> *A service is any act or performance that one party can offer to another that is essentially intangible and does not result in the ownership of anything. Its production may or may not be tied to a physical product.*

The element of intangible is also included in Kotler's definition. In addition the important element of ownership is included.

Manzini (1997) proposes a more comprehensive definition of a service and product-service combination:

> *Service: the direct supply of the activities of some individuals or organization (the provider) for the benefit and the satisfaction of other individual or organization (the user). The relationship between providers and users is direct: they have to interact face to face, sharing the same time and, traditionally, the same place (with the diffusion of telecommunications technology, this second feature may not be necessary)*
>
> *Product-service: an integrated whole of mutually dependent products and services. Every product, in order to exist in the market and be used, may need some services. And vice versa: every service, in order to be provided, may need some products. In these cases, what we usually call "product" or "service", in reality, is a product-service. In the recent evolution of the system of production and consumption, products and services are more and more clearly conceived as product-services.*

Here the product and service is set in a holistic perspective as all products (except from the singular use product such as paper cup) need some kind of maintenance and repair during use (glasses needs washing). This is important as all products can basically be transformed into product-service combinations, but not all services can be transformed into these such. The motive for developing product-services based on products is often the fostering of customer loyalty.

Goedkoop et al. (1999) claim that *product* and *service* appear no entirely separated fields but rather two poles of the same axis called means for adding value.

The relationship between products and services can be clarified by making use of the different phases of theproduct life span. The meeting between the product and product life phase system leads to what Goedkoop et al. (1999) call the Product-Service Cross. Here, along the life span, the product go through a specification phase, sale, production, distribution, installation (set-up), use, maintenance, repair, update (function extension) and the end-of-life management. Synchronously, services are designed as well, tools are made for them, they are tested and redesigned, although the character of the creation process differs from the product creation. Table 5.1 shows examples of services.

Table 5.1 Examples of services

Product-Service Examples
• Software programs are intangible and is a service although you can touch the floppy-disc or CD-ROM. The CD-ROM is a product supporting the service. • A tailor made suit has more to do with service than just some pieces of cloth • Telecommunication is a service, where the operator arranges communication services, and where telephone exchange nodes, -networks and -receivers are objects to support the service. • Insurance companies and other financial organizations are often talking about 'their new products', which is basically a service

Furthermore, Hoogerwerf (1996) states that separation can be made among services themselves, i.e. between standard and customized services.

Standard services are services where the desired function is completely fixed. The customer has no influence on the output, apart from his decision on wether or not he finds the output from the service to meet his needs.

The individual needs and wishes of the customer are taken into account even before delivering the service. None of these services is twice the same. Trust in the capabilities of the supplier is the most important. During development of the solution, interaction between client and supplier will take place (Hoogerwerf, 1996).

Verbeek argues that the distinction between standard and customizable services is important in the development of successful services, and that the development of services are different compared to development of products (Hoogerwerf, 1996).

Verbeek (Hoogerwerf, 1996) studied 14 new, innovative services in the field of Information and Communication to find out the essential steps for successful service development. Based on the study, Verbeek presents a process for designing services (Hoogerwerf, 1996). The essential part of Verbeek's study is that a comprehensive investigation of customer needs are essential. Apart from the service, the company delivering the service also has to develop a system for the delivery of the service. It is therefore essential to know how the customer will react to how the service is delivered, and what he is willing to pay for or what action he is willing to take to acquire this service himself. This means that the distinction between products and services by only tangibility may seem too simple.

Goedkoop et al. (1999) distinguish four different categories describing a product service combination as shown in Table 5.2.

Table 5.2 Four categories describing a product service combination

Four categories describing a product service combination
1 Services are added to products. Example: Service and maintenance contract when buying a car.
2 A service provider can add products. Example: A mobile phone operator can supply GSM telephones to their customers Example: A bank can set up an ATM-machine for their customers to give access also outside opening hours.
3 Products and services are developed in combination to provide their interdependent function fulfilment. Example: Training systems for complicated products.
4 Innovation can take place by changing the whole system, substituting a Product-Service system by an improved system.

The discussion above combine into a set of characteristics which can be used to describe a service as shown in Table 5.3 (Lamvik et. al, 2000)

Table 5.3 Set of Characteristics describing a service

Characteristics describing a service
• Services are usually composed of a group of technical systems. These systems are part of the physical infrastructural setup of a service and could either be dependent or independent of each another. Technical systems are often operation ready and runs in the "background" even during a non-event. • The same infrastructure should support more than one user at different times. • Users usually have no ownership of the whole or components of the infrastructure. • Buying access to the functionalities (instead of products) of the service infrastructure is the key to the delivery of a service. • A service is short lived. The normal economic benefit for the service deliverer occurs when he satisfies the customer in a way which makes him come back for more. • Product-service combinations appear to undergo simultaneous production and consumption

A service provider is dependant on that customers return regularly. A producer producing a long-lived product is likely to be not so dependant on a returning customer. Consequently, a service provider must have a much clearer focus on customer needs and wants than a product provider.

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Based on these characteristics, four generic types of services are identified and shown in Table 5.4 (Lamvik et. al, 2000)

Table 5.4 Four basic types of services (Lamvik et. al, 2000, Low et al, 2001)

Four basic types of services
1 *Subcontracting services within the supply chain.* These services are usually subcontracted to other companies by the OEM in the process of manufacturing a product. This can be procuring complete subsystems or subassemblies which were normally produced or assempled inhouse, but is now aquired from outside the OEM.
2 *Third party services.* These are services organized by a third party whose products are usually not returned to the OEM at the EOL. (i.e. washing machines in a launderette service)
3 *Producer managed services*. These are services promoted by the OEM where products are returned for EOL management.
4 *Services on top of products or products on top of services.* This is a cross between (2) and (3) where a maintenance/upgrade activity is offered by the OEM or third party service provider for an agreed period of time, but the products are usually not be returned to the OEM at EOL.

5.6 Trends matching the product-service combinations concept

The product-service combinations concept matches with global trends in consumption and production, as well as in government policy making (Goedkoop et al., 1999).

For *consumers* today is the era of mass customisation. Fast delivery is demanded from producers, retailers, logistic service providers, and other players of the value chain. The client is regarding product and service as two parts of the same commercial deal, thus erasing the borderline between product and service (Goedkoop et al., 1999).

Product industry adapts with increasingly flexible production networks. Lean organisations serve quickly changing individual's preferences. Increasingly, the production chains are directly steered by actual market demand. In the sector of durable goods, it is already quite common that the consumer decides which products are being made and the actual time of production. This is a major shift from the situation in the past where the producer made these decisions alone. Services are regularly brought in, to bridge the gap between production infrastructure and individual demand. Services can contribute in improving the relation and communication between manufacturer and individual customer (Goedkoop et al., 1999).

Global competition puts the product industry under severe pressure to shorten the design, development and production time. The adequate use and introduction of new information and communication technology in industry is indispensable for surviving in this competition. The sequential introduction of new models and software induces a new need for assistance, training, update and take-back services (Goedkoop et al., 1999).

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Service industry makes more and more use of hard- and software to raise service level or to reduce costs. Efficiency will pay, as in Western economies personnel is expensive. Although automation of mass-services will eliminate people's jobs at first, the automation quite often results in a loss of personal contact. New ways to preserve the relationship with the individual client are needed. In traditional services competition is increasing. Margins are under pressure so new concepts are needed. Product-service combinations can offer new and stable markets for specialised service providers (Goedkoop et al., 1999).

In environmental policy, policy documents refer to the need for combined change of production and consumption habits, and several researchers announce the need for system changes (Goedkoop et al., 1999).

5.7 Contribution towards improved environmental performance by product-service combinations

The main contributions from utilization of product-service combinations are from dematerialization and shared use of resources (Gardner, 1999).

5.7.1 Ecoefficient services

Ecoefficienct services are services which have an environmental and economic benefit compared to an equivalent group of products and activities. For example, most personal cars spend most of their lives parked, taking up space and not utilizing their primary function, i.e. transporting people. The average car in the Netherlands is used for only one hour 12 minutes per day being unused the remaining 23 hours (Gardner, 1999). This kind of use of production means is neither efficient nor effective.

If cars are shared by a neighborhood or a community, the car is utilized more efficiently. Furthermore, the number of cars on the road simultaneously would decrease. However, efficiency benefits may not significantly reduce the number of cars manufactured, as each car is used more than a equivalent privately owned one, and may need replacement more often than one with a shorter daily millage. However, there is reason to believe that provided the vehicle is maintained sufficiently, the car may have a longer technical life than an average privately owned, as they are often disposed due to other reasons than merely daily wear. On the other hand, the sharing reduces the number of car dependant people which in the longer run can reduce the number of cars produced (Gardner, 1999).

The environmental and financial benefits of car sharing are their major assets, but car sharing can also strengthen community ties by fostering a sense of shared interests in a more viable community.

Car sharing is by no means a substitute for the everlasting goal of making each car more efficient and in the long run eliminate the gasoline-powered engines. The car sharing is an activity enhancing the eco-effectiveness of a transportation system.

Many researchers support the approach of improving environmental performance of products and product system by replacing material goods by services. However, there is a question wether or not this approach significantly contributes to improvements, and how the introduction of a service economy affects other stakeholders.

Modelling Sustainable Europe

The project “Modelling Sustainable Europe” (SuE) (Wuppertal Institute, 1996) was designed to supplement existing European initiatives towards forecasting economic and employment trends with a broadened and deepened intellectual framework in order to put short term economic developments in perspective with the long term goal of sustainable development (Wuppertal Institute, 1996). SuE was the first system dynamics model of the EU 15 (European Union with 15 members in 1996) economy not based on financial, but on energy and material flows

The core purpose of the simulations was to develop and to apply a tool to improve the information basis for decision makers, enabling them to take the kinds of side effects and rebound mechanisms into account. Results give at least hints at the most socially conscious policy towards sustainable economic development (Wuppertal Institute, 1996).

The simulation model was designed using system dynamics, or deterministic linear dynamics. The goal was to design a model to act as a tool to help identifying opportunities on the macro level, identify winning sectors and win-win-strategies (Wuppertal Institute, 1996).

The model was aimed at delivering policy decision support through different scenarios and their comparison. For details on the background of the model and further details, see (Wuppertal Institute, 1996):

The ecoefficient services scenario

One of the scenarios tried to estimate the effect an increasing ecoefficient service sector would have on the economy. The ecoefficient services scenario focused on the efficient use of goods instead of efficient production. It was based on the assumption that a similar consumer satisfaction and thus standard of living can be generated from permanently maintaining and upgrading a high quality good as from purchasing a new one after only limited use time, and from substituting goods for services (Wuppertal Institute, 1996).

This ecoefficient service sector scenario was simulated by manipulating one parameter of the model (preferences for material goods) to trace the economic and ecological consequences of changing consumption patterns towards a more sustainable consumption (Wuppertal Institute, 1996).

A first simulation run assumed that the market share of long-lived goods slowly increases up to the year 2015, and that as well 10% of material goods purchases were substituted by services. Taking these into account, an acceleration in the growth of living standard shows up. However, the CO_2 emissions, to be reduced according to the EU proposals presented in Kyoto, instead do increase by 110% (as compared to 140% in the business-as-usual scenario). The scenario obviously works towards the right direction in a number of aspects, however without generating sufficient results (Wuppertal Institute, 1996).

A new scenario was therefore established in a top-down manner in order to identify the measures necessary for significant effects. Pushing the increase in service efficiency high enough that a relative reduction of throughput compared to business-as-usual can be achieved, it turns out that the reduction in normal good is significant (about 20%), but even more significant are the increase in durable goods and eco-efficient service provision, which together provide as much services by 2015 as the total consumption did in 1985. This becomes much more dramatic, if we go for an absolute reduction as compared to current levels of throughput (Wuppertal Institute, 1996).

All in all, the simulated situation showed to be unsatisfactory in that the radical scenario seemed to be the most promising one concerning its environmental and labour performance, but the model seemed to lack the ability to handle the details. On the other hand, the less radical scenarios did show, that changes of consumption patterns that lead to a rise of the service efficiency of a factor of 1.6 in 31 years should be enough to break the growth trend of an overall ecological indicator like CO_2 without doing the same to the economic system (Wuppertal Institute, 1996).

The basis for the modelling of global industrial structures in the “Limits to growth” showed similar results. An approach utilizing business-as-usual, draws a very bad picture of the future. Although a transition towards replacing material goods for services indicates only minor contributions, it can be a promising start. There is however reason to believe that the modelling of the effect ecoefficient services may have on the economy modelled by a single parameter is too simple. The SuE project team calls for ecoefficient services and long-lived goods, claiming that long-lived goods can contribute towards dematerialization. The environmental performance of long-lived products is largely dependant on the product at hand. As described in Table 5.5, products which consume energy during utilization is likely to have their largest contribution in the utilization phase of its life span. An automobile has 85-90% of its environmental load during utilization (SAE, 1995). Furthermore, an old automobile has higher emissions than a brand new one. Thus a long-lived automobile has no beneficial contribution for reducing emissions. If the engine of the automobile could be replaced by a new one keeping the body of the car, the car would use state-of-the art combustion technology, this car could not emit more waste gases than the new car. Consequently, by building a product structure with a long-lived core platform and a modular approach for short-lived subassemblies and parts, these would be easily replaceable and keep up with technological evolution.

Consequently, indications that a strategy for introducing ecoefficient services will contribute towards sustainability is present. Long-lived goods, products and services however, seems to be a promising approach when utilized in a creative way.

Quantitative assessment of product service combinations

Goedkoop et. al. (1999) propose tools to assess the potential of product service combinations. The product service combination can sometimes only be compared with a set of individual products and services that have the same combined functionality to the consumer which makes a comparision difficult. By making the comparison, the relative strengths and weaknesses of the product service combination on each of a four axis model is explored (Goedkoop et al., 1999).

The four axes are (Goedkoop et al., 1999):

- *company identity and strategy*
  To which extend does the product service combination match the company's identity and strategy?
- *customer acceptance*
  To which extend would the market accept the product service combination?
- *environmental load*
  What are the environmental characteristics at function fulfilment level and how do these relate to overall environmental load on society?
- *economic potential*
  What are the economic characteristics at company level, and at the level of the business sector?

Quantitative assessment of the two axes environmental load and economic potential are possible to perform. However, the axes “company identity and strategy” and “customer acceptance” are much more difficult. Individual expressions of emotion, experience and instinct play an important role in these two axes and are virtually impossible to quantify. In stead Goedkoop et al. propose to use these axes as go / no-go criteria when contemplating the introduction of a new system.

Based on the Profit pool concept described by Gadiesh and Gilbert (1998) Goedkoop et. al. developed a quantitative approach for assessing the environmental and economic issues of product service combinations.

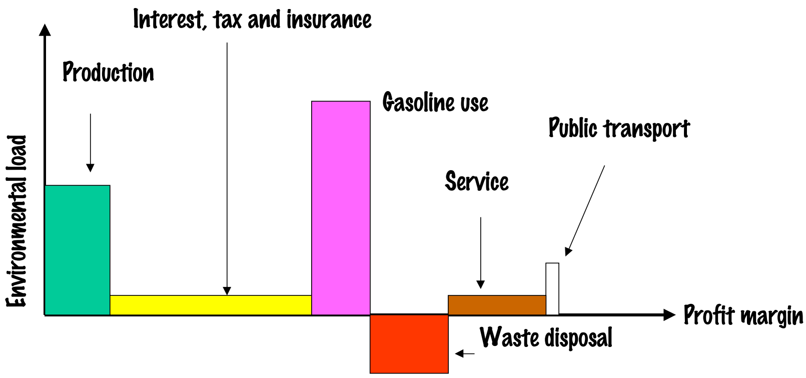
The key of a profit pool analysis is the composition of a graph in which all relevant commercial activities in the business area of a company are plotted. A profit pool analysis involves identifying and selecting the activities of the value-creating pool. The activities may include the whole value creating chain (from product cradle to grave). The volume and financial contribution of transactions must be estimated for each value creating activity. This will result in the total value created by all activities in the pool, and the (estimated) value creation of the individual products and services. Profits generated from each activity must be estimated. This results in an estimated total profit realised within the pool, and in the estimated profit of each product and service (Goedkoop et al., 1999).

The profit of each activity can be presented graphically through the value creation per activity on the horizontal axis and the margin in percentage on the vertical axis. Comparison with a reference system will visualize which of both systems is most profitable and creates most profit and value, in the relevant parts of the lifespan. If a product service combination is developed by a strategic alliance of companies, the profit pool can also visualize the benefit from the contributions of each partner to specific parts of the valuechain.

Instead of using the traditionnal LCA methodologies as described in the ISO 14000 documents, Goedkoop et al (1999) propose a variant of the profit pool procedure. Environmental load is introduced along the vertical axis, and thereby assess economic and environmental issues in combination.

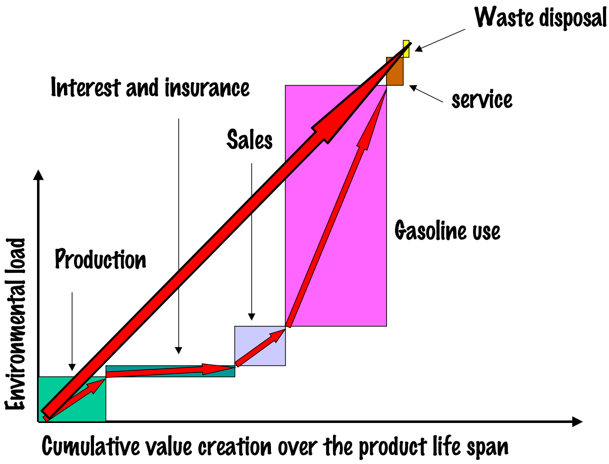
Plotting the environmental load against the economic profit in a single graph can visualize the potential to maximise profit at the lowest environmental load (Goedkoop et al., 1999).

Figure 5.2 Environmental load plotted against the profit margin for each product service life phase create along the value chain (Goedkoop et al., 1999)



To analyse the results, Goedkoop et. al. introduces an E2 (Economy-Environment) vector, based on the eco-pool and profit pool. Plotting cumulative value against cumulative envrionmental load and combining each product life phase in both directions, generates the overall vector, as illustrated in Figure 5.3.

Figure 5.3 Cumulative value plotted against cumulative envrionmental load and combined in both directions to generate the overall vector



Goedkoop et. al. argues that the angle and direction of the overall E2 vector explains the potential environmental and economic benefit when comparing the product service combination with a reference scenario (Goedkoop et al., 1999).

- Equal value with reduced environmental load will show benefitial overall results when introducing the new product service combination.
- Equal environmental laod with reduced value means that consumers will save money, which till be used for alternative consumption and thus increased environmental load. This situation visulalizes the results of the rebound effect.
- In a situation with incresaed value with slightly reduced envrionmental load shows that consumers are willing to pay more for the new consumption pattern, and spend less on other consumption. The net effect is that, even as the environmental load for the system itself remains constant, the overall environmental effect is positive as result of the reduced consumption.
- The normal situation is when products and services become cheaper and more efficient simultaneously. In such a situation the overall sustainability gain for society is determined by the angle of the additional alternative consumption vector in the new situation.

Thus Goedkoop et. al. (1999) argue that the steepness of the alternative consumption vector turns out to be a crucial factor. The vector is meant to show the effect of alternative consumption if a consumer gets more or has less money to spend. If the alternative consumption is less steep than the E2-vector of the reference system, we assume the overall environmental effect is positive, as is shown in next figure. If the alternative consumption vector is steeper, we will see an overall increase of the environmental load.

Goedkoop et al. (1999) apply the E2 vector to three case studies to show its applicability. The choice of the reference system, the functional unit and assumptions in the allocation of economic and ecological effects have important effects. Furthermore, the analysis is a static picture in time. When important changes occur (such as changing market situations or tax systems), new assessments are required. However, most fundamental problems include the analysis and modelling of the effects of the introduction of a product service combination on the actual changes of consumer behaviour, which the model cannot capture.

5.7.2 Dematerialization

Dematerialization is an important means for contributing to reducing global and local environmental load.

According to the results of Altshuller's investigations of patents, weight is naturally contradictory to the use of energy. This is not a surprise to anyone. However, Altshuller presents in the contradictory matrix four different solutions to this contradiction.

For product which are to be moved or transported at some time during its life phase, weight a critical parameter. Hanssen has presented five different generic product classes which are distinguished between which product life phase their main known environmental load is occurring (Hanssen, 1997). These product classes are shown in Table 5.5

Table 5.5 Generic product classes (Hanssen, 1997)

Product class	Description	Example	Main environmental load
1	**Products by chemical reactions in the use phase**	Paint, gasoline, food products etc.	Use phase
2	**Stationary products which don't consume energy on their own**	Office chair, cement products, etc.	Product manufacture including raw materials extraction
3	**Stationary products which consume energy on their own**	Electric motors, light bulbs, etc.	Use phase
4	**Mobile products which don't consume energy on their own**	Packaging products, etc.	Product manufacture including raw materials extraction / Use phase / Use phase of supersystem
5	**Mobile products which consume energy on their own**	Vehicle, ship, etc.	Use phase / Use phase of super system

Table 5.5 illustrates that products often don't need a detailed life cycle analysis to identify areas where attention should be focused. Several products also shows that their main contribution to environmental load lie outside the product structure itself, but occur during meetings between the product and product life systems.

Example: Mobile phone

Investigations of the mobile phone shows that the main environmental load contribution lie outside the product itself. The mobile phone of the late 90's is light (100-300g) and consumes small amount of energy. Investigations by (Low, 1998) shows that bringing a mobile telephone from England to Singapore, adds the contribution of extra fuel consumption by the airplane due to the extra weight, which is in the magnitude of 10 years use of the same telephone.

Small mobile electronic devices in general consume minimal amount of energy, and it is therefore reason to believe that these mobile products all will have a significant improvement of reducing weight.

Dematerialization is seen as a prerequisite for achieving an overall factor X improvement in environmental performance. Definitions of dematerialization vary, but in general, the concept refers to the absolute or relative reduction in the quantity of materials used and/or the quantity of waste generated in the production of a unit of economic output.

Cleveland and Ruth (1999) question the hypothesis that dematerialization through decoupling human economy from energy and material inputs is realistic and which may achieve a factor ten increase in environmental performance as some researchers argue (Factor Ten Club, 1997).

Analysts at the Wuppertal Institute have developed the concept of "material input per unit of service" (MIPS) to measure material resource productivity (Hinterberger et al., 1997, Schmidt-Bleek, 1994b). MIPS includes two types of material flows. Direct materials inputs are the natural resource commodities that enter the economy for further processing. "Hidden" material flows, or "ecological rucksacks," are materials removed from the environment along with the desired material and the material moved or disturbed in resource extraction or in building and maintaining infrastructure. Examples include waste rock from ore separation, plant biomass harvested in logging that later is separated from the desired forest product, overburden produced from a mining operation, soil erosion in agriculture, and dredging of waterways. MIPS is intended to provide an indicator of the potential for overall environmental impact from economic activity (Bringezu, 1997, Cleveland and Ruth, 1999, Schmidt-Bleek, 1994b).

Bringezu (1997) applied the MIPS methodology to the German economy, defining its material productivity as the ratio of GDP to the direct and hidden inputs of materials (the inverse of IU) (Bringezu, 1997, Cleveland and Ruth, 1999). The results from the study (Bringezu, 1997) suggest a possible decoupling of material input from economic performance.

Hinterberger et al. (1997) argue that MIPS is a good indicator of the overall environmental impact of economic systems (Cleveland and Ruth, 1999, Hinterberger et al., 1997). Hinterberger et al. (1997) claim that MIPS is the

> *only measure introduced to date that can be used to compare relative environmental demands, and which can be translated directly into the realm of economics (Hinterberger et al., 1997) (p. 8).*

Thus, they argue that MIPS is a reliable indicator of the efficiency with which materials are converted to GDP and of the impact that the mobilization of materials has on the environment.

Cleveland and Ruth (1999) believe that the MIPS concept is not comprehensive enough to fulfill these promises. Hinterberger and colleagues (1997) add all material flows together based on weight, whether they are tons of copper mined, tons of sediment eroded, or tons of CO_2 released to the atmosphere. They argue against the use of a weighting system to aggregate materials, claiming that they do not

> *see any practical and convincingly superior suggestion to weighting material flows in a more differentiated way (p. 9)*

Cleveland and Ruth (1999) argue that other indices are better, albeit imperfect, as methods of aggregation, and question Hinterberger and colleagues' claim for the potential factor of ten reduction in material intensity that they claim is supported by empirical analyses of MIPS (Cleveland and Ruth, 1999). Furthermore, Cleveland and Ruth claim that the so called decoupling not consistent with other research who suggest an ongoing strong link between material inputs and the economy (Cleveland and Ruth, 1999).

What Cleveland and Ruth seems to oversee is the postulate behind the MIPS concept, i.e. that

> *The majority of environmental effects can be traced back to the transfer of mass (Von Weizsäcker et al., 1997)*

The focus on weight is important for all activities which involves energy consumption for transportation. Studying the statistics (energy balances we see that the transportation sector worldwide utilizes 26,4% of total final energy consumption in 1995, up from 24,2% in 1985 (WRI et al., 1998). The data also shows that energy consumption in the industry sector is reduced from 40,7% in 1985 to 37,5% in 1995. Although the data do not show that transportation sector is the largest consumer of energy, transportation is a major contributor to energy consumption and thereby environmental load.

In the perspective of these findings, the focus reduction of weight of any artefact will reduce potential environmental effects caused by emissions from transportation.

The MIPS concept tries to visualize the amount of nature, in kilo or tons, which is consumed or made available for a specific benefit for the individuals in the society, through a service. Based on the background postulate which we may argue is inconsistent, this unit of measurement seems valuable to be able to compare different services and alternative routes. The product with the highest utilitarian value is also the best environmentally sound product, which means a low MIPS factor. A high MIPS factor represents a low resource productivity, i.e. a high environmental load (Schmidt-Bleek and Tischner, 1990).

Cleveland and Ruth misinterpret this concept when they believe this means that materials and economy are decoupled. The service is still the entity holding the need or want. However, the means to accomplish this need or want, usually a product, may be replaced by a new function which is supported by a means (a product).

Hinterberger et al. (1997) argue that no reliable system exists for aggregating waste material flows according to their environmental impact. But this does not mean that material intensity analyses approach is perfect. Apart for no reflection over toxicity, it is unclear to which degree an aggregate indicator based on weight conveys accurate and meaningful information about the level and trend in the ecological impact of society's waste stream. Just as weight often has little to do with why users choose one material over another, the environmental harm of a material often has little directly to do with its mass, unless it is transported over a distance. However, for a given waste, the same quantity released to different media and different ecosystems in different locations will have different impacts. Thus, a decline in the total mass of wastes released could be accompanied by no change or even an increase in ecological impact due to qualitative changes in the waste stream (Cleveland and Ruth, 1999).

As the move toward a sustainable economy will require a reduction in the material footprint of society. As the present global industrial structure is more or less based upon distributed manufacturing of goods and services, the overwhelming demand for transportation give an indirect environmental effect caused by this demand. The MIPS concept focuses on this issue and tries to capture the view of the basic potential for environmental effects, i.e. the need for transportation.

5.8 A strategy for developing intrinsic product-service combinations

5.8.1 Drivers for product-service combinations

Service providers as well as product providers can introduce product-service combinations. On a company scale, the new product-service combination should improve business opportunities. A strategy for combining products and services thus do not need to contain any element of environmental load and sustainability.

For product-oriented companies, adding services is done in order to (Goedkoop et al., 1999):

- escape from a commodity market
- create superior value for clients
- build up direct customer relations, to intensify contact or to increase contact frequency
- supply a total offer: product plus service element which could be lease, product upgrading, repair, take-back, refurbishing, etc.
- discourage newcomers by increasing the quality level throughout the value chain

- anticipate or respond to new or expected policy, legislation or fiscal measures

Thus, product-oriented companies can add elements which support cusomer loyalty, where the customers come back for more.

For service manufacturers, adding products is done in order to (Goedkoop et al., 1999):

- protect market share (most services can be copied in a wink)
- reduce costs (automation)
- extend service
- communicate innovations (hardware innovation is easier to communicate than an intangible innovation)
- lower the (financial) entrance threshold for new clients

However, introducing a product service combination may not be the correct strategy. The drawback may be greater than the benefits in the market. Some of the reasons for companies to reject a product-service combinations are (Goedkoop et al., 1999):

- the company's competitive advantage lie in technical knowledge and product quality control rather than in providing service or vice versa
- for a service provider, the company's competitive advantage lies in direct contact with the clients, not in automation or product infrastructure
- the company is not large enough to control the whole value chain
- the market simply does not accept the product-service combinations which the company naturally cannot ignore.

5.8.2 Eco-drivers for product-service combinations

Motivation for improving environmental performance, are additional drivers for companies striving for competitive advantage. Some drivers are generic for environmental improvements, but not necessarily drivers for product-service combinations.

Generic eco drivers

- improving image in the market
- regulation on extended producer responsibility
- health and safety management
- practising societal marketing principles
- published product tests
- costs reduction related to environmental load
- feeling responsible for the company's environmental load
- NGO and societal pressure
- green purchasing by authorities or consumers

In some cases specific drivers encourage the introduction of product-service combinations:

- legislation threat, client's wishes, feeling responsible, image building and competitor's dominance (for instance in case of take-back systems)

- servicing client’s environmental problems
- covenants with authorities
- green purchasing by authorities

As described in 3.7.1, Van Hemel (1998) found that in small and medium sized enterprises (SMEs), the drivers for Ecodesign success are merely internal stimuli (See Table 3.1). She shows environmental benefit, cost reduction and image improvement are dominant. Amongst external stimuli, although less important, market demands, laws forcing and supplier developments are most important. Goedkoop et. al. report that for innovations towards product-service combinations this last category is of much higher importance compared to the ecodesign innovations (Goedkoop et al., 1999).

5.8.3 Identity drivers

Not every company desires to combine services with products. Not every company is capable of combining them. Not every product-service combinations initiative is accepted by the surrounding network and the clients. Financial and eco-drivers are important, but identity issues like management style, company structure, employee properties and surrounding network characteristics play a key role too (Goedkoop et al., 1999).

A product organisation differs from pure service providers. A service organisation can fully concentrate on a positive client’s relation and satisfaction. Service organisations have a direct interface with end-users and therefore interact to a higher extend with the client.

At the end, a product organisation has the same goal, a satisfied customer. This is translated to a general strategy to make good quality products that meet the client’s expectation. Therefore, much attention of a product organisation is focused on the development, production and distribution processes in itself. Generally, product organisations make use of many suppliers, and are more oriented towards intermediate organisations like distributors and knowledge sources.

Goedkoop et al. (1999) report that the product life phases differ significantly from the service life phases. The innovation risks are different. Development lead times differ dramatically. Furthermore, staff and supporting systems are selected to contribute to different core competencies. They will be different, or at least will be used differently.

Generally, for service organisations management styles are highly based on commercial data and motivating people versus more skill and controlling oriented styles for product organisations.

This is a key element when extending a product into a product service combination. This leads to a strategy where network building and vertical integration can become more benefitial than to magnify the original organisation to include the service element.

Manzini (1997) argues that the short term strategy for sustainability have to promote solutions, and specifically a mix of products and services, to be implemented in the present or in the near future with the available technologies and in the contemporary socio-economic context.

Thus, Manzini (1997) sees the development of services as a means aimed at anticipating some local intrinsically sustainable solutions:

> *"the shift to a sustainable system requires a strategic design activity aimed at promoting" new services" in terms of practicable solutions; i.e.: as innovative (sustainable) product-services that could represent a socially acceptable alternative for the users and a new market opportunity for the producers"*

Manzini distinguishes between strategies for the development of product-service combinations (Manzini, 1997)

- **From products to (new) services**
  From a technical point of view services can improve the use of materials and energy and they can improve the use of information (and reduce consumption). From an economic point of view, the service economy pushes service providers towards the reduction of consumption for a given unit of service and furthermore, Manzini argues that only in the framework of the service economy can we imagine a flourishing economy in a context of decreasing materials and energy consumption. Besides, services can generate new social links and vice verca, relationships can generate new services.
- **Cleaner service development (CSD)**
  This is the traditional DFE approach where the service is analyzed within the framework of life cycle analysis and redesigning the service based on the recognized causes of environmental load. Cleaner service development emphasizes that also services have an environmental impact. They are often presented as “non-material entities”, which is wrong. Although it is true that some services present a low material and energy intensity (e.g. telecommuting,...), it is easy to verify that other services are highly material and energy intensive (e.g. travel services, medical services...).
  Furthermore, it is essential that the “service sector” also have to integrate the environmental issue in their strategies and have to start programs of cleaner services development, as the case have been for producers of products for some time.
  This is the traditional ecodesign approach where an existing product is redesigned to become more environmentally friendly. However, it remains an incremental strategy which do not contribute to sustainability.
- **Sustainable product-service development**
  This is a strategic design activity aiming at changing the supply/demand relationship on which the existing product service mix is based and involves a systemic discontinuity. The strategy requires some changes in consolidated habits while offering innovative solutions. The escape from the “business as usual” approach requires that business adapt to the market opportunities that a radical environmental improvement involves by redefining their business into their place in the intrinsically sustainable system (Manzini, 1997). This

implies all three dimensions of environmental performance: ecoefficiency, ecoeffectiveness and ecosufficiency.

5.8.4 Remarks from observations of product-service combinations

Three observations in industry represent the last and most promising category. These are

- Xerox ecoserie copying machine,
- Interface Inc. and their flooring system
- Electrolux's pay-per-wash system

All three companies have laid down ambitions environmental goals in their overall business strategy. In the case of Xerox this implies *zero waste from zero emission manufacturing plants*. In the case of Interface Inc. they strive to become *the first sustainable industrial enterprise anywhere*. In the case of Electrolux, the vision is *Lead the development of environmentally sound products and processes. Work to encourage demand for environmentally sound products*

As noted in section 5.4.6, Rank Xerox started in 1968 with dismantling of their copying machines and recycling parts. This approach developed into a system for chain management, in which the total logistic and technical process is aimed at recycling of the copying equipment and supplies. The Xerox ecoserie copier is built upon a product platform where vital elements of the product has a design long lifetime (of up to 100 years) (Ehrenfeld, 1998). The Used copiers are dismantled at a disassembly plant. Parts are tested and selected for re-use. Worn out parts are turned into scrap and used as raw material for producing new parts. A new copier is assembled from reused parts, (partly) recycled parts and new parts. The resulting ecoserie copier is according to Xerox, completely equivalent to other new copiers, as it meets the same specifications and it is tested in the same way. The copier is delivered to the customer in reusable or recyclable packaging. The packaging material is taken back by the service field engineer. Up to three quarters of the components can be reused and some parts can be recycled up to 98%. All existing and reusable components are tested and if they meet the same criteria as those for new components, they are used again in the Xerox ecoserie copier.

This system shows that it is possible to design complicated products in a way where a large part can be reused or recycled. The take back of a large number of machines is furthered by leasing the machines in stead of selling them. The additional maintenance service improves the reuse and recycling rate of supplies and used parts. The guarantee agreements ensures the user the quality of the output of the machines. Besides, such an modularized product structure ensures that the different modules and components containing old technological solutions can be replaced when improved solutions are found, i.e. solutions for energy utilization, paper handling etc.

The Xerox example illustrates that such a shift towards integrated chain management (including suppliers and consumers) and more service in stead of just selling a product can also be applied to other complicated products.

It also illustrates the need to both have a wisely designed product structure, and the need to have an infrastructure to establish the material flow both during delivery and take-back of products.

Interface Inc. is leasing flooring systems (carpets) based on nylon for office buildings. Flooring systems are supplied to buildings in squares. That is, the carpet is modularized into squares. When pieces of the carpet is worn out, they can easily be replaced by new ones. The worn pieces are returned to Interface for recycling. By-products from the production line is also recycled. Unfortunately, the technological processes are still not able to make carpets from recycled materials only.

Interface Inc. also relies on a modularized product structure, although not as sophisticated as the Xerox copying machine. Modularisation makes replacement of parts a real option, and can extend the product life significantly.

However, an excellent product service combination supporting ecological principles may not give sufficient economic benefit for the company. Recent results indicate that consumer acceptance of a ‘leasing carpet’-system is rather low and not resulting in the foreseen economic success (Ehrenfeld, 2001).

Electrolux installed a pay-per-wash system at the Gotland Island in Sweden, where customers borrows a washing machine at installation cost, and pays for the use of the washing machine. All machines have internet connection and allows for remote reading of use. The washer is connected via an “intelligent” electrical meter and the Internet to a central database that keeps track of consumption. The ownership to the machine is kept by Electrolux. Service is also Electrolux’ responsibility. When the machine has served its duty, it is taken back and can be scrapped, remanufactured or used as a source of spare parts

This example also illustrates the need for an infrastructural element ready for introducing functional sales. The infrastructure in the form of internet connection is used for measuring operation time. As Electrolux has full control of all elements of delivery, service and take back, this infrastructure is present.

As the visions of these three companies express, they have made a strong commitment to the idea of improving environmental performance of their products.

All three observations indicate that both the infrastructural element of the value chain and the modularization element of the product structure are important and must be established prior to take the step into the function economy.

Based on these three observations, there are indications that there are three issues which form the common denominator for developing product service combinations. The three observations emphasize three

These are

1 *A modularized design* where a product platform and product structure is developed to be prepared for disassembly and re-assembly which makes the product easy to take apart completely, but also prepared for partly disassembly for replacement of worn out subsystems or parts. This is utilization of the *separation in structure and between parts* principle.

2 *An infrastructure*. That is both an infrastructure which optimizes the material flow, and an infrastructure which optimizes the information flow. Strategic alliances through vertical integration aligns the two way material flow to render supply and take back of the technical means or product possible. The information flow is needed to track utilization of the product's functionality. The company supplying customers with the function, can track and compare the actual utilization with the service and maintenance plan, and replace worn subsystems and parts when needed. This is utilization of the *separation in space* principle.

3 *Control*. The control and ownership of the product is the key element for introducing functions to the customer. Ownership of the product is transferred from the customer to the producer or function supplier. In this situation, the customer hno longer has full ownership of the product, but procures access to the product's functionality when needed. This is utilization of the *separation in time* principle.

All these three activities makes a company able to deliver the function to the customer, replacing the delivery of the product.

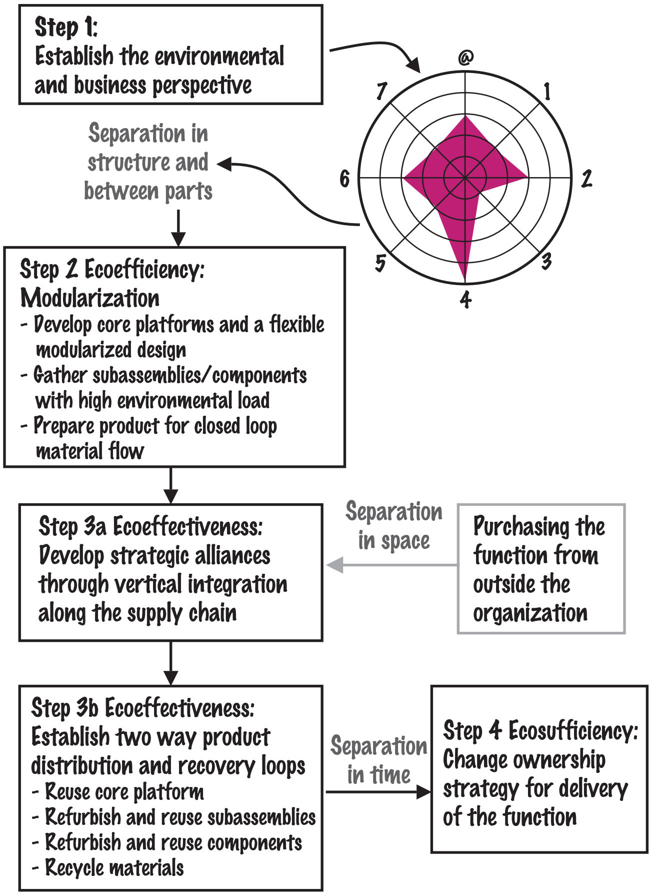
5.8.5 Strategy for leap improvement of environmental performance

As described in chapter 1.7.4, the intended effects of any actions is followed by an unintended side effect. The relationship between the two is regulated by the second law of thermodynamics, and so that the unintended side effects are unavoidable. The unintended side effects are the source of all environmental influences, and arise in all phases of the product life, i.e. product planning, product development, marketing, utilization of -materials, -manufacturing resources, -transportation resources, product use phase, product EOL-phase and reuse / recycling phase.

The intended actions of a company is to satisfy a solvent market by the delivery of competitive industrial products and simultaneously create sufficient earnings. The product delivers the primary function the customer see as his need or want which happens to be supported by the means, i.e. the product. The goal is to present a strategy containing principles and methods for eliminating, or at best reducing the unintended side effects of a product system which arise during all meeting between the product and the product life systems.

The proposed four step strategy is illustrated in Figure 5.4. Each step of the strategy is explained in detail below.

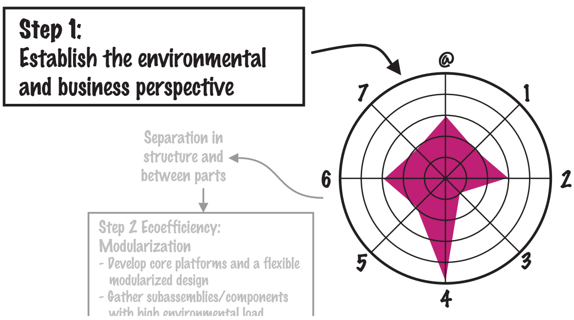
Figure 5.4 Four step strategy for developing product-service combinations



5.8.6 Step 1: Establishing the environmental and business perspective

Step 1 of the strategy involves establishing the environmental and business perspective, and is illustrated in Figure 5.5. A brief overview of this step is presented here. For details, reference is made to the most comprehensifve source, i.e. the EcoDesign Manual of Brezet and Van Hemel (1997).

Figure 5.5 Step 1: Establishing the environmental and business perspective



Establishing the environmental perspective

It is essential to be able to visualize the kinds of environmental problem a product can cause during its life span. This involves mapping the potential harmful elements of products and processes involved in the delivery of selected products. The most beneficial approach is to select a product from the company's portfolio and analyze this product with the goal of mapping important elements contributing to environmental load.

Another way to classify the different types of environmental problem is to break them down into geographical scale levels'. The higher the scale level, the more sources that contribute towards these problems and the longer it takes for the improvement to become perceptible. When tackling local environmental problems one often has to contend with a number of different parties. Global problems, such as depletion of the ozone layer, make it essential that agreements on the best solutions are reached at the global level.

Establishing the business perspective

From a business point of view, it is important for an enterprise to be able to anticipate environment-related social trends. Ecodesign has become part of the business agenda in many industrialized countries and increasingly in developing countries.

Motivation to implement ecodesign on the grounds of business economics can come from two different directions: from within the business itself (internal drivers) or from the immediate surroundings (external drivers).

Environmental requirements can be seen as a threat by one company and as an opportunity by another; one will focus on preventing a backlog, whereas the other will wish to take the lead. Those companies that view ecodesign as an opportunity will anticipate environment-related social trends and be aware of how to convert them into internal drivers for ecodesign in the form of entrepreneurial benefits.

Internal drivers which must be identified and explained

One of the main findings in research on ecodesign projects is that motivation throughout the whole organization is required to achieve a satisfying result. These are found among the internal drivers which must be analyzed and explained, and includes:

- Managers' sense of responsibility
- The need for increased product quality.
- The need to improve the image of the product and the company.
- The need to reduce costs.
- The need for innovative power.
- The need to increase employee motivation.

External drivers

The main external factors which stimulate a business to improve its environmental merits are discussed below.

The two main factors that encourage environmental improvement in the surroundings of any company are the government through legislation and regulation and market demand from industrial customers and end-users. These issues must be analyzed and explained. Other stakeholders which must be analyzed are

- Social environment.
- Competitors.
- Trade organizations.
- Suppliers.

Influences on external drivers

Important and widely-recognized changes in society will increasingly influence some of the main external drivers. A company beginning to implement ecodesign needs to be aware of these changes.

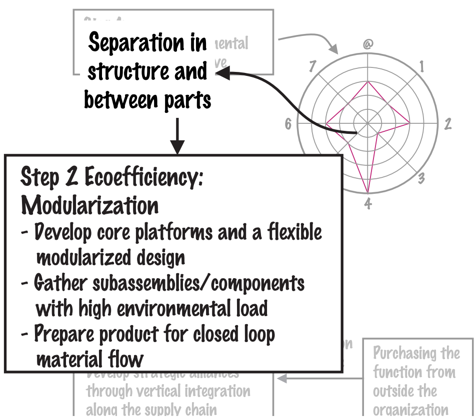
- Increasing value chain pressure.
- Public opinion.
- Energy costs.
- Waste charges.
- Take-back obligation.
- The obligation to provide information.
- Norms and standards.
- Ecolabelling schemes.
- Subsidies.
- Environmental competition.

The result of this activity is a fundamental understanding and quantification of the material and energy flow through the value chain. Establishing the environmental perspective makes the company aware of the systemic picture and the sources of environmental influences. This makes the company able to develop in detail the strategy for improving the overall enviornmental performance.

5.8.7 Step 2: Optimizing the ecoefficiency dimension

Step 2 of the strategy involves optimizing the ecoefficiency dimension, and is illustrated in Figure 5.6.

Figure 5.6 Step 2: Optimizing the ecoefficiency dimension



Through the traditional product development and ecodesign activities the effort is focused on the product level and its total life span. The goal is to reduce the overall environmental load throughout all phases of the product life span. This is achieved focusing on ecodesign strategies 1 through 7 of the ecodesign strategy wheel (Brezet and Van Hemel, 1997). For details, see (Brezet and Van Hemel, 1997).

The approach is to utilize traditional product development and ecodesign approaches, and will lead to incremental improvements in environmental load through:

- total life models
- the MET-matrix
- systems view of the product structure
- laws of evolution of technical systems
- a clear focus on the primary function of the product through the translation of customer needs and wants into technical criteria
- life cycle analysis is needed to track the environmental load of each element of the product life span, and to compare different technical solutions with each other.
- the tools attention, escape and movement for stimulating the creative thinking process keeping in mind the function
- the separation principles utilized upon the product structure which makes room for modularization of the different components of the structure.
- modularization for easy disassembly and reassembly for service and maintenance and end-of-life management

A qualitative approach like the MET-matrix is suitable for establishing an overview of the harmful elements. The MET-matrix is, however, not suitable for documentation purposes towards external stakeholders. This kind of analyses is better performed through a more detailed life span analysis: through Life Cycle Assessment, standardized in the ISO 14040- documents (ISO 14040, 1997, ISO 14041, 1998, ISO / CD 14042, 1999, ISO / DIS 14043, 1999, ISO / TR 14048, 1999). The life span analysis can soon become too complex, especially if the product is complex in its origin. Various shortcuts have been developed to speed up the process when a quick decision is required; for example, during the product design process. These shortcuts are often called “streamlined” approaches to life span analysis. The aim of a streamlined life span analysis for the design process should be to:

- gain an overview of the major environmental impacts of a product throughout its life span; and
- identify the environmental priorities that will be addressed through the design process.

One streamlined process approach involves three steps:

1. a flow chart or process tree;
2. a limited inventory analysis;
3. and an impact assessment matrix.

These can be prepared by company staff with the assistance of environmental experts (if required).

1 Process Tree

- The process tree includes all processes involved in the delivery of the product.

2 Limited Inventory Analysis

- The next step is to prepare a basic inventory of materials, resources, energy, wastes and emissions related to the different life span phases which have been identified as important. As a minimum, the following information should be collected:
- Materials and resources

- What materials / resources are used?
- What quantities are used?
- Are they renewable or non-renewable?

- Energy
  - How much energy is consumed in production, use and disposal?
  - What form is the energy that is used (coal, gas, oil, etc.)?
  - How is the product transported, and how far?
- Wastes and emissions

- What wastes and emissions are produced?
- Are any of them toxic or hazardous?

This analysis will require input from suppliers, customers and other organizations. A matrix can be used to summarize this information.

3 An impact assessment matrix

The next step is to analyze the impacts that the product has on the environment. An impact assessment matrix is a useful tool for analyzing those impacts, in relation to the product life span.

What is obtained by optimizing the ecoefficiency dimension?

Step 2 of the strategy for leap improvement results in an optimized product. This product has improved environmental performance compared to the original design. The result of the redesign can be visualised through the ecodesign strategy wheel as described in section “EcoDesign Manual”, page 106 and Figure 3.16 (Brezet and Van Hemel, 1997). The original design and the redesign is plotted in the strategy wheel, and shows improved environmental performance according to the selected improvement strategies of the company. On the product component level, the result can be

- a replacement of high-impact to the use of low-impact materials, i.e. materials which are cleaner, have low energy content, are recyclable, etc.
- a reduction of materials usage, i.e. reduction in weight, volume, production waste, lower energy consumption, etc.

On the product structure level, the result can be

- an optimization of production techniques through alternative production techniques and / or fewer production steps
- an optimization of the distribution system through optimization of packaging and energy-efficient logistics,
- Reduction of impact during use through reduced energy consumption, use of cleaner energy sources, fewer and cleaner consumables, no waste of energy / consumables, etc.

On the product system level

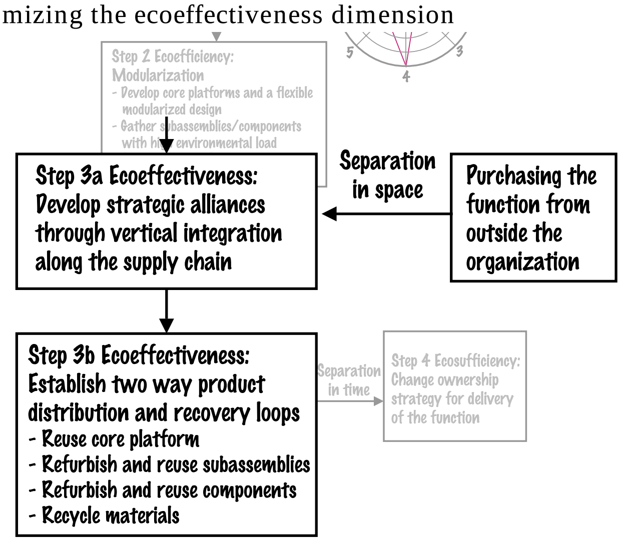
- Optimization of initial lifetime through improved reliability and durability, easier maintenance and repair and a modular product structure
- Optimization of end-of-life system through promoting recycling, safer incineration etc.

Step 2 of the strategy for leap improvement of environmental performance results in optimization of the product. This step covers only a minor focus on the element of closing material loops, but the product is prepared for disassembly, reassembly and reuse of the product, subassemblies, components and parts.

5.8.8 Step 3: Optimizing the ecoeffectiveness dimension

Step 3 of the strategy involves optimizing the ecoeffectiveness dimension, and is illustrated in Figure 5.7.

Figure 5.7 Step 3: Optimizing the ecoeffectiveness dimension



Through the development of the ecoefficiency dimension, the product is modularized through isolating the subassemblies, components and parts which represent the largest contributor to environmental load. Through modularization the product is easy to assemble, disassemble and reassemble both for service / maintenance and for final EOL treatment. The modules are built upon a platform, which is prepared for reuse through a long design life.

Through the product analysis a comprehensive and holistic view of the product system is obtained. Through the overall system structure, the product becomes only a component of system. This means that it is important to understand the holistic system where the product operates. All stakeholders along the value chain contribute to the environmental load of the product and thus to the environmental performance. By establishing a two way logistics route, where products and spare parts are supplied downstream, whereas returned products, -modules -subassemblies and -parts are supplied upstream the value chain, a robust reuse loop can be established. This is obtained through business integration along the value chain.

Two different approaches for network creation exist. Horizontal integration in the view of industrial ecology, focus mainly on linking value chains together, as vertical integration mainly focus on linking the value adding activities in a value chain to the same controlling unit, either by take-over of companies or through strategic alliances between companies.

Vertical Integration

Vertical integration involves a set of decisions that, by the nature of their scope, reside at the corporate level of the organization (Hax and Majluf, 1996, Porter, 1980). These decisions are threefold:

1. Defining the boundaries a firm should establish over its generic activities on the value chain (the question of make versus buy, or integrate versus contract). Here the major suppliers are integrated into the network giving mutual benefits for all parties.
2. Establish the relationship of the firm with its constituencies outside its boundaries, primarily its suppliers, distributors and customers
3. Identifying the circumstances under which those boundaries and relationships should be changed to enhance and protect the firm's competitive advantage.

This set of decisions is of critical importance in defining what the firm is and is not, what critical assets and capabilities should reside irrevocably within the firm, and what type of contracts the firm should establish to deal with its external constituencies (Hax and Majluf, 1996).

One may conceptualize a firm as a chain of activities that relates to the administration, production, distribution and marketing of the goods and services that constitute the primary outputs. The degree of ownership the firm chooses to exercise over these activities will eventually determine the breadth and extent of its vertical integration. To decide this question the firm has to weigh carefully the economic, administrative and strategic benefits against the cost resulting from the vertical integration. This is a question that goes far beyond the simple economic analysis of make-or-buy decisions. It also involves issues of flexibility, balance, organizational market incentives and capabilities for managing the resulting enterprise or alliance network (Hax and Majluf, 1996).

The major benefits of vertical integration can be classified into four categories:

- Cost to internalize economies of scale and scope, and avoid transaction costs from imperfect markets.
- Defensive market power, which provides autonomy of supply or demand, as well as protection of valuable assets and services.
- Offensive market power which allows access to new business opportunities, new forms of technology, and differentiation strategies.
- Administrative and managerial advantages arising from more simplifies managerial infrastructure when basic tasks are brought inside as opposed to left outside the firm. This involves especially the issue of controlling the logistics of the returned products, and routing returned modules subassemblies and parts to the correct reuse facility within the value chain.

What is obtained by improving the ecoeffectiveness dimension?

Optimizing the ecoeffectiveness dimension will contribute establishing the required network to close material loops, and significantly improve environmental performance through replacing virgin with reused components and parts.

Through step 3, the the network of alliances which can mutually benefit from a two-way material logistics flow is established. This gives room for a two way logistics route, where products and spare parts are supplied downstream, whereas returned products, -modules -subassemblies and -parts are supplied upstream the value chain, a robust reuse loop can be established.

Establishing such a vertically integrated network needs to focus on the mutual benefits for both internal and external stakeholders along the valuechain. The main focus of each stakeholders naturally lie in their own core business. Thus, it can be challenging for each stakeholder to explore the overall benefit along a valuechain, which may turn into reduced advantages for individual partners. Thus, this part of the strategy can be easier if the company stays in control of all activities along the valuechain.

Establishing the vertically integrated network along the valuechain leads to the creation ofa robust reuse loop, where products and spare parts are supplied downstream, and returned products, -modules -subassemblies and -parts are supplied upstream the value chain.

Step 3a of the strategy for leap improvement of environmental performance results in optimization of the infrastructural element of the value chain. The major focus is on the element of closing material loops, but will give best results when the product is prepared for disassembly, reassembly and reuse of the product, subassemblies, components and parts through a modular design based on product platforms.

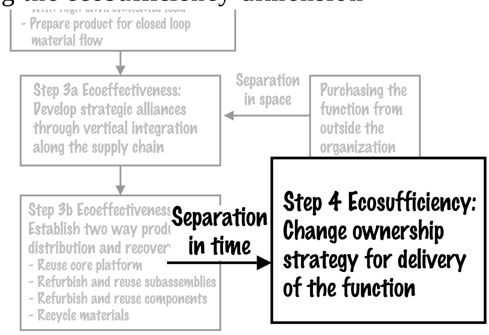
Step 3b of the strategy contain an optimization of the control element of the value chain. Vertically integrating stakeholders along the valuechain brings control of the product creation closer company. Thus, control of the product also means a possibility to control the environmental performance in a better way.

Step 3a and b gives room for redefining the overall business strategy for the delivery of functions instead of products.

5.8.9 Step 4: Optimizing the ecosufficiency dimension

Step 4 of the strategy involves optimizing the ecosufficiency dimension, and is illustrated in Figure 5.8.

Figure 5.8 Step 4: Optimizing the ecosufficiency dimension



Step 3 of the strategy for leap improvement of environmental performance includes the element of transferring ownership of the product from the customer to the producer. This involves changing the original strategy of supplying the market with products as the core business, to supplying the function of the same products. This is not a simple task, as it involves actuating different properties compared to the physical product alone. The producer must visualize for customers that there are value adding elements for them in such a transfer of ownership.

Since requirements are drivers for competitiveness and since systems engineering is performed largely independent of implementation, much of the competitiveness of a system is determined prior to the definition of the specific engineering implementation. Thus, to be more competitive, more effort needs to be expended in the up front abstract activities and less in the following more concrete activities. This makes the product planning phase important. The planning phase of the product development activities involves clarification of the task by investigating market, company and economy issues related to the planned product, service or product service. Several product / service / product-service ideas will be found and will need to be discussed in order to select suitable alternatives for further development. The result will be a more detailed proposal. In this sense, product planning is similar to the search for solutions that take place later, and therefore the same methods are used. The difference being that it takes place on a more abstract and preliminary level.

Pahl and Beitz (1996) argue that irrespective of whether the task is based on a product proposal stemming from a product planning process or a specific customer order, it is necessary to clarify the given task in more detail before starting product development. The purpose of this clarification of the task is to collect information about requirements that have to be fulfilled by the product / service / product-service, and also about the existing constraints and their importance.

One clear barrier for the implementation of product-service combinations is the issue that companies compete by adding new features to their products. Thus the core function of the product which is essential in developing product-service combinations becomes hidden behind all these extras. As Michl argues one strategy for developing product-service combinations and thereby reduce the overall environmental effects, is to obtain a clear focus on the basic customer needs and wants and translate these into functions.

When translating customer needs and wants into technical criteria, the barrier of psychological inertia must be removed. However, radical innovation and the risk of missing the target customer group must be balanced. The eight laws of evolution combined with the formulation of a visionary ideal final goal can be used as guidance for the technical issues of this balance. As described above, creative thinking without a guiding framework can end up nowhere. A too strict framework however, would jeopardize the creative thinking process.

Van der Horst et al. (1999) conclude that the need for methods for generating new ideas are needed. Altshuller (1984) argue that the fundamental barrier to innovation is the psychological inertia. TRIZ represents a methodology to try to tear down this barrier by identifying outrageous goals using the ideal final result operator. Here, TRIZ gives a significant contribution to the ability to deliver functions to fulfil consumer needs.

Through the planning processes of traditional product development activities combined with strategy eight of the ecodesign strategy wheel keeping in mind the BCS-ladder, the effort is focused on the systemic level of the system delivering the primary function throughout its total life span. The goal is to reduce the overall environmental load throughout all phases of the delivery of the function satisfying customer needs and wants. This is achieved through focusing on the primary function utilizing:

- systems view
- laws of evolution of technical systems
- focus on the primary needs and wants of the potential customer
- focus on which elements of satisfaction which makes the customer come back for more. This involves convincing the customer about the benefits without adding extra features but still focus on the primary function fulfilling customer needs and wants.
- the separation principles utilized upon the system structure delivering the function which makes room for separating ownership from the customer, and where the product / service deliverer takes responsibility of the technical means delivering this function.

- the separation principles utilized upon the organizational structure of the service deliverer, optimizing the infrastructural effectiveness of the function delivery process.

This phase is performed through market- and trend analyses to describe the core of the customer wishes. The needs are mapped onto various functions or technical criteria that support the needs. This is not a straight forward task, although tools like Quality Function Deployment (QFD) (Akao, 1990) may be suited. Engineers and designers must focus both their analytic and creative effort and find the core issue of the needs and wants of the customer.

Alternative means that can support the delivery of the functions are then identified. It is important to see the technical system from a holistic view, in the sense that such a system often relies on some kind of infrastructure. To deliver a function, some kind of delivery system is needed, and alternatives may be absent if the psychological inertia is not removed.

Technical systems are selected which embodies the required technologies identified in the above process. These technical systems will form the infrastructural setup of the service which could be dependent (i.e. telecom services – network and customer premise equipment must work together to deliver service) or independent of each other (washing machine and tumble dryer).

When performing activities which leads to efficiency and effectiveness improvements, there is always a risk to suffer for the rebound effect, i.e. the gains in reduction of potential environmental effects, may be realized through other activities with even higher potential for environmental effects. This is an issue which producers and service providers cannot guarantee themselves against, and is an issue which is outside their area of responsibility. This decision belongs to the customer who finds a benefit in buying access to the service.

This is a difficult, but very important dimension of the overall environmental performance, as it basically is dependant on the understanding of individual needs.

Companies have to understand how their products comply with the needs of individuals. The fundamental human needs of Max-Neef (see Table 2.5) can guide companies into such a scenario and gain competitive advantage when performed correctly.

What is obtained by improving the ecosufficiency dimension?

Improving the ecosufficiency dimension in step 3 brings the product under full control by the producer. The transition of ownership from the customer to the producer makes the producer able to control service and maintenance in a better way, control take-back and replacement when better solutions are available, etc.

This approach supports strategies which promote a significant reduction in the amount of materials leaving the system. The approach also support Extended producer responsibily legislation initiatives where full control of the product along the valuechain can result in a better control of the many available product life phase routes. When ownership is left to customers, collection and reverse manufacturing of products may unwanted costs, environmental loads violation of the laws which can reduce competitive advantages in the market.

Instead of regulation based on punishment, it is important to base it on incentives for choices and behavior for activities that have a lower potential for environmental effects.

5.9 Conclusion

This chapter presents a strategy for leap improvement of environmental performance of industrial product systems. The strategy involves four steps and three different dimensions on completely different levels of a company and its interactions with its surrounding environment.

1. establish environmental and business perspective
2. optimizing ecoefficiency dimension on the product level
3. optimizing ecoeffectiveness dimension on the infrastructural level
4. optimizing ecosufficiency dimension on the holistic system level

Combining the three dimensions can give a leap improvement in environmental performance.

The strategy involves utilizing the separation principles of TRIZ to operationalize the contradictory elements of removing side-effects in the industrial ecology context. The strategy involves utilizing the holistic systems view and total life models as a basis to grasp the hierarchy of systems and their interactions with each other, and between the product and the overall system where the product is a component and the company is the supplier.

The strategy furthermore involves understanding why any customer wants to be a consumer in the overall system. The customer is consuming the function which the system provides utilizing the technical system of the product. This may not be only the primary function, but also involve elements of the social system which is affected by certain elements of the product.

When the overall system structure is identified, the structure analyzed keeping the separation principles in mind.

- Separation in structure and between parts represents an optimization of the product life of the technical subsystem, i.e. the product. This involves the traditional ecodesign approach where the product developer gradually improve the product into a modularized system containing modules and subsystems attached to a long lived core platform. The modularized product is prepared for two way product delivery and return logistics routes and prepared for closing material loops.

- Separation in space represent viewing the company and its interactions with suppliers, competitors and other stakeholders in a holistic system.The relationships between all parties can contribute to create a network for two way product delivery and return logistics routes for the mutual benefit for all parties.
- Separation in time represent the development of a product-service combination. As the two way product delivery and return logistics routes are established and up and running, the transfer of ownership from the customer to the service supplier creates a product-service combination.

CHAPTER 6

DISCUSSION

This chapter discusses the findings in chapter 5. The strategy for transforming products into product-service combinations is discussed in relation to validity, applicability, completeness and environmental benefit, and implications of introducing product service combinations through a function economy are pointed out.The intention of the chapter is to put a critical view on the strategy described in chapter 5 and the role of product service combinations in a function economy and its implications for present drivers for product development.

6.1 Validity of the strategy

The validity of this strategy for transforming products into services is somewhat difficult to determine. To verify if whether or not can give significant results, it must be implemented in industry. However, this section will discuss the validity of the strategy. Questions asked are

- Where is the strategy applicable?
- Are all four steps of the strategy needed or is the same result achieved by using only some of the steps to introduce a product service combination?
- What time horizon is needed to introduce the strategy?
- What is the environmental benefit of introducing such a strategy?
- Is there potential to achieve leap improvement in environmental performance?

The answers to these questions will contribute to support the hypothesis which this research is based upon, as described in chapter 1.

6.1.1 Where is the strategy applicable?

The main result of this research work is this strategy. Is it valid and where is it applicable?

The five product classes

In view of the five product classes as described in Table 5.5, the strategy is valid for all except class 1: products which function by a chemical reaction during the use phase. These products are normally totally consumed during the use phase or go through chemical reactions which make them unsuitable for a reverse process. Thus a modular design of these products would become meaningless in the vital phases of their lifespan, i.e. the use phase. A paint product can take the form of a two-component polymer based paint system, which harden during its application and drying. However, in an EOL situation, separating such a product into its original components would not be practical in terms of energy resources.

Paint systems as services would take a different form. A company selling paint systems as services can take the form of selling corrosion protection systems rather than paint products only. A corrosion protection service would be protecting e.g. an oil producing offshore steel structure from corrosion during a specific number of years. This service would also be based on a painting system, but would involve a service contract where a company takes the responsibility of service and maintenance where corrosion is prevented through inspection and reapplication of the paint system where needed.

In such a service scenario, the strategy for transforming a mechanical product (paint) into a service (corrosion protection) would not be applicable, based on at least two reasons:

1 The motivation for transforming a product into a service can be based on environmental benefit, but at the bottom line, the economic benefit is the basic driving force in a market economy. Introducing a service therefore needs an economic benefit compared to an alternative. This means that the product must still have some kind of value also at its end-of-life. This may not be a real value to everyone, but the service provider must see the value of product take-back and reissuing the product for a new life or to a new user/customer. This is a clear prerequisite for the validity of the strategy presented above. A clear company motivation must be established for closing the material loop prior to transforming the product into a service.

2 Considering a paint product, it has no practical value at its end-of-life apart from the value of preventing emissions. The chemical reactions these products go through, are normally irreversible. Similarly, a food product is normally totally consumed, and has no practical value after use.

The same situation will be true for e.g. a food product.

The other product classes (see Table 5.5) mobile/stationary and non-/consumer of energy during use, all have a use phase quite different from the products of class 1.

In a product service combination, the ownership of the product stays on the hand of the producer. This means that a function supplier can stay in control and decide when EOL of this product occurs. EOL situation occurs when the product no longer satisfies the needs of the customer. This can be due to

- *Technical obsolescence*: the product itself is worn out and no longer functions properly.
- *Economic obsolescence*: new products in the market are more economic in terms of cost. They have a lower cost of ownership e.g. lower cost during use like lower energy consumption.
- *Ecological obsolescence*: new products in the market have a less harmful impact on the environment e.g. through reduced energy consumption. Ecological- and economic obsolescence often go hand in hand, although this is not necessarily the case.
- *Esthetic obsolescence*: new products in the market have a more appealing form or a more fashionable design in the perception of the consumer.
- '*Feature*' *obsolescence*: new products have come onto the market that offer more or better features i.e. secondary properties are transformed into primary properties.
- *Psychological obsolescence*: a new product has greater emotional value (e.g. present/gift or inheritance) or the present product has a negative emotional value.

In a product service combination, each end-of-use may not be equivalent of end-of-life. In a product service combination, the service provider can utilize the service and maintenance program to indicate when the physical products have reached obsolescence for some reason described above. A technically obsolete product may go into an EOL situation, for component, part, base material or energy reclamation, while a esthetically obsolete product which is still functionally usable, may go into a market of different esthetic norms.

White et al. (1999) identify four alternative ways for the provision of product-based services.

1. The service provider may be totally separate from the product manufacturer. Independently from traditional distribution channels for products, product-based services may be provided by a specific service provider, either within the customer organization or external to it (e.g. maintenance or cleaning services).
2. Services may also be provided by service intermediaries, who buy products from manufacturers and supply their services to customers
3. Services may be more integrated with manufacturing, e.g. supplied by a specific service division within a manufacturing company (e.g. automobile manufacturer combining service offerings with the purchase of a car).
4. It could be possible to envisage a joint entity, manufacturing products for use in the production of service offerings.

Each of these alternatives provides a different set of incentives for product and service design, but they also differ in the potential for environmental performance. As described in chapter 5, the main environmental improvement from a transition from a product to a service, is though dematerialization. Not all services encourage dematerialization, and therefore is a service in itself not necessarily an improvement in environmental performance. Car sharing in itself involves shared use of the product. Approximately 90% of the environmental load along the total life span of a personal car can be traced to the use phase (Von Weizsäcker, 1997), and this load will not be reduced having several users of the same car. Ideally, this situation could lead to a reduced number of cars in the market.

The improvement in environmental performance stems from the dematerialization, which involves closing material loops. Reuse, reuse of subassemblies and parts, remanufacture and reclamation of raw materials can reduce the extraction and use of virgin materials. Based on the four categories for the provision of product-based services of White (1999), only category 4 would fit with the service scenario applicable using the product to service strategy described in chapter 5. The main aspects where the strategy is applicable is when a product is designed in a way which makes it prepared for disassembly, reassembly, reuse, etc. This makes the product prepared for closing material loops. Secondly, the control of the value chain must stay somewhere. Vertical integration is described above to take control of the value chain. However, the one in control need not be the manufacturer. The controlling stakeholder can very well be the service provider, buying access to a manufacturing facility, both for manufacturing and remanufacturing.

Product-service combinations that fall into categories 1 through 3 of White (1999), do not have the same tight mutual integration between service provider and product manufacturer, which the author of this dissertation argues is necessary to close material loops in an efficient way.

6.1.2 Are all four steps of the strategy needed?

When introducing environmental issues as a part of the strategy of a company, it is important not to be too ambitious. To identify the processes, products or services with largest contributions to environmental load can form the basis for further work. Improving one of these processes, products or services can be the next step. Strategies currently used by industry is selection of low-impact materials, reduction of materials usage, optimization of production techniques, optimization of distribution system, reduction of impact during use, optimization of initial lifetime and optimization of the end-of-life system

The options for improvement, clustered in accordance with the ecodesign strategy wheel, are subsequently assessed for their anticipated environmental merit, their technical, organizational and economic feasibility, and their market opportunities. Generated alternative solutions are assessed against the internal and external drivers for ecodesign. The ecodesign priorities must be established by the entire product development team; all representatives of management and the marketing, purchasing, research and development, and production departments should have their say.

It may be beneficial to assess the environmental quality improvement not only in terms of environmental effects but also in financial terms.

This is where the majority of companies are today. They try to improve their products to be prepared for recycling, reduce the use of toxic emissions, and harmful materials, and furthermore, reduce overall material consumption.

Step 1 Establishing the environmental and business perspective

Step 1 of the strategy is the basis for all work on improving environmental performance of products and a company as a whole.

However, establishing an environmental baseline for a whole company may be in itself a very ambitious task which involves large resources to complete. Establishing a Finnish-to-Start-relationship between step 1 and 2 will act as a barrier to further progress in environmental performance. Knowing when a baseline of satisfactory quality is the true goal of step 1.

Furthermore, the baseline is forms the basis for establishing the strategy for progress in environmental performance for each product and value chain, and all other systems supporting the value creating activities of the company. Developing a strategy describing the overall and fundamental goals of a company's future is essential for all development activities. Developing this strategy belongs to the management level of the company.

Step 1 may be performed in isolation, and this is the introductory step for all companies. Companies may already have performed this task without even thinking about transforming their products into services. However, performing step 1 only will not lead to any improvements apart from improving knowledge about a company's own activities, which by itself is a valuable result.

Step 2 Optimizing the ecoefficiency

Step 2 Optimizing the ecoefficiency dimension can by itself contribute to improved environmental performance. This is the traditional product development activities focusing on environmental performance, and involves reducing material and energy flows in all product life phases, and preparing the product for disassembly and reassembly, i.e. closed material loops.

Developing a modular design belongs to the product development team. This activity cannot however, be performed in isolation from other activities of the company. Clear mutual understanding of the overall goals between the product development team and company management is essential to secure progress in the same direction.

It is not likely that step 2 is performed without performing step 1, as step 2 heavily relies on the strategy for improvement established in step 1. Apart from that, step 2 can be performed without going further to step 3 and 4.

Step 3 Optimizing the ecoeffectiveness dimension

Step 3 Optimizing the ecoeffectiveness dimension also relies on the strategy established in step 1. If the strategy explains that the infrastructural element of the value chain in mind is the goal for improving environmental performance, optimizing the ecoeffectiveness dimension is an appropriate mean to reach this goal. However, there is reason to believe, that the benefit will be larger if step 2 and 3 is seen in a holistic view where both dimensions mutually support each other.

White et al. (1999) classify services into two categories, i.e. non-material services and material-based or product-based services. The strategy developed here is intended for product-based strategies, and does not intend to contribute to a leap improvement of non-material services which includes traditional services such as banks, health care and hair salons.

Product-based services, involves some kind of product. The product based services can be divided into product function services and product extension services where the main difference is the ownership of the product.

Both of these subcategories are covered by the strategy. The difference lie in the separation of ownership between customer and product. For a product extension service where the customer still has ownership of the product, step 4 of the strategy has not been performed.

Step 4 Optimizing the ecosufficiency dimension

Step 4 Optimizing the ecosufficiency dimension involves changing lifestyles of customers. This step can be performed in isolation from any of the other steps. Changing lifestyles hits the core of the consumption patterns of the industrialized economies. Moving forward towards a more sustainable production and consumption patterns must contain elements of changing lifestyles. WBCSD reject the ecosufficiency dimension although accepting the need to reduce pollution and resource depletion they do not agree that reducing living standards will achieve a better-balanced world. There is no generally accepted equity between sufficiency and a reduction in standard of living. Viewing consumption patterns towards products and services that satisfies sufficient levels of lifestyle while limiting the use of resource and pollution to acceptable levels, and simultaneously reject other links between product/service provider and customer than the sales situation only, can only be seen as a defence of business as usual where present practice is presented as the only available option.

WBCSD and industry cannot reject looking into the sufficiency issue as well, despite the risk of reducing markets. It should rather be seen as opportunities for competitive advantage.

6.1.3 What is the environmental benefit of introducing the strategy?

The strategy for transforming products into product service combinations is established as a means to achieve leap improvement in environmental performance.

Section 6.1.2 describes that the four steps of the strategy do not need to be performed in combination to achieve an improvement in environmental performance. However, the four steps can also be seen as steps in increasing complexity and increasing potential for improvement.

Step 1 is the tasks of identifying present baseline through establishing the environmental and business perspective. This is the simplest step of the strategy. This step is always the starting point for improvement activities, i.e. establish the baseline which all improvement options are compared to.

Step 1 is also the task with least potential for improvement in environmental performance. Establishing a baseline can give rise to new knowledge that can contribute to identifying obvious options for improvement and that do not need any further development for action. Other more comprehensive options need further development through the subsequent steps of the strategy. Improving the ecoefficiency dimension through traditional ecodesign activities which are the activities of the most proactive companies today, will give a contribution to improved environmental performance. However, achieving a leap improvement of factor 2, 4 or even 10 is not likely. Furthermore, improving the ecoeffectiveness dimension through optimizing the infrastructural elements of the value chain, will give a positive contribution, but a leap improvement will be absent. To achieve such an improvement, all four steps needs to be performed in combination, i.e. improving all three dimensions of steps 2, 3 and 4.

The challenge for improving environmental performance follow the potential for improvement. Step 1 requires time and effort for investigation, understanding and documenting the material and energy flows through a company. The challenge of this task is to understand when sufficient knowledge about the internal process network is established. Full documentation of all material and energy flows though a company will never be complete, as these are dynamic processes which makes a documentation task always behind with the real world.

Step 2 is more challenging in the way that new solutions must be generated. Establishing something new is always more challenging than documenting an existing solution. The product development team developing the new solution must look into the future and foresee how customers respond to the new solution.

Step 3 is even more challenging as all stakeholders must contribute to optimizing the infrastructural element of the value chain, both the physical- and the information infrastructure. Here all stakeholders must make some agreement on which direction to move forward. The stakeholders do not necessarily have the same view on this issue. This question is also relevant for step 2, but the solution space available is larger in step 3 making the task more difficult.

Step 4 means changing consumer lifestyles and supplying this lifestyle with products and services of leap improvement in environmental performance. Here the degree of freedom (for the customer) is very large. The solution space is larger than a company is able to manage, and therefore the risk of failure is impending.

One of the hypothesis for this dissertation was not only to show that environmental performance of industrial products can be improved. This issue is already shown in many research projects and also in industrial products in the market. However, the leap improvement is not so clear. Each of the steps described in the strategy will give an improvement, but performing all four steps is believed to give a leap improvement in performance.

The potential for improvement of the different steps of the strategy in some degree follow the BCS ladder and the thoughts on improving environmental performance of Stevels, as illustrated in Table 6.1.

Table 6.1 Levels of EcoDesign (Stevels, 1999)

Level	Purpose	Primarily issue of	Investment	Change of consumer lifestyle	Infrastructure change	Institutional change
4	Green system innovation	Stakeholder involvement	++++	++++	++++	++++
3	Green function innovation	Research	++	++	+	+
2	Radical EcoDesign	(Pre) concept feasibility	+	0	0	0
1	Green improvement	Product Creation Process	0	0	0	0

0= no change, +=minor change, ++=medium change, ++++= very high change

Environmental benefits increase from 0-50% for green improvement (level 1 of the BCS ladder) up to 200-500% for function and system innovations (level 3 and 4 of the BCS ladder) (Stevels, 1999) where product service combinations are located. However, as Table 6.1 indicates, that the implications of a product service combination to the stakeholders increase tremendously. This indicates that a leap improvement of environmental performance is applicable if all four steps of the strategy are finalized.

6.2 Critique of the function economy

The ideas behind the service based economy is described in chapter 1.7.3 and 1.7.4. The underlying idea for is that market actors make decisions that are sub-optimal from the point of view of the ultimate utility of the final customer (Heiskanen and Jalas, 2000). A shift toward services integrates the value chain and places the supplier more closely into the customer's operations. The supplier takes on such tasks as product ownership and maintenance, even product use. Through superior economies of scale and higher competence, the supplier is able to optimize materials use better than the customer, who is impeded from optimizing by informational and other transaction costs. The more the transaction is about the product function, and not the physical product, the less the supplier has the incentive to sell excess material.

From this perspective, the idea of a service economy implies the redefinition of the boundaries of the firm. When the manufacturer is forced to take responsibility for the product beyond the conventional point-of-sale through legislation on extended producer responsibility, the manufacturer may have the incentive to extend product life, improve product use, or in other ways save materials used per product function.

Understanding product service combinations is interesting for companies as well as governmental regulators. Knowledge in product service combinations enables authorities and legislators to formulate the next steps in environmental policies concerning production and consumption patterns focusing on consumption rather than investment. Knowledge in product service combinations enables companies to find strategic options for business growth, renewal, innovation and diversification. Knowledge in product service combinations is especially inspiring for those companies who regard sustainability as an innovative vision for management strategies and competitive advantage.

Today customers procure products based on several criteria in addition to functionality. Many customers want their belongings to do more than to function well only. Michl argues that our preference for appealing forms has to do with our ownership of things. Products we own tend to be perceived by others as a part of our personality. We unconsciously take this issue into account, and choose products that can give a positive impression on our surroundings. An appealing product is therefore given preference instead of a product found ugly. Criteria for appealing products are that they appeal not only to us as individuals but also to those we respect in our associates and surroundings (Michl, 1999).

Thus, the ownership issue may be a serious barrier to cross by the idea of functional sales. However, customers who feel the ownership of the product is important, will not likely be a customer of a functional sales service. Establishing a functional sales service involves first of all an identification of need. To make a business out of this idea, the need for this function without ownership to a product must be investigated and analyzed.

Heiskanen and Jalas (2000) claim that another serious argument against the service focused economy is the lack of realistic inclusion of environmental load into prices of commodities. Materials are seriously under-priced with regard to their environmental externalities. The same point can be emphasized regarding energy. Although many customers today may value improvement in environmental performance, environmental load are usually not visible in the product or service offering due to the intransparency of markets with regard to externalities. Consequently, as materials are cheap and labour expensive, the result may be that the current model of manufacturing and selling products, rather than services, makes economic sense even in an integrated value chain under current price conditions (Heiskanen and Jalas, 2000). However, the conclusion by Heiskanen and Jalas (2000) seems to be drawn base establishing a cost model where environmental load is given a monetary value. This is no common agreement in the research community to measure environmental load through monetary figures. Based on non-monetary indicators, the conclusions of Heiskanen and Jalas (2000) will probably be different.

When promoting a function or service economy, these are very important questions, and the views of Michl arises a fundamental contradiction between a function economy and the emergence of competition and differentiation in a market economy. Michl claims that

> *without inter-human pressures (as described above) hardly any design culture would emerge at all. In a society where people would be forbidden to own things and have personal belongings, where they would be allowed only to use things but not to own them, the design of things would inevitably deteriorate because without representative pressures, and possibilities, the reason for making products appealing (appealing to whom?) would be absent (Michl, 1991).*

Western industrial design culture is based on an economic system where competition for profit is a vital element. Michl (1991) argue that producers who supply goods or services based on commercial motives only, have given them a rather greedy reputation. Furthermore, he claims that an attitude he has seen in society, expressing that the only morally acceptable way to produce functional and beautiful things, is based on human needs directly. In this sense the phenomenon of appealing form, prestige and social status, is an example of unintended side-effects of intentional human activities.

However, the failure of the planned economies (Soviet Union, East European countries, China, Cuba and others) where production for functions and use replaced production for profit, Michl (1991) claims can serve as a reminder that competition for the consumer's spending power is still the most effective mechanism for generating functionally effective and aesthetically appealing industrial products.

Following the arguments of Michl (1991), the key to economic growth is the development of product diversity reflecting diversity in customer choices. Producers differentiate their product properties and compete in delivering the sufficient set of secondary properties and features which are found attractive to the customer.

It is important to remember when arguing that transformation to a function or service based economy, physical products will still be needed. Apart from consultant or labor work using no tools and communicating orally only, a service is always dependant on some kind of physical product. It is a misunderstanding that when the function or service economy is established, no more products are manufactured, and environmental pressure from industrial activities will disappear. Industrial products will still be present and indeed needed. The difference lie in how these products are being utilized.

In a function economy the set of features and secondary properties must be of a different form, and attract the customer in a different way. Playing on the benefits of having access to functions without the need to procure the products which delivers this function can be promoted through the marketing mechanisms which are often so successful promoting todays business practices.

However, the introduction of services does not mean that competition is over. Competition among the traditional service providers, bank, insurance, health care, etc. is hard enough to accomplish the steadily development of service variants, service features and other primary and secondary properties to attract customers. Thus, there is no reason to believe that a flourishing service economy will deteriorate in reduced economic development.

6.3 Implication of introducing product service combinations

6.3.1 Time horizon

The time necessary to have success in supplying a product service combination in the market is difficult to determine. Results are not achieved overnight. The different steps described in chapter 5 all needs time to complete. However, steps 2 and 3 may be performed in parallel, and thus proceed faster.

An important factor here is customer acceptance. Today, consumers may not want to share a product with someone else. They still want the ownership to the product. A product service combination, like any individual product, is dependant on the acceptance among customers. This means that a long timeperiod may pass before consumer markets are accepting the new consumer/producer relationship. The reason for the long transition period lie in the fundamental shift in business practice which requires long time to complete in many areas of industry.

6.3.2 Identity and strategy

As the potential for improvement in environmental performance increases, the challenge for achieving the improvement also increases, and simultaneously, the risk of failure increase too. As described above, an increased service element requires the supplier to stay in closer contact with the customer when supplying a product service combination. Not every company desires to combine services with products. Nor is every company capable of doing so, and not every new product service combination initiative is accepted in the surrounding network.

The identity of the producer may become a barrier to the product service combination strategy. The skills and qualities of the company’s employees and the relative power of its stakeholders can to a large extent affect the company's decision to introduce a product service combination (Goedkoop et al., 1999). Most of these factors relate to the culture of the company. They include management style, company structure, ethical values and the ways of building, managing and maintaining relationship with stakeholders in the interfacing network. Thorough insight into the business’ identity and its strategic position among competitors and markets, is a prerequisite for a comprehensive analysis of the potential success in introducing a product service combination in the marketplace. As the strategy described in chapter 5 shows, step 1 of the strategy involves establishing the identity and strategy of the company towards the environmental consciousness.

A product service combination must comply with the core business activities of the company. However, a redefinition of the overall strategy from delivery of products to the delivery of function may be required through the result of the analyses, and a process of increasing awareness can identify core skills and competence to deliver this service. The introduction of a product service combination needs both core competencies normally found in a traditional product manufacturer and a traditional service provider. Lacking competencies may be procured from the outside or acquired through strategic alliances.

It is important to have both competencies which are slightly different due to the value of the service. Goedkoop et al. (1999) argue that the value of a services lies in the quality of the organization structure providing the service and the established network of clients. The value contained within the product is partially transferred to the service element. Furthermore, the time available to respond to market changes is disturbed by the significant difference between services and tangible products regarding product/service development which leads to a very different management and development culture (Goedkoop et al., 1999). A product service provider must manage both cultures, and utilize the potentially positive synergistic effects from both.

Service organizations are often in closer contact with the customer, and must react rapidly to customer response. A service provider also need a support organization to take care of administrative processing. Alliances with specialized service providing organizations could offer solutions that could accelerate the introduction of new systems (Goedkoop et al., 1999).

It is important to identify all stakeholders that play a role in the old and new situation (Goedkoop et al., 1999). These can include local, national and European authorities, distributors, competitors, environmental groups and press. Furthermore, scenarios which visualizes how each stakeholder is affected by introducing the product service combination must be identified and analyzed. It is also important to estimate to which extent each actor can influence the changing situation. This analyses will support the decision on which actions to take regarding each stakeholder prior to introducing a product service combination to prevent losing market shares due to noise in the value chain.

6.3.3 Investment

Cost is an important factor in determining the viability of options for introducing product-service combinations. In the case of a washing machine vs. a launderette system, it may be more expensive to rent a machine or use a launderette than purchasing a machine. Purchasing a washing machine becomes the most economically rational choice (Cooper, 1999). As noted above, this observation shows that environmental and social considerations are not included in this decision. Other indicators need to be included to visualize the benefits and drawbacks on other than the monetary level only.

As noted above, the issue that materials are cheap and labour expensive represents a barrier to the product service combination with a closed material loop element. Products are cheaper than services because of the relatively small labour element in large-scale manufacturing compared to a service. Consumer demand for a larger service element is therefore limited due to cost. Legislation on extended producer responsibility may alter this argument.

For a business which is fully dependant on a regular cash flow, a shift from selling products to product service combinations represents a shift in this situation. The product is normally procured through a lump sum, while the product service combinations would probably require e.g. a monthly payment by the customer. This shift in cash flow represents a major barrier to a shift to a business model based on product service combinations.

Changing the relationship between product- and service-elements, require different governmental regulating incentives to escape from this kind of lock-in situation. Government policy currently favours the traditional “transactional economy” model of high economic growth through individual acquisition and ownership. To change this, through e.g. green tax reforms, some kind of adequate financial incentive for product manufacturers to become service providers can serve as a solution.

6.3.4 Consumer lifestyle and customer acceptance

Heiskanen and Jalas (2000) reports that a review of the diffusion of the concept of product-service systems, indicates that companies do not yet see it as a source of competitive advantage, due to the lack of practical, realistic models, and to the lack of market demand (Heiskanen and Jalas, 2000).

Thus, consumers still see no competitive benefit in a product service approach which they are willing to spend money to acquire. The source of this can be companies, which are not able to visualize the benefit for customers, or customers may not be ready for this kind of thinking. However, consumers will need to adapt their life styles in order to benefit from advanced green developments through product service combinations. However, this is a rather upside-down approach, as a prerequisite for competitive advantage is to capture the voice of the customer, which is not always the voice in terms of environmental resource use.

As described above, selling functions instead of physical products may be found very unappealing by customers. Each customer has its own characteristic needs. The service provider must clearly understand the ownership issue prior to adding a service in this market segment. However, customers can be clustered into rather homogeneous market segments, and some of these segments may indicate a positive perception of transferring ownership to the function supplier (Goedkoop et al., 1999). This means that the introduction of the product service combination must be defined in terms of the targeted market segments where the product service combination could be introduced through matching commercial offers with a reasonable chance of success.

The marketing function must understand what arguments for procurement customers in each of the selected market segments are likely to adhere to (Goedkoop et al., 1999). The demands of the identified customers must be understood through a clear view of all benefits and drawbacks of the product service combination. The product service combination's offer must comply with these demands, and modified if necessary. In addition, an estimate of the expected rate of acceptance for the product service combination in each of these segments will provide reliable market input data, which is needed for the combined economic / environmental analysis.

6.3.5 Institutional and infrastructural change

Although product service combinations have existed in several decades, very few services have been designed explicitly to address environmental concerns, or are marketed on environmental grounds (Heiskanen and Jalas, 2000). Despite this, the shift from products to services has gained an increasingly broader audience and interest.

Some institutional changes can already be observed. The environmental and social issues are being raised to the awareness of business managers, policy-makers and the general public. Corporate social responsibility has become important to proactive companies.

The service approach has many similarities with other current business trends as described in chapter 5, such as lean and flexible production, knowledge-intensity, customer integration (Heiskanen and Jalas, 2000). Furthermore, services may be a way to find and explore new business opportunities when facing saturated markets. Goedkoep et al. (1999) emphasize the role of product-service systems as sources of business with high added value.

Resource efficiency and dematerialization have gained acceptance as goals for environmental policy (Heiskanen and Jalas, 2000). Many current policy developments, such as climate policy, integrated product policy and fiscal policy, may in the future shape the institutional conditions for a shift from products to services.

In our industrialized society monetary values are still the only values measured and which makes a difference. Monetary values still represents the resources that all industrial activities are measured against. A holistic view is promoted as vital for developing investment analyses that form a picture of the overall contribution along the complete value chain, and complete product life. However, the product life approach still seems to be difficult to implement despite the last decade's focus on life cycle engineering. Cost in the future is apparently hard to imagine for investment activities. The examples are numerous on new solutions with a documentable benefit summarizing the environmental and financial load across the product life. The fear for new solutions and fear for changing consumer habits, business practices can be solutions for the lack of life span thinking among consumers and in industry. This is an example of technological lock-in where it is not enough to have a solution which is superior in primary property performance, but needs to be superior in secondary properties performance as well.

One of the strategies for escaping technological lock-ins as described in section 1.6.2, was through innovation (which is described earlier in this dissertation) and regulation by authorities. Regulations are beyond the control of companies. Governmental regulation are often meant to guide industry, correct selection of technology and foster innovation to make society and industries become interrelated for the benefit of both. Unfortunately, this often turns out different from the intended objective, both because of unsatisfactory legislation, but also because industries are not able to look beyond the regulations to benefit from it. This may lead to a documentation focus rather than an innovation focus on finding new and improved solutions.

The forthcoming legislation on extended producer responsibility may provide regulatory activities which may break the technological lock-in and force a total lifespan thinking into business practices.

Furthermore, infrastructural changes are vital for supporting product service combinations in the sense that a true material loop closing mechanism require optimized transportation of goods and services. Lacking coordination in this scenario, may result in a boomerang effect where the achievement in environmental performance is spilled in non effective transportation and recycling.

Thus, the shift from products to services will require a review and reform of a number of the current institutional conditions that set the stage for business activities.

6.4 Conclusion

This chapter has tried to put a critical view of the strategy developed in chapter 5.

Introducing product service combinations as means to reduce the material and energy flow through the economy, requires the removal of some serious barriers to succeed.

- Consumers and other customers must accept the transformation from a product to a service, which may require changing lifestyles from individualism and ownership of things to a corporate culture necessary to develop product service combinations and succeed in the market. The service provider must understand customer acceptance prior to the service introduction.
- Products are cheaper than services because of the relatively small labour element in large-scale manufacturing and consumer demand for a greater service element is therefore limited due to cost. Furthermore, government policy seem currently to encourage the traditional “transactional economy” model of high economic growth through individual acquisition and ownership. Under-priced materials and over-taxed labour

may obstruct the spread of service approaches even in business-to-business contexts.

To change this scenario, a ecological tax reform supporting a shift from products to services would therefore be welcomed.

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CHAPTER 7

CONCLUSION

The intention of this report is to contribute to a leap improvement in enviornmental performance of industrial products. The results of the dissertation are directed towards companies that want to eliminate, or at best reduce the unintended side effects of their activities and industrial products. The main result of this dissertation is a strategy containing principles and methods for reducing the unintended side effects of a product system which arise during all meetings between the product and the product life systems.

This chapter summarizes the main findings of the research work and reflects upon the hypotheses which formed the basic research questions presented in chapter 1.9.Furthermore, the chapter presents recommendations for further research.

7.1 Introduction

The theme of this dissertation is industry's deployment of the power of product development and creative techniques for leap improvement in environmental performance of products and product service systems.

The basis for the research was that due to the nature of any action through utilizing resources to obtain a desired effect, there is always a unintended side effect which causes the environmental load.

The goal of the dissertation was to develop strategies containing principles and methods for reducing or aparently eliminating the unintended side effects of a product system that arise during all meeting between the product and the product life systems. The means for reaching this goal was the state of the art in product development and creativity models.

The dissertation is directed towards companies that want to eliminate, or at best reduce the unintended side effects of their activities and industrial products. The benefit involves

- reduction or elimination of risk of financial loss and loss in reputation
- reduction or elimination of risk of damaging impacts on humans and nature
- motivation of customers for returning products at their end of life
- establishing and clarification of the company's ethical values
- clarification of the company's ethical values compared to values of society
- satisfies requirements from stakeholders

The basis starting this dissertation was that the unintended side-effects are in their nature physical contradictions. Although all basic laws of physics naturally must be satisfied, the contradictions can trigger the creation of new solutions where the environmental performance is significantly increased, and hence the environmental load significantly reduced.

7.2 Summary of results

Through literature and industrial studies, it was shown that despite considerable effort the last decade in product development and ecodesign, we still see only incremental improvement of environmental load from industrial product and product systems which is not even enough to stabilize human made environmental effects in the atmosphere and ecosphere. To achieve a real reduction and aligning the ecological balance a significant reduction is needed of man made environmental influence is needed.

It was argued in chapter 2 that to understand the contributions on environmental influence from the different subsystems, a conceptual understanding of the total system is needed. A full understanding of the total system is not an achievable option, but that cannot be an excuse for not doing the best possible job of collecting information and piecing and put together a comprehensive conceptual or even formal model of the system, its components and their interactions.

When the system is established, the question becomes: how satisfying is the output from the system compared to the input? Intense discussions are still going on among researchers around the world trying to define the concept of ecoefficiency and whether ecoeffectiveness is the concept to measure. This dissertation explains that both are needed concepts and are operating on different levels within the hierarchy of systems. However, if the consumer is not satisfied with the product or service, it becomes meaningless to talk about both efficiency and effectiveness. Thus, the product also needs to be sufficient, i.e. have the sufficient characteristics to become attractive to the customer. To achieve benefits from an increased eco-efficiency and eco-effectiveness of a technical system, it is essential that the consumer behavior is reflected in the selected solutions.

This gives basis to distinguish the two concepts efficiency and effectiveness even more, i.e. they are separated threefold. Thus, the challenge of environmental load of technical system is to find solutions to a threefold problem of

- Ecoefficiency: technical efficiency, which is the internal efficiency of the detailed solution of the product
- Ecoeffectiveness: organizational effectiveness, which is the infrastructural effectiveness of the product system
- Ecosufficiency: Sufficiency within the social system

The ecosufficiency dimension is needed to complete the interface between the technical- and social system.

The three different dimensions of economic and environmental performance of technical systems, cannot be combined, but they are simultaneously severely interconnected. The ecoefficiency dimension concerns the basic utilization of the technical solution of the product. The ecoeffectiveness dimension concerns the infrastructure in which the product operates.

Closing material loops is a challenge within the ecoeffectiveness dimension, and cannot be included in an efficiency parameter, which simultaneously covers the technical solution of the product. However, the technical solution affects how the material loops can be closed, and prepares the product for such EOL scenarios.

The ecosufficiency dimension concerns the production volume and sales, and thus is an indicator for customer satisfaction, and is present to prevent a boomerang effect where a beneficial improvement of the two other efficiency directions, turns into an increased production volume where the benefit is absorbed. The ecosufficiency dimension also describes the value of the product. The parameter includes a description of wether or not the product brings any quality of life.

Chapter 3 presented different theoretical models of the product development activities. The theoretical models describing the phases of activities involved in development work, are fundamental in all product development projects, including projects where the focus is improving environmental performance.

The link between the function means tree (i.e. the abstract level) and the product structure of components and parts (i.e. the physical level) is identified as a weak point when developing strategies for developing alternative solutions for improvement. This is one of the main challenges: to link the product model and the total life system model for the specific product. This is absent in the general product development models, and will be beneficial to identify the relationships between the product and the different product life phases and the embedded properties which are created during the synthesis phase of the product development activity.

The tools for estimating environmental load is identified as belonging to the physical level of the product structure, i.e. the lower levels of the function-means tree. Here the consequences of dispositions selected in the conceptual phases are visualized and alternatives for improvements are limited.

We therefore need to develop tools and guidelines for guiding the thinking process of the product developer into alternative solutions which breaks the present apprehension on how identified functions are satisfied using traditional means. This statement calls for investigating how methods of creativity can contribute in breaking the psychological inertia and come up with the correct balance between traditional and untraditional means to satisfy the identified functions. Traditional means to fit with present apprehension on how a need normally is satisfied and to satisfy a business' short term economic goals, and untraditional means to consolidate a component carrying the radical innovation contributing to moving forward towards sustainability, both in environmental and economic sense.

Chapter 4 described the creation process. Considering the area of sustainable development, researchers presently seem to be diverging into chaos, i.e. they have accepted that there is a dissatisfying situation where improvement of present solutions are required in the short term and new creative solutions are needed in the long term. Researchers around the world still have not united around a definition on the term sustainable. A lot of creative approaches are proposed trying to break with existing patterns creating pieces of valuable research results contributing to a broader understanding. However, the overall process of creating a sustainable society remains unsolved. All the bits and pieces within this chaotic phase will eventually lead into a converging phase where each piece of research work fits together into an overall solution.

The situation presently seems to be too much focused on analyzing data and generating alternatives to the details found to be the source. This approach automatically leads to incremental improvements of environmental performance. The reason for this approach may lie in the phenomena of technological lockin where companies and industries try to defend large investments in production capacity etc. which totally rely on present technological solutions, and which are not flexible enough to handle a totally different solution approach.

Furthermore, different techniques for generating new ideas for further development into product systems, are presented. The different techniques can be classified into tools for attention, escape and movement. The benefit of this three-part structure is that it opens the way to the development of an infinite number of methods for creativity. Importantly, techniques can be developed that are specifically suited to the issues the user is dealing with. As long as the new technique contains elements that focus attention, provides escape from the mental patterns normally associated with the topic, and encourages a high level of flexible mental movement, there is reason to believe that it stands as good a chance of working as any other creative thinking technique, and provide beneficial results.

The escape and movement phases are especially important when generating ideas which require mental escapes to challenge the laws of physics. Movement is also emphasized as important when moving forward from the mental escape into ideas for further development.

The model for the creation process is used as basis to suggest an approach balancing the need for accuracy and scientific validity as the hard creativity on the one hand and fantasy, mental escape and movement as the soft creativity on the other hand. The balance the two opposite issues is proposed to be integrated into the general product development model.

The modifications and redesigning products into new artefacts which makes a real difference in improvement in environmental performance, requires a fundamental analysis and understanding of the primary and secondary functions of the product. The tools and techniques presented in 4.5.2 Attention can contribute to this goal. This activity requires more of a hard creativity rather than the soft type as the scientific analytical skills, becomes more important than emotions and fantasy. The tools and techniques presented in 4.5.3 can contribute to generating ideas which can represent a true mental process of escape through identifying the ultimate scenario utilizing different means satisfying the defined function. Here, there is a transformation in the use of skills from the analytical to the emotional and fantasy related skills. The need to generate ideas without immediate judgment can contribute to identifying ideas with potential for improving environmental performance. Furthermore, the tools and techniques presented in 4.5.4 an contribute to moving the ideas into beneficial concepts which can be developed into profitable products and services.

Chapter 5 presents a strategy for leapwise environmental improvement of industrial product systems. The strategy involves four steps integrating the three different dimensions of environmental performance on completely different levels of a company and its interactions with its surrounding environment.

1. establish environmental and business perspective
2. optimizing ecoefficiency dimension on the product level
3. optimizing ecoeffectiveness dimension on the infrastructural level
4. optimizing ecosufficiency dimension on the holistic system level

Combining the three dimensions can give a leapwise improvement in environmental performance.

The strategy involves utilizing the holistic systems view and total life models as a basis to grasp the hierarchy of systems and their interactions with each other, and between the product and the overall system where the product is a component and the company is the supplier.

The strategy furthermore involves understanding why any customer wants to be a consumer in the overall system. The customer is consuming the function which the system provides utilizing the technical system of the product. This may not be only the primary function, but also involve elements of the social system which is affected by certain elements of the product.

When the overall system structure is identified, the structure analyzed keeping the separation principles in mind.

- Separation in structure and between parts represents an optimization of the product life of the technical subsystem, i.e. the product. This involves the traditional ecodesign approach where the product developer gradually improve the product into a modularized system containing modules and subsystems attached to a long lived core platform. The modularized product is prepared for two way product delivery and return logistics routes and prepared for closing material loops.

- Separation in space represent viewing the company and its interactions with suppliers, competitors and other stakeholders in a holistic system.The relationships between all parties can contribute to create a network for two way product delivery and return logistics routes for the mutual benefit for all parties.
- Separation in time represent the development of a product-service combination. As the two way product delivery and return logistics routes are established and up and running, the transfer of ownership from the customer to the service supplier creates a product-service combination.

Chapter 6 presents a critical view of the strategy developed in chapter 5. Introducing product service combinations as means to reduce the material and energy flow through the economy, requires the removal of some serious barriers to succeed.

- Consumers and other customers must accept the transformation from a product to a service, which may require changing lifestyles from individualism and ownership of things to a corporate culture necessary to develop product service combinations and succeed in the market. The service provider must understand customer acceptance prior to the service introduction.
- Products are cheaper than services because of the relatively small labour element in large-scale manufacturing and consumer demand for a greater service element is therefore limited due to cost. Furthermore, government policy seem currently to encourage the traditional “transactional economy” model of high economic growth through individual acquisition and ownership. Under-priced materials and over-taxed labour may obstruct the spread of service approaches even in business-to-business contexts.

  To change this scenario, a ecological tax reform supporting a shift from products to services would therefore be a governmental regulating contribution to improved environmental performance of industrial product systems.

The main result of this dissertation is a strategy for companies to use to develop product-service combinations for leapwise improvement of environmental performance. The strategy presented is an operational model presenting the key elements which a trasition from product- to service-based business activities, must contain.

The final proof that this strategy will lead to or at least contribute to leap improvement in envrionemtnal performance is difficult, as it has not been tried in industry. In addition, the difference in time between the end of a development project and the appearance of results from industrial projects in which the strategy has deliberately been used, makes it difficult to measure the results within a limited time period.

7.3 Research hypothesis and theoretical contributions

The basic questions this dissertation have tried to answer was presented in chapter 1.9.2.

The main supposition the research was based upon was that

> *It is possible for a company to achieve leap improvements in environmental performance using internal resources only*

During the research work, no observations have been made indicating that the basic supposition was wrong or had serious weaknesses. The supposition seem to be necessary, but not sufficient to achieve leap improvements in environmental performance.

For a company, the main focus must be on utilizing internal resources for the most efficient valuecreation of the organisation. An organisation cannot rely on external resources without internal players interfacing these external forces. External stakeholders are important players to exchange information and arguments, but an organisation must rely on internal resources on creativity and product development to increase and support competitive advantages.

To measure progress, it is important for a company to become aware of its own contributions to the local- and global environmental load. Lack of knowledge about a company's own emissions and resource use are barriers for progress in environmental performance, and may become an important limit for keeping market shares and access to new markets.

It is also important to understand the sources of environmental load. The source is described through the second law of thermodynamics, which explains how all actions have side-effects. A try to remove the side-effects of actions is a true physical contradiction which violates the second law. Any clever solutions aiming to reduce the side-effects of the original action will have side-effects of its own.

Research contribution

This research has contributed to

> *a clearer understanding of the source of environmental load during the meetings between product and product life system where any action to reduce the original load will result in load of its own which means that the fundamental cause of load is still not resolved. Any attempt to remove the fundamental cause of side-effect is a true physical contradiction which violates the second law of thermodynamics.*

Measurements is needed to understand the current status of a business regarding environmental performance. Furthermore, measurement is needed to establish the perspective for improving environmental performance. The current status forms the basis for all improvement related activities. without measurement, establishing a vision for goals of the future becomes impossible. As all improvement measures are relative to some viewpoint, current status regarding efficiency of material and energy flows through the company as a system with its interfacing upstream and downstream network of systems, is vital. Especially, when establishing a vision for leap improvement it is essential to know and understand current status, and develop goals and system boundaries for product and product system development projects. Thus, hypothesis A

> **A** *Methods for measuring environmental load of a product system in a sufficient way is needed to keep track of progress of environmental performance.*

is supported through this research.

The link between the function means tree (i.e. the abstract level) and the product structure of components and parts (i.e. the physical level) is identified as a weak point when developing strategies for developing alternative solutions for improvement. This is one of the main challenges: to link the product model and the total life system model for the specific product. This is absent in the general product development models. It will be beneficial to identify the relationships between the product and the different product life phases and the embedded properties which are created during the synthesis phase of the product development activity.

Thus, the findings support hypothesis B

> **B** *Traditional product development models lack sufficient elements making them suitable for environmental considerations in development of industrial products.*

Traditional product development models lack the element of life span thinking, which is essential in development products when focusing on environmental performance.

Furthermore, traditional product development models lack the element of integration along the value chain. It is not enough only to see the relationships between the product and product life phase systems. This finding also support hypothesis B. The theory of disposition illustrates the need to include this integration dimension, i.e. all decisions performed during product development, affects type, content, efficiency or progress of activities in subsequent product life phases.

When considering environmental performance, large amounts of information is needed to understand the environmental interactions between the product and its meetings with the product life phase system. However, it is not enough to acquire the product life span perspective, and gather information on the meetings between the product and product life systems. The information must be relevant and meaningful with respect to protecting the environment and human health and / or improving the quality of life. Moreover, the information must be able to inform decision making in the product development activity to improve the performance of the product or product system.

Consequently, integration along the value chain is essential for leap improvement of environmental performance of industrial products.

Research contribution

This research has contributed to

a clearer understanding of the need not only to integrate the different disciplines across a company's operations, but also integrate along the value chain to capture the valuable information which arise during meetings between product and product life systems.

The tools for estimating environmental load is identified as belonging to the physical level of the product structure, i.e. the lower levels of the function-means tree. Here the consequences of dispositions selected in the conceptual phases are visualized and alternatives for improvements are limited. This finding supports hypothesis C

C *Traditional product development models lack the support systems to conquer barriers and break out of existing mind patterns of technological lock-ins to create completely new systems with significantly improved environmental performance for delivering customer needs.*

Traditional product development models focus too much on existing mind patterns. The demands of time to market makes using existing information and redesigning existing product systems important elements to reach milestones on the time schedule. Traditional models favour the need for rapid product development. Although the models do not support performing the work insufficiently, it can turn into rush jobs spoiling the opportunities to make a real difference in improving environmental performance.

By explicitly expressing the important link to creative methods for systematic generation of ideas, the situation described here can be avoided. The models emphasize the need to focus effort on the conceptual stage of the development activity. Brilliant ideas may arise from nowhere, but this situation rarely occurs when new ideas are needed. A product development team cannot rely on serendipity when they have a deadline to meet.

As argued in chapter 3.8, "Discussion on innovation- and general product development models" and 3.11, "Concluding remarks on innovation and product development", product development models focus too much attention to existing mind patterns. The demands of time to market makes using existing information and redesigning existing product systems important elements to reach milestones on the time schedule. This finding also supports hypothesis C.

Research contribution

This research has contributed to

a clearer understanding of the need to include creative techniques into the early phases of product development proejcts where dispositions for subsequent project phases and subsequent product life phases are disposed and locked against subsequent major modifications. Creative techniques contribute to the break out of existing mind patterns and contribute to the creation of solutions which reduce the business-as-usual pattern and which acts as a barrier to leap improvement in environmental performance

Market forces sustaining present business practices are still strong enough to keep supporting consumption growth without improvements in material and energy use. Customers are simply not ready for integrating reduction thinking into their criteria for selection. This lack of positive market response of truly innovative products and services, is also a barrier for further development of ideas which can break out of technological lock-ins and create completely new systems with a true benefit in material and energy consumption and significantly improved environmental performance for delivering customer needs. This is also a barrier to using environmental criteria as guidelines for creative thinking. The market forces are however, the leading guidelines for product development, and naturally cannot be neglected.

The lack of positive market response can also explain why industry is evasive to establish long term visions of their environmental perspective, and develop strategies to reach these visions. The vision and goals for environmental performance defines the boundary conditions for product development projects in a company. This seems to be the main cause why exploring results of unbiased creative exercises, which may lay outside current business practice, are often rejected and further development is omitted.

The phenomena of technological lock-in is used in the dissertation as one explanation to the reason why mostly incremental improvements of environmental performance are found in industry at present.

Thus, hypothesis D

> D *it is possible to overcome the barriers of renewal due to technological lock-in by stimulating internal players and resources within a company*

is supported. Establishing a vision with the company's environmental perspective and goals has been identified as vital to stimulate for finding solutions for leap improvement in environmental performance. The vision becomes incentives to establish strategies for leap improvement. Establishing outrageous goals will stimulate for finding solutions which differ from current procedures and thus break out of technological lock-ins which form barriers to leap improvement.

This also supports hypothesis E

> E *innovation and product development are the only activities where companies themselves can stay in control, and combine internal interests with the external interests of customers and nature, i.e. to develop technical systems where their interactions with social systems and natural ecosystems are optimized based on sustainability criteria.*

is supported by the resulting strategy prresented in chapter . The external influencing issues initiating internal response are affected by increasing supply chain pressure, public opinion, energy costs, waste charges, take-back obligation, norms and standards, eco labelling schemes, subsidies, environmental competition, etc. All of these are out of internal control, and the only issues companies control themselves are the response to these issues. This is another argument supporting research question E.

Boundary conditions which form the framework in which a company has to operate, changes continously. Customer attitudes in the market, legislation, suppliers and competitors are all dynamic in their behavior, although a static environment would be predictable and therefore appreciated. A company is not able to control these interfacing elements of the system network where it operates. They are controlled by other stakeholders, and can only in a limited sense influence decisions to comply with their own goals. Innovation is here identified as one of the potential strategies to overcome technological lock-ins. Satisfying requirements from customer and other stakeholders through being innovative, is the core issue of internal players of an organization.

The product development task is therefore the only activity where the company itself can stay in control and approach the market based on their own vision and goals.

Creativity as a vital element of the early phases of product development, is essential in developing ideas and new solutions to develop further into products and product systems to approach the market. The product is expressing to the market the creative abilities and tacit knowledge of the members of the product development team. Creativity and product development is thus visualizing the tacit knowledge of the individuals of the organisation.

The theories of Nonaka and Takeuchi explain the link between creativity, innovation and product development, and explains how environmental awareness and consciousness, can be distributed throughout an organization.

Research contribution

This research has contributed to

> *a clearer understanding of the need to identify and develop the company's environmental perspective. The need to develop strategies for improving environmental performance of company internal processes, product systems and systemic networks of actors along the value chain is vital to achieve leap improvements in environemntal performance.*

It is claimed that the strategy presented in chapter 5.8, will significantly improve environmental performance of industrial products and product systems. The strategy is developed using the separation principles on the structure of the product system to overcome the physical contradiction of eliminating the side effects of the action of design, manufacture and delivery of a product. However, we must not fool ourselves through believing that the side effects can be removed, and that is not the intention of the separation principles. Product developers cannot challenge physical laws with success. However, the mental escape by thinking laterally that removing side effects is a potential option, makes new creative ideas arise through the use of the separation principles.

Thus the word apparently is important when considering research question F:

F *When combining innovation on technical, social and organizational/ infrastructural levels, it is possible to design industrial product systems with greater benefit and apparently without side effects by significantly reduced environmental loads, compared to when considering technical, social and organizational/infrastructural innovations in isolated.*

and

G *utilizing the creative tools and methodologies can guide the development of transitions from products to product-service combinations.*

The proof of these two hypotheses is the strategy for transition to product-service combinations presented in chapter 5.8. The strategy presented is an operational model presenting the key elements which a trasition from product- to service-based business activities, must contain.

The eighth line of evolution was originally formulated by Altshuller to read the development of technical systems proceeds in the direction of increasing the S-field involvement. This can be interpreted as explained in 5.4.3 as an evolution towards decreased human involvement. Other findings in literature also support the notion of increased automation of technical systems in general. This indicates that the product to product-service transition is a tendency from which industry can benefit and increase competitiveness.

Research contribution

This research has contributed to

a clearer understanding of the barriers to overcome to transform products-based business to service based business.

7.4 Recommendations for further research

A number of themes have been presented in this dissertation, and they can all be elaborated further. However, it is more important to take the existing and currently developed strategy into practice. It is important to further investigate step 2, 3 and 4 to understand under which circumstances the theoretical model works satisfactory and which circumstances it is insufficient.

- Take the existing strategy of product service transition into practice. Apply the existing sets of tools in order to solve a specific transition from product to product service combination, and explore the benefits and weaknesses.
- Clarification of how to further stimulate the implementation of a transition from product based to product service based business activities. Apply cross boundary research on the links between economics, policy,

business strategy, product and service development, consumer behavior, company involvement, etc.

Thereafter, the research efforts can be focused on specific issues. From the insight of this dissertation a feew areas can be identified:

- Extend the insight for how to close material loops in value chains. Design for environment approaches for preparing products for disassembly and reassembly. Is standardization of components adviseable or prefferable? How do standardization of components affect changing consumer lifestyles, and how can changing lifestyles merge with standardized remanufactured attractive products?
- Explore how to make an environmental vision the commitment for all actors along a whole value chain.
- Changing human behavior is probably a lot more difficult approach than changing technical systems. However, the social change into behavior that reflects sustainability criteria in activities has a much larger potential for real jumps forward than changing the interacting technical systems. Afterall industries supplying technical systems is only supplying goods and services customer wants to acquire.

  Consequently, research on consumer behavior and lifestyles, exploring what we think quality of life actually means can give insight into the understanding on why a service approach is unsuccessful within certain industry areas.

  This emphasize the need to understand how consumers and business customers accept procuring functions and services at the expence of procuring products. Customer acceptance is vital for the transition from product focus to service or function focus.

  The ecosufficiency approach must focus on what goods and services are sufficient to meet the basic needs to maintain a sufficient quality of life in respect of the democratic principles of individual freedom.

CHAPTER 8

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