

DESIGN FOR RECYCLING IN CONCURRENT ENGINEERING

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FOREWORD

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I hope this study encourages the companies which are working for electrical electronic and other products. I think this thesis will be a assistant to designers who work for environmental products.

Finally, i would like thank to my family. Special thanks to my sister for helping me during the study. Also, i would like to thanks my parents for supporting me during the all education period.

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ABBREVIATIONS

ABS	: Acrylonitrile Butadiene Styrene
AEM	: Assembly Evaluation Method
CAD	: Computer Aided Design
CE	: Concurrent Engineering
DFA	: Design for Assembly
DFD	: Design for Disassembly
DFE	: Design for Environment
DFR	: Design for Reliability
DfR	: Design for Recycling
DSP	: Design for Sequence Planning
EEE	: Electrical Electronic Equipment
EOL	: End-of-Life
PCB	: Printed Circuit Board
RoHS	: Restriction of Hazardous Substances Directive
VDI	: The Association of German Engineers
WEEE	: Waste Electrical Electronic Equipment

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DESIGN FOR RECYCLING IN CONCURRENT ENGINEERING

SUMMARY

Nowadays, companies are looking for new production techniques to be able to compete with other companies. Therefore, the companies, which are given up sequential engineering, adapted the concurrent engineering. Concurrent engineering is the approach that breaks the walls between all disciplines. CE can be implemented at design stage; therefore, mistakes at production stage can be prevented at design stage.

With concurrent engineering approach, companies can respond to market demands rapidly so, everyday new technological products are developed by the companies. Reducing technological cycle of products causes the increase of waste electrical electronic products.

In Western countries, regulations are prepared to guide the public to collect of end-of life products. Disassembly and recycling processes are done with control of government. End-of-life products are separated from each other such as following; Wear-out cycle, technological cycle, design cycle and redesign reasons.

End-of-life products are disassembled before the recycling process. Disassembly is the systematic removal of parts from an assembly. Disassembly process types are; Sequential and parallel, destructive and non-destructive, total disassembly and selective disassembly. Most common used disassembly type is selective disassembly, because, disassembling only the needed parts allows to required parts reuse, recycling.

Design for recycling totally contains design for disassembly and design for recycling options. Design for recycling is not a popular design approach for companies, but legislations, marketplace and cost reduction, forced companies to implement design for recycling. Design for recycling has three options, in order to their priority, reuse, recycling and incineration.

In design for recycling approach most important changes due to design for disassembly and material selection issues. In this study, a ball mouse and an optical mouse have been disassembled and these mice were compared according to design for recycling rules and design for disassembly rules. Finally, the differences on mouse design in a time interval are reviewed.

EŞZAMANLI MÜHENDİSLİKTE GERİ DÖNÜŞÜME UYGUN TASARIM

ÖZET

Günümüzde şirketler piyasa rekabetine direnebilmek için her geçen gün yeni yollar aramaktadırlar. Bu sebeple sıralı mühendislikten vazgeçen veya istediği verimi alamayan şirketler, eşzamanlı mühendisliği benimsemişlerdir. Eşzamanlı mühendislik ile bütün disiplinler arası engeller ortadan kalkarak çalışmalar eşzamanlı olarak yapılmaktadır. Eşzamanlı mühendislik, ürünlerin tasarım aşamasında da kullanılarak ürünlerde tasarımdan sonraki aşamalarda ortaya çıkabilecek hatalar engellenmiş olacaktır.

Şirketlerin, piyasa taleplerine eşzamanlı mühendislik ile hızla tepki verebilir hale gelmeleri teknolojik değişimlerle birlikte yeni ürünler her gün artarak ortaya çıkmaktadır. Ürünlerin teknolojik ömürlerinin hızlı tükenmesi, hızlı moda değişimleri, atık elektrikli ve elektronik ürünlerin artmasına sebep olmaktadır.

Çeşitli batılı ülkelerde regülasyonlarla veya halk bilinçlendirilerek ömür sonu mamuller toplatılmakta, demontaj ve geri dönüşüm işlemleri devlet kontrolünde sürdürülmektedir. Bu ömür sonu mamuller ise kendi aralarında ayrılırlar. Bunlar; Aşınma ömrü, teknolojik ömür, tasarım ömrü, yeniden tasarım sebepleri.

Ömür sonu mamuller geri dönüşüme uğramadan önce demontaj prosesine tabi tutulurlar. Demontaj prosesi sistematik olarak montaj halindeki bir ürünün parçalarına ayrılması işlemidir. Demontaj prosesi uygulama alanlarına göre, sıralı ve paralel, yıkıcı, yıkıcı olmayan, toplam demontaj, seçici demontajdır. Demontaj prosesleri içinde en çok kullanılanı seçici demontajdır çünkü geri dönüşüme uğrayacak olan ürüne bir zarar vermeden parçalara ayırarak, gerekli parçaların tekrar kullanımına olanak sağlar. Demontaja uygun tasarım yapılırken karşılaşılan en büyük problemlerden biri kompleks ürünlerdir. Bu tür ürünlerin demontajını kolaylaştırmak için ise parçalar, bağlantılar ve bağlantı elemanları için uygulanması gereken kurallar bulunmaktadır.

Geri dönüşüme uygun tasarım, bütünüyle geri dönüşüm seçenekleri ve demontaj prosesini kapsamaktadır. Geri dönüşüme uygun tasarım şirketler tarafından pek rağbet görmese de yasal zorunluluklar, pazar baskıları ve maliyetin azalması sebebiyle giderek yaygınlaşmaktadır. Geri dönüşüme uygun tasarımda üç seçeneğimiz vardır, kullanım önceliklerine göre bunlar; Yeniden kullanım, geri dönüşüm ve yakma işlemidir.

Geri dönüşüme uygun tasarımda en önemli değişimler demontaja uygun tasarım ve malzeme seçimlerinden kaynaklanmaktadır. Bu çalışmada bir toplu mouse ve optik mouse demonte edilerek karşılaştırılmış, yıllar içerisinde bu üründe geri dönüşüme uygun tasarım açısından ne gibi değişimler olduğu belirlenmiştir.

1. INTRODUCTION

Nowadays, fast changing technology, fashion trends, customer demands pushed the engineering companies to new researches. Concurrent engineering is the best way for response to consumer demands. Companies take up seriously concurrent engineering because, it has a great number of benefits like reducing product development costs, improving quality, reducing manufacturing times. Design processes such as, design for manufacture, design for environment, and design for assembly, to help the new product development stage are implemented in design stage. These information will be given in second and third sections.

Fourth section is about product's end-of-life stage. This section consist of end-of-life strategies and end-of-life scenarios for the difference countries. Also, processes and current end of life technologies will be mentioned.

The fifth section consist of design for disassembly approach for design for recycling because design for disassembly is the previous design stage for products recovery. To ease the design for recycling basic design for disassembly rules are mentioned in that section, such as reducing fastener number, basic connection types, etc. Besides, this section consists design for disassembly sequence planning rules.

Design for recycling approach is mentioned in sixth section. To implement the design for recycling, keeping the rules is needed. Most of them related to design for disassembly approach but especially material selection issue special to design for recycling approach. Data collection and rating system for components are important subjects for design for recycling and they are mentioned in this section also.

Finally, a case study will be implemented in seventh section. In the case study an optical mouse and a ball mouse will be reviewed and compared according to design for recycling approach. Each of the mice will be disassembled manually and reviewed related to design for disassembly and design for recycling approaches. Fastener types, component types and material types are reviewed in seventh section.

2. NEW PRODUCT DEVELOPMENT PROCESS

At new product developing process, there will be many demands and limitations depend on design and production. Predominantly these are: Design autonomy as possible, creativity, minimum tolerances, time and place necessary for creativity, production producibility, desire for using tested technology, maximum tolerances, and production pressure because of quick solution.

Two types of approaches are used in new product development process. These are sequential engineering and concurrent engineering approaches. Nowadays, for developing new or existing product mostly sequential engineering is used. Concurrent engineering is at the opposite of sequential engineering. Technically and economically concurrent engineering is the approach that succeeds if implemented to achieve aims. Because of these reasons, latterly concurrent engineering is getting popular [1].

2.1 Sequential Engineering

Before understanding of concurrent engineering, it is a right way to describe the sequential engineering. Because, it is important to know advantages and disadvantages for implementing the concurrent engineering.

In a manufacturing organization, marketing identifies the need for new products, price ranges and their expected performance from customers or potential consumers. Design and engineering generally receive loose specifications. Besides, they work alone to develop the technical requirements and final design detail as well as the related documentation such as drawings and bills of materials etc.

As design is carried out in relative, manufacturing, test, quality and service function only see the design in an almost complete state. As the process is sequential in progression, each stage of product development following completion of the previous stage, it is commonly known as sequential engineering [2].

Sequential process of a new product development is illustrated in Figure 2.1. Each design stage starts only when the previous one is complete. Product design develops a product and then throws it to the production engineering department.

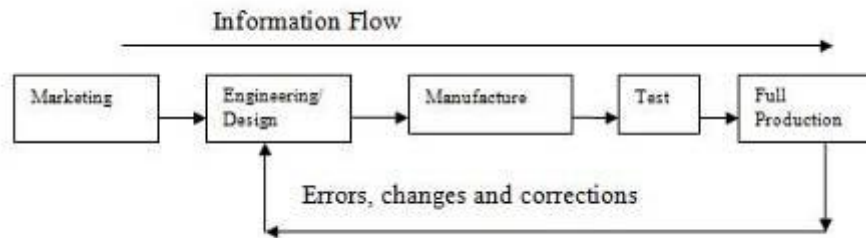


Figure 2.1 : The sequential engineering process

Later, production engineering tosses the product into the factory, and the same problems occur with same aspects of production and quality control. The opinions of the specialists are asked only when the design is completed. The product designers and manufacturing engineers know where the quality problems are, but have not eliminated them. Finally, the marketing people are called in. They have already heard the complaints of the production engineers, plant management and quality control department about the product. Figure 2.2 illustrates the sequential engineering flow diagram and gives more information about design development stage sequentially.

In this sequential method of operation, a change required in a later stage will delay the operation and cause additional costs in the following stages. Additionally, the subsequent stages will be delayed until the current stage has been completed.

This traditional sequential method has not entailed the dialogue between design and the downstream processes except through a series of standard engineering change orders. In summary, they include; Insufficient product specification, leading to an excessive amount of modifications, little attention to manufacturability issues of the product at the design stage, the estimated costings are usually degrees of magnitude in error, due mainly to the uncontrolled late design change costs [2].

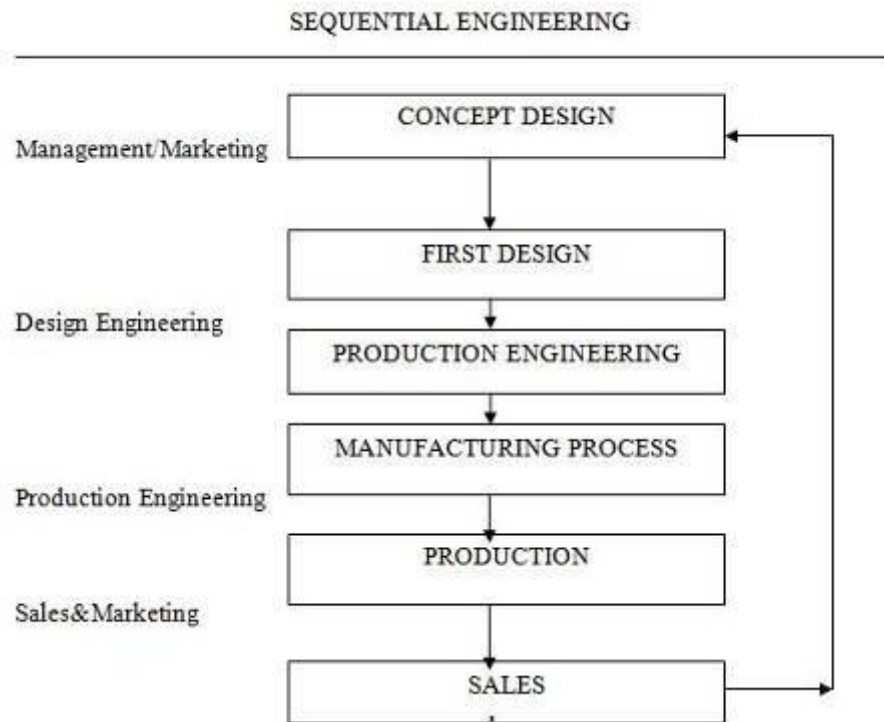


Figure 2.2 : Sequential engineering flow diagram

2.2 Concurrent Engineering

Concurrent engineering (CE) is a systematic approach, which meets customer's demands and provides product development. Designers consider that philosophy at design stage. To implement the concurrent engineering a team must be composed and this team must be multidisciplinary. Concurrent engineering philosophy improves the product quality also decrease development time and costs by preventing the errors at design stage. Concurrent engineering provides high product functions, lower costs and optimum quality at design development stage [3].

Figure 2.3 illustrates that a team designs new product development in concurrent engineering concurrently.

When detailing a design all of the specialists' decisions are notified so the corrections on the design are prevented. This method decreases time loss due to the redesign; by the way, design costs can be minimum.

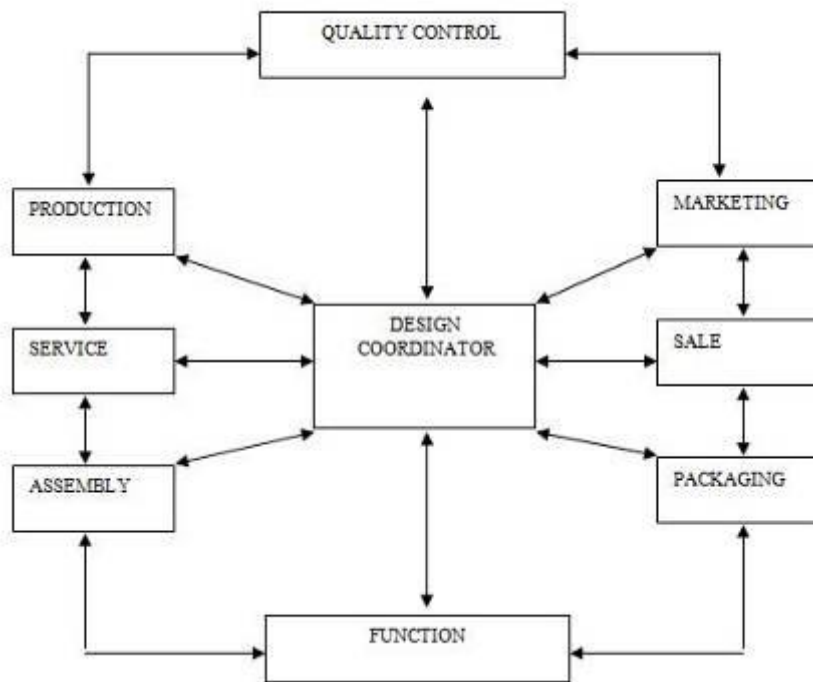


Figure 2.3 : Concurrent engineering blog diagram [3]

With the concurrent engineering approach;

- The role of manufacturing operation increases on product design decisions.
- Flexible teams could be made up.
- Customer demands are in the foreground when determining the product's functions.

2.3 Comparison of Concurrent Engineering and Traditional Engineering

In traditional engineering a relatively short time is spent defining the product. A relatively long time is spent designing the product and long time is often spent redesigning the product. The key to shortening the overall design time is to better define the product and better document the design process.

Traditionally, the development of a product had been seen as a cycle of plan, do, check, act. This is the relatively recent term that is applied to the engineering design philosophy of cross-functional cooperation in order to create products, which are better, cheaper, and more quickly brought to market.

This new trend reunites technical and non technical disciplines such as engineering, marketing and accounting.

At Figure 2.4 concurrent engineering and traditional engineering is compared basically due to number of design changes and time.

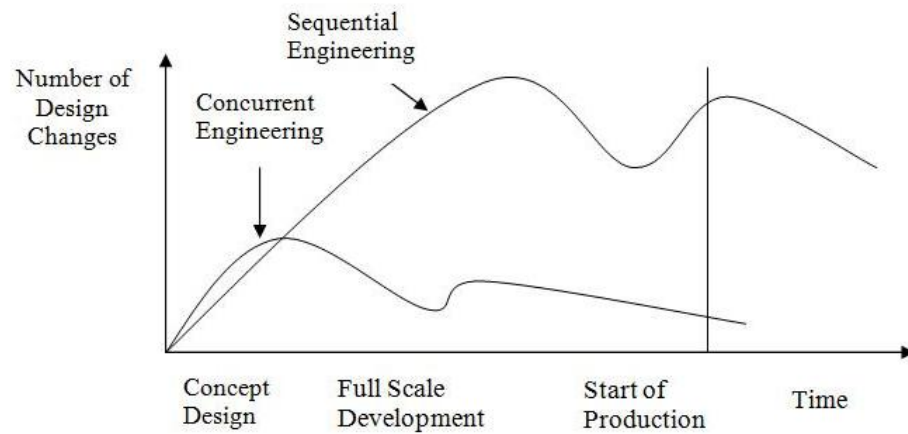


Figure 2.4 : Example of design changes as a function of time for automobiles [4]

3. CONCURRENT ENGINEERING

Demand of customers, fast change in technology, environmental issues, hard competition on quality and cost, and shorter time to market products with additional new features are new challenges for engineering companies.

This expensive technology was largely ineffective, because the new tools were used with existing structures, practices and attitudes. Products continued to arrive in the market place at unsatisfactory quality levels, and often too late achieve sales and profit objectives. Their efforts were also undermined by short-term successes during market booms.

A new product development strategy and implementation has evolved and teamwork has gained importance in product development. This has been due to the need to get the output research faster. Companies that are implementing concurrent engineering and overall concurrent project management in product development have realized great success, which supported this revolution [2].

In this section, concurrent engineering will be discussed extendedly. This section consists, concurrent engineering benefits and objectives. Moreover, this section consists concurrent engineering design processes and some basic principles about concurrent engineering. The aim of this section is a preparation for design for recycling approach.

3.1 Concurrent Engineering Requirements

Concurrent engineering provides a systematic and integrated approach to introduction and design of products. The concurrent engineering approach is illustrated in Figure 3.1 graphically.

Effective concurrent engineering practice requires good communications between different functions associated with the product life cycle. The information must have common ownership, be shared freely and easily and freely accessible. Since information is the power in functionally organized traditional companies. Concurrent

engineering is therefore the integration of all company resources needed for product development, including people, tools and resources, and information [2].

- Requirements of representation products to new markets in global economy.
- Regeneration of organizations and redesign of working areas.
- To dominate the market, new product development time requires being short.
- Urgent requirement to new technologies for product development.
- Remaining customer demands about reliability and quality.
- Due to increasing complexity of new technology products, remaining customer demands on service and maintenance.
- Coming into question of environmental protection subject thus new product development according as to environment [1].

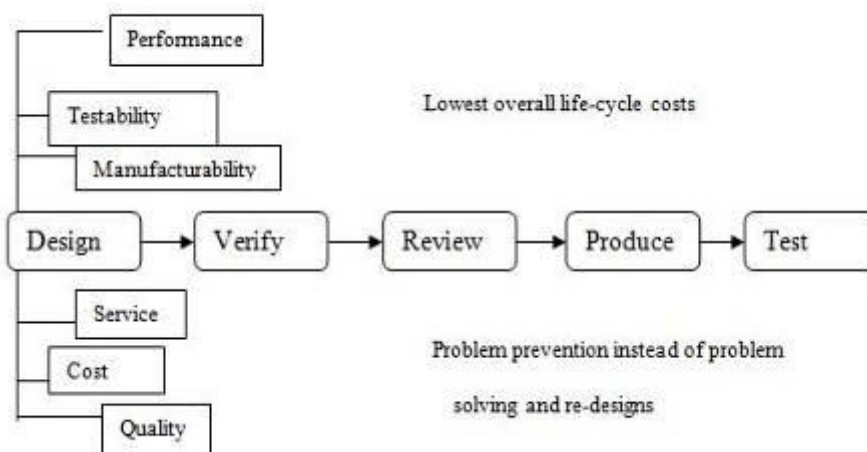


Figure 3.1 : The Concurrent engineering process [2]

3.2 Objectives of Concurrent Engineering

Studies considering the costs associated to a product during its entire life cycle have demonstrated that usually costs are determined during the design phase. So, the best savings can be done during the design stage moreover, the earlier the improvements are made. The purpose of concurrent engineering is to guarantee that the decisions taken during the design of a product result in a minimum overall cost during its life cycle [2].

The main objectives of concurrent engineering may be summarized as follows:

- Decreased product development time;
- Improved profitability;
- Greater competitiveness;
- Greater control of design and manufacturing costs;
- Breaking the walls between departments;
- Decreasing the new product development time;
- Improving the product quality

3.3 Benefits of Concurrent Engineering

Concurrent engineering was implemented at automobile industry firstly. Automobile industry has implemented concurrent engineering, without using its name. These studies compared the time to market of Japanese and Europe automobile manufacturers. Figure 3.2 and Figure 3.3 shows the projects studied, typical Japanese companies could develop and introduce a new car to market in 43 months where this time was 63 months for the projects studied in Europe.

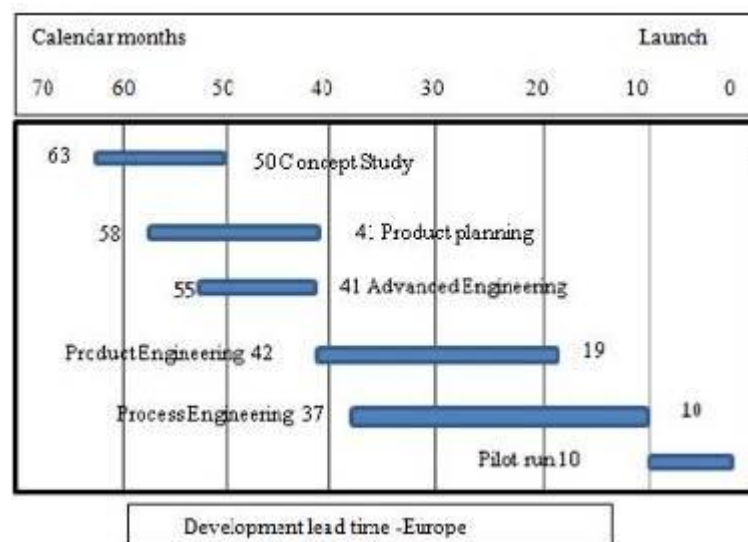


Figure 3.2 : Comparison of EU and Japanese development lead times (EU) [2]

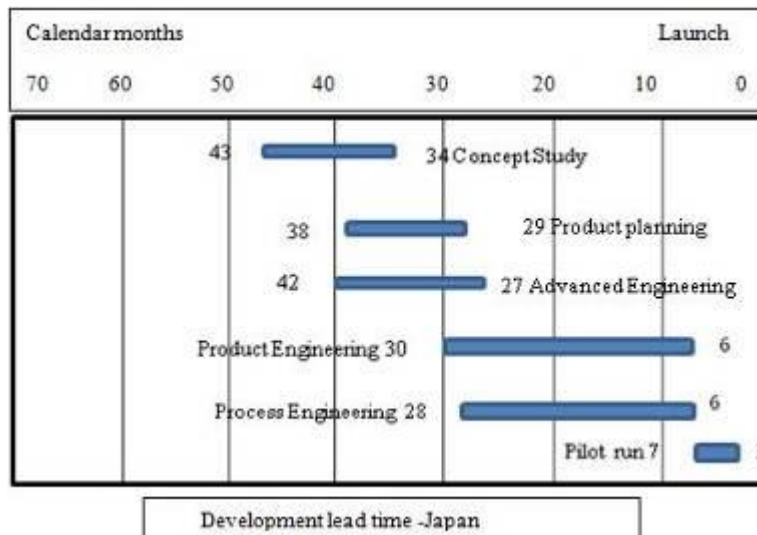


Figure 3.3 : Comparison of EU and Japanese development lead times (Japan) [2]

Figure 3.4 shows the reducing trends in product life times and the increasing development times for electronic products. The increase in product development times is partly due to the increasing complexity of the products.

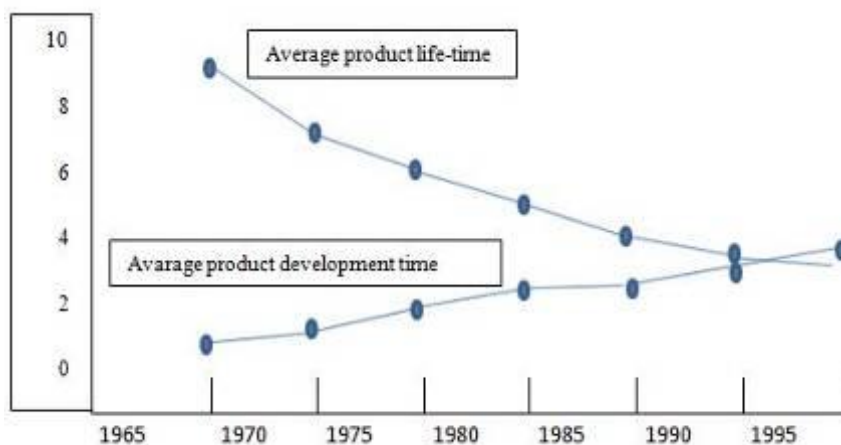


Figure 3.4 : Product development time versus the product's lifetime

Delays in bringing a product to market certainly result in greater losses of profit. A simple method to measure the impact of delays in launching a product, as shown in Figure 3.5 for example, considering a 12-month market window, a delay of two months in launching a new product will result in 24% loss in total lifetime revenue.

Concurrent engineering is necessary to companies that desire to remain competitive, improve their products and processes continuously and keep their development ahead of the competition.

Reduction of time to market allows companies to increase their market share and reduce design changes and design iterations. They are more easily manufacturable, serviceable and are of higher quality. Once released to manufacturing, production progresses quickly to full volume because the process is well defined, documented and controlled. The remarkable performance achieved by world-class companies has been the best proof of the effectiveness of concurrent engineering. It is important that a company sets specific aims for itself when moving from the sequential engineering to the concurrent engineering [2].

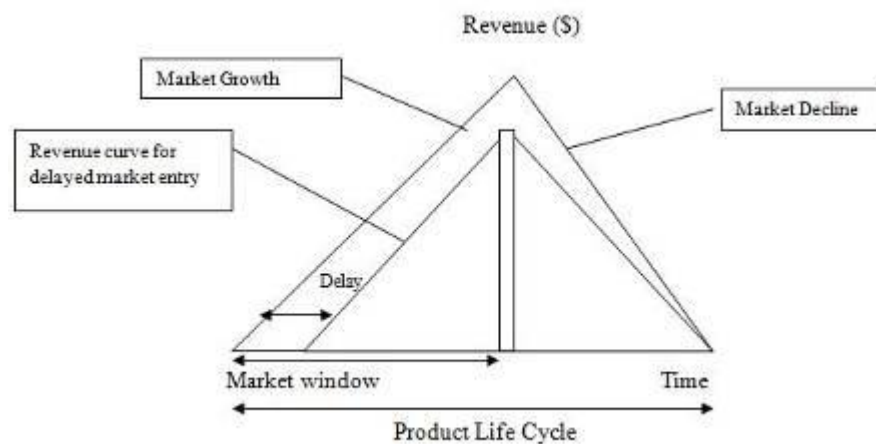


Figure 3.5 : Revenue loss due to delay to introduce a new product

3.4 Basic Principles of Concurrent Engineering

Concurrent engineering is founded on five fundamental principles:

- **Early Problem Discovery:** Problems discovered early in the design process are easier to solve than those discovered later.
- **Early Decision Making:** The window of opportunity to affect a design is much wider during an early design stage than at a later stage. Teams often have the natural tendency of making quick and novel decisions, which is good, except those decisions should be continuous as well.
- **Knowledge Leveraging:** The interest of product design is often very large. It may be impossible to create a general purpose automated or knowledge-based system, which will use suitable tools and knowledge-driven rules (to guide decision-making).

- Common Understanding: Teams will work better if they know what other members are doing.
- Ownership: Teams will work spiritedly to make good product if they are encourage to make decisions in shaping the design and are given ownership of what they produce [5].

3.5 Components of Concurrent Engineering

The achievements of concurrent engineering come from the success of its components. Success of concurrent engineering depends on the part of those who participate in it. In concurrent engineering, every participant is expected to contribute to making the final product, from marketing and industrial designers, analysts, to production engineers and support personnel. The following discussion describes the basic components of concurrent engineering [5].

3.5.1 Multidisciplinary setup

Concurrent engineering is planned around multidisciplinary teams that specialized about process for the product development [6]. The multidisciplinary team is occurred from several disciplines some of are:

- Product planners
- Product concept engineers
- Engineers and analysts
- Product designers
- Prototype engineers
- Production engineering planners
- Management and control

3.5.2 Teamwork

The fundamental of the concurrent engineering is, to combine team abilities to produce results greater than any single team member effort. At concurrent engineering, people play an important role in making the process work. There are qualities to look for concurrent engineering workgroup:

- Authorization: This means giving a design team freedom, authority to get the job done right.
- Assignment: Identifying what skills are required for what portion of the work.
- Organization: This definition requires of the major objectives of the team including team building procedures, brainstorming, and other human dynamics tools.
- Measurement: The team should focus on collectively defining the product development goals.
- Technical Memory: It is responsibility of the technical core team to provide an environment fit to capture the lessons learned into some form of technical memory to use later.

3.5.3 Global participation

In the concurrent engineering teams subcontracting companies must be included as participants. The distributors often tell consumer demands to product manufacturers. Requirements can be stated in joint terms, which the subcontractor can effectively satisfy.

Nowadays, because of the growth in the complexity of products and the increased reliability on specialized technologies to manufacture them, partnership has become an increasingly important issue.

A list of typical participants of a virtual company is shown in Figure 3.6, they are mostly contract employees. There is a global partnership between the participants, the product manufacturers, process planners, robots, machinists, parts suppliers or materials suppliers, and product supporters.

Establishing a partnership can be strategically very important. It can eliminate or minimize the needs for in house inspection. Other claimed benefits of partnership include greater satisfaction to the customer, simplified recycling, fewer computer entries, smaller inventories, and greater economy of scale.

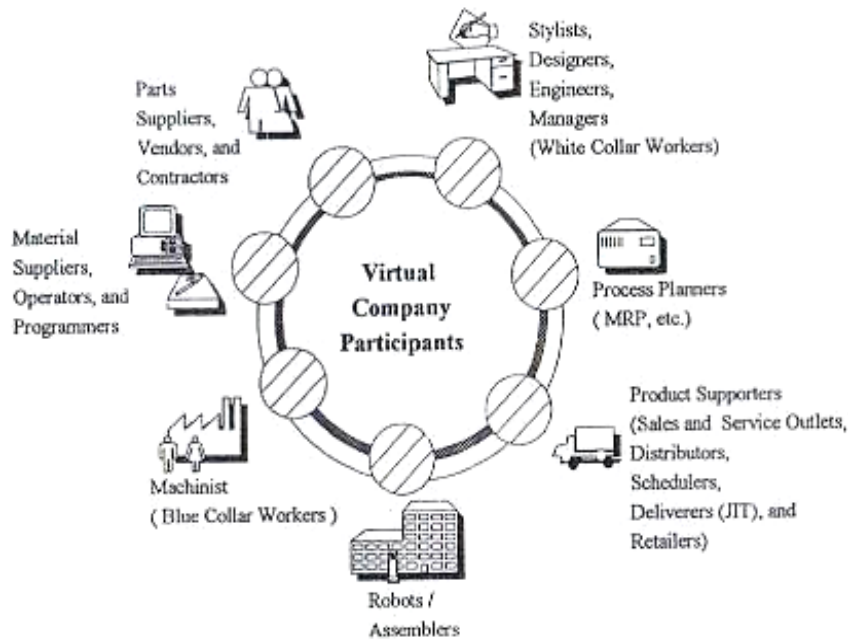


Figure 3.6 : Typical participants in a virtual company [5]

For example, the mobile phone manufacturers such as Nokia, Samsung, Sony Ericsson, and Motorola made a deal about battery chargers. As known, each manufacturer has a specific charger jack to prevent the consumer's problems they decided to standardize the all of the mobile phone's jacks.

The suppliers design and develop the product with their mentality or comment of the specifications. Such work order can proceed in a traditional fashion as long as the suppliers are able to satisfy stated requirements. Figure 3.7 illustrates the traditional customer supplier relationship graphically [5].

In the traditional customer supplier relationship one of the major faults is that no input search before specification is developed. To decrease this, manufacturers sometime engage in a two-phase contractual agreement with their trading partners. This is shown in Figure 3.8 graphically.

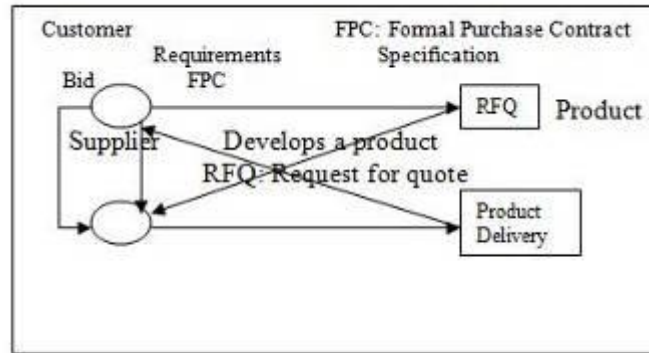


Figure 3.7 : Traditional customer supplier relationship

For customers to include subcontractors and suppliers as partners from beginning there is a third alternative. This is shown in Figure 3.9 there is collaboration at all levels. The subcontractors and suppliers learn how to apply concurrent engineering tactics in their share of the product. This type of contractor is known as a strategic partnership.

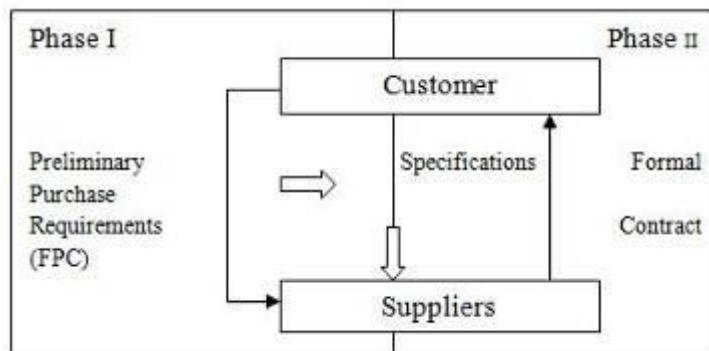


Figure 3.8 : Two-phase contractual agreement

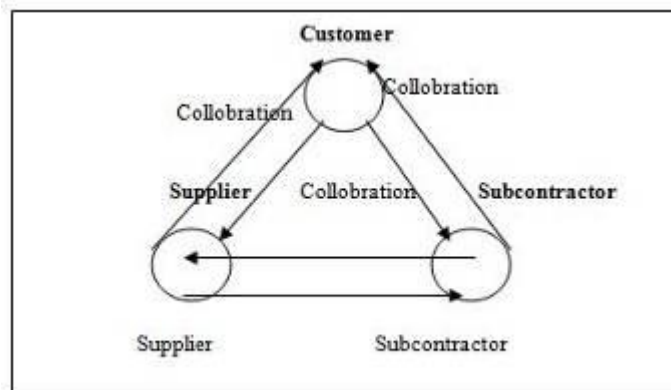


Figure 3.9 : Via partnership & Mutual Learning

3.6 Design Processes in Concurrent Engineering

Common purposes of the design processes are, measuring of design quality and carry out the measured design. Quality is defined by words such as; parts number, ease of assembly, size of tolerance and functionality [4].

Some of the design processes are:

1. Design for manufacture
2. Design for assembly
3. Axiomatic design
4. Design for quality
5. Design for maintainability
6. Design for reliability
7. Design for environment

3.6.1 Axiomatic design

Axiomatic design is very difficult because, axioms are not clear, apparent and easy to apply. Owing to axioms are suitable for comment, experiences are very important on decisions. The designs, which are made with axioms, do not satisfy [4].

The fundamentals of axiomatic design:

- Number of functional limitations and requirements must be minimum.
- The functional requirements, which are most important, must be first, the most insignificant must be last.
- The content of information must be set down to least.
- If functional requirements are connected each other, last design parts must separate one another.
- Suitable solutions can be found with lots of way.

Results of axioms:

- Numbers of parts are not criterion for efficiency.
- The cost of product is not proportional to surface area.
- Number and complexity of the surfaces must be minimized.
- Avoid from mistakes to separate the parts as demanded.
- Use standardized parts as possible.

3.6.2 Design for manufacture

Design for Manufacturing (DFM) and design for assembly (DFA) are the integration of product design and process planning into one common activity. The aim is to design a product that is easily and economically manufactured. The importance of design for manufacturing is underlined by the fact that about 65% of manufacturing costs of a product is determined by design decisions, with production decisions responsible for only 20%.

The heart of any design for manufacturing system is a group of design principles or guidelines that are structured to help the designer reduce the cost and difficulty of manufacturing an item. The following is a listing of these guidelines [6].

- 1.Reduce the total number of parts
- 2.Develop a modular design
- 3.Use of standard components
- 4.Design parts to be multi-functional
- 5.Design parts for multi-use:
- 6.Design for ease of fabrication
- 7.Minimize assembly directions:
- 8.Maximize compliance
9. Minimize handling

3.6.3 Design for reliability

Design for Reliability (DFR), is a process discipline that refers to the designing reliability into products. This process consists of tools and practices and describes the organization needs to have in place in order to drive reliability into their products.

Redundancy is one of the most important design techniques. Redundancy means that if one part of the system fails, there is an alternate success path, such as a backup system. Redundancy significantly increases system reliability, and is often the only viable means of doing so [7].

Many tasks, techniques and analyses are specific to particular industries and applications. Commonly these include:

- Failure mode and effects analysis
- Accelerated testing
- Thermal analysis
- Reliability growth analysis
- Avoid single point of failure
- Electromagnetic analysis
- Built-in test
- Reliability simulation modeling
- Fault tree analysis
- Statistical interference

3.6.4 Design for assembly

Design for assembly is a process that products are designed with ease of assembly. It will take less time to assemble if a product contains fewer parts, with reducing assembly costs. Additionally, if the parts are provided with features, which make it easier, this will also, reduce assembly time and assembly costs

Design for assembly can take different forms. In the past various rules and recommendations were proposed in order to help designers, considering the assembly problems during the design process [7].

3.6.5 Design for maintenance

First principles of design for maintenance are lower the service costs and improving customer satisfaction.

Fundamental principles of design for maintenance are:

- Providing ease of maintenance to components,
- Common parts use,
- Facility of distance diagnosis,
- User definition facility,
- Preventive maintenance concept

One of the most important effects to product performance is, thinking about maintenance activities in design stage to optimize the maintenance times. By the way, customers are informed about replacement part, which has to change. Planning of after sales services prevents unexpected defects [1].

3.6.6 Design for environment

At present days, companies are increasingly are interested in environment. To handle with the environment problem about increasing consumption and productions must be controlled in environment sensitivity.

The design for environment (DFE) approach is grounded in comparing performance, costs, and the risks associated with alternatives. It uses cleaner technologies substitutes assessments and life cycle tools to evaluate the performance, costs, and environmental and human health impacts of competing technologies. A goal of design for environment is to encourage pollution prevention, front-end, innovations through redesign rather than relying on end-of-life controls to reducing potential risks to human health and the environment.

Design for the environment encompasses many issues including design for disassembly and design for recycling. The importance of designing for disassembly became apparent as recovering parts and materials from end-of-life products increased in popularity. There are a number of benefits of achieving efficient disassembly of products as opposed to recycling a product by shredding, which include:

- Components, which are of adequate quality, can be refurbished or reused.
- Metallic parts can be separated easily into categories, which increase their recycling value.
- Disassembled plastic parts can be easily removed and recycled.
- Parts made from other material such as glass or hazardous material can easily be separated and reprocessed [8].

Although most products can be disassembled eventually, lengthy disassembly does not make for economic recycling, as the cost of disassembly is likely to be much larger than the revenue gained through recycling the parts and materials from the product. It is for this reason that designing products for easy disassembly has increased in popularity enabling more of the product to be recycled economically [1].

3.6.7 Design for quality

Design and product qualities are proved by results, which are obtained from various, tests that done for product quality characteristics. To this end, it is needed to pilot run trials or other practices that are improved at laboratory.

A product's quality occurs while improving the product. Features must be introduced at design phase because product features, which are determined in this early stage create product's qualification.

The following definitions are needed to provide product quality.

- Determining quality characteristics
- Determining quality level that is necessary and prescribed
- Reaching to exact quality level
- Control of reached quality level
- Comparison of values with target values

Design for quality accommodates troubleless presentation of product. Wrong decisions are prevented at design stage with detection of parameters, which effects to product quality [1].

4. END OF LIFE STAGE

Decreasing rates of nonrenewable resource consumption provide motivation for research in sustainability and improving our natural environment. Countries and companies are generating aims for achieving sustainable development and reducing resource consumption with the hope of preserving the natural environment for future generations. The environmental problem is an extensive, complex problem, and some areas of study are energy consumption, recycling, and environmentally related substance control [9].

With the decisions below this chapter provides end-of-life considerations for consumer products, end-of-life definitions and process and technology focused end-of-life research, and end-of-life strategies will be considered in this chapter.

4.1 End-of-Life Definitions

The definition of end-of-life is the time when the product no longer satisfies the initial purchaser or first user. This allows for reuse and service in addition to recycling as possible end-of-life strategies. Other definitions, starting from the last user, exist but do not include low environmental impact end-of-life strategies such as reuse and service. Table 4.1 shows end-of-life strategies and their definitions.

The highest on the hierarchy according to calculated environmental impact is reuse, then service, remanufacture, recycling and last disposal through either incineration or landfilling. Ranking highest is product life extension, through reuse of the product. Moving towards reuse of the product as a whole is an ideal solution for the product end-of-life.

Recycling with and without some disassembly first leads to two applications into the original application, frequently called primary recycling, and recycling in a lower-grade application, or secondary recycling. In the case of secondary recycling, the material quality does not meet the original specifications, but still can be used in applications such as plastic park benches and garbage cans.

Table 4.1 : Definitions of end-of-life strategies [9]

Name	DEFINITION
Reuse	Reuse is the second hand trading of product for use as originally designed.
Service	Servicing the product is another way of extending the life of a durable product or component parts by repairing or rebuilding the product using service parts at the location where the product is being used.
Remanufacture	Remanufacturing is a process in which reasonably large quantities of similar products are brought into a central facility and disassembled. Parts from a specific product are not kept with the product but instead they are collected by part type, cleaned, inspected for possible repair and reuse.
Recycling with disassembly	Recycling reclaims material streams useful for application in products. The components are separated mostly by manual disassembly methods.
Recycling without disassembly	The purpose of shredding is to reduce material size to facilitate sorting. The shredded material is separated using techniques based on magnetic, density or other properties of the materials.
Disposal	This end-of-life strategy is to landfill or incinerate the product with or without energy recovery

Lowest on the hierarchy of end-of-life strategies is disposal of the product through two methods: incineration and disposal. Figure 4.1 shows relation between end-of-life options and product life cycle [9].

For comparison, other definitions of end of life options are presented:

- Reuse the product as a whole, for either the same or a new application.
- Reuse sub-assemblies and components by remanufacturing and refurbishing.
- Recycling the materials involved by 1. Recycling in the original application; 2. Recycling in a lower-grade application; 3. Recycling of plastics by decomposing their long plastic molecules.
- Safe incineration with energy recovery and disposal.
- Incineration without flue gas purification and uncontrolled dumping fall under the category prohibited options.

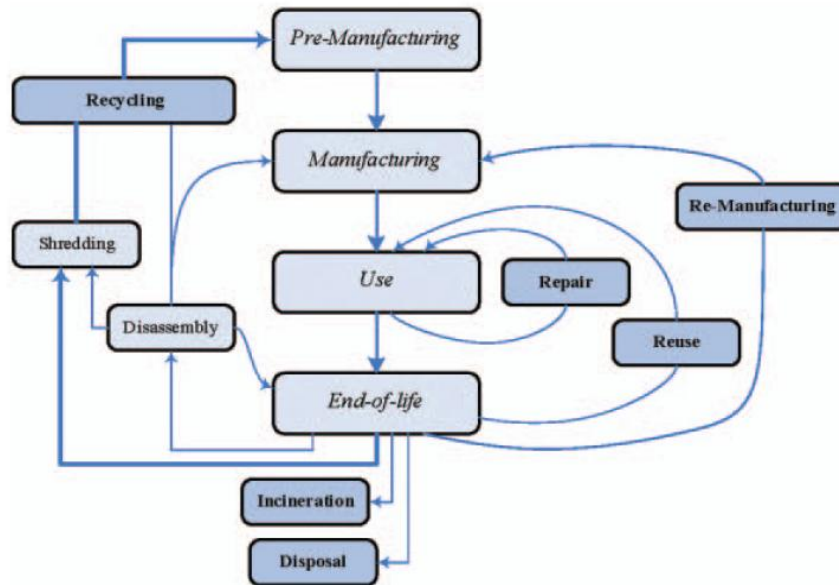


Figure 4.1 : End-of-life options and their relation to product life cycle [9]

4.2 Classification of End-of-Life Strategies

There are six characteristics, which are necessary to classify the end-of-life strategies. These characteristics are given in the Table 4.2 in order to higher accuracy.

The product characteristics are important because they can be used to classify products into end-of-life strategies with high accuracy. These product characteristics are used because they provide general information, describe the physical properties and describe the technology and design changes of the product. These Product characteristics are generic and definable over a wide range of products with diverse functions.

One major factor in improving the accuracy in classification is the use of relative numbers. The addition of the ratio between wear-out life and technology cycle contributes to the improvement in agreement between classified and observed end-of-life strategy [10].

4.3 Current End-of-Life Scenarios

In this section, the current end-of-life scenarios for products are described for the different regions under review. In Table 4.3, the findings are summarized.

Table 4.2 : Technical product characteristics

Product Characteristics	Definitions	Input Ranges
Wear-out life	The wear-out life is lifetime of product purchase until the product no longer satisfies its original functions.	0-20 years
Technology cycle	The technology cycle is the period of time that the product will be on the leading technology before new technology makes the original product unfashionable or less desirable.	0-10 years
Level of integration	A product with a high level of integration has a single huge part that implements many functions.	High, medium, low
Number of parts	The number of parts is the approximate number of parts in the product.	0-1000
Design cycle	The design cycle is the frequency with which companies design new products or redesign their existing products.	0-7 years
Reason for redesign	Original design, Evolutionary design, Feature change	Users enter 1, 2, 3, 4, 5

4.3.1 Japanese end-of-life scenarios

Tokyo and Kyoto send collection personnel to the user's homes on their request, and charge a fee when removing the retired appliances. This method does not require payment for leaving the retired appliance. However, the owner of the retired appliance should sort placed things according to the city's regulation.

The processing of large appliances varies from one city to another. The only commonality in disassembly and mechanical processing is that the cities shred the appliances to retrieve the iron from the shredded parts. However, the cities have different policies as to reuse of product, and incineration of plastics. In Tokyo, appliances with a remaining useful life are reused, plastics are not incinerated. The other cities do not reuse retired goods. Small goods are generally incinerated without disassembly or shredding. No parts are retrieved for reuse or remanufacture [11].

4.3.2 West Europe end-of-life scenarios

In countries like Germany, the Netherlands and Sweden, a collection infrastructure is present in most communities. People can hand in their used appliances, or they can call the city hall that comes and takes them away. This system does not guarantee however that all people actually use this service.

The disassembly and mechanical processing of streams of used appliances is done on a commercial bin [11].

Table 4.3 : Current end-of-life scenarios

ISSUE	JAPAN	WESTERN EUROPE	USA
COLLECTION	Each municipality has its own policy. Some let people drop off retired appliances on specific date and locations free-of-charge.	A collection infrastructure is present in most communities.	Most cities have pick-up services for large appliances.
DISASSEMBLY	Little or no disassembly is done. Some corporations have their own pilot plants though.	Disassembly as a step prior to mechanical processing is done at a number of recycling facilities	Little or no disassembly is done. Some disassembly takes place to recover reusable components from IT equipment.
PROCESSING	Appliances are shredded only for retrieving iron. Plastics are usually landfilled. Small appliances are incinerated.	Remaining plastics fractions are usually incinerated for energy recovery. Precious metals, copper and aluminum are often recovered.	Still the majority of small appliances is landfilled.

4.3.3 United States end-of-life scenarios

Some cities or countries provide pick-up of major home appliances. Several cities have recycling centers that collect refrigerators, air conditioners, freezers and some televisions. For both of these types of programs there are no additional fees collected by the municipal waste management company.

Other cities have programs that encourage users to drop off their used appliances and electronic equipment and other consumers can pick up these products at no cost.

Because of the lack of national level legislative incentives in the United States, recycling initiatives vary in approach and size throughout the country. Most large appliances are sold to scrap processors for recycling. Shredding is the most common disassembly technique used in the appliance recycling industry. The residue is generally disposed of in landfills. Little or no disassembly is done in the United States [11].

4.4 Processes and Technologies at End-of-Life Stage

End of life stage consists more than one options. To choose the best option from end of life options it must be known the product's characteristics and parts. Also to choose the best options end of life process and technologies must be known. They will be mentioned in the following.

Remanufacturing is the process that, quantities of similar products are brought into a central facility and disassembled. Parts can be reused when the wear-out life is longer than the technology cycle. In most cases, there are important market opportunities for these parts.

Disassembly is motivated by two goals, to achieve pure used materials and to isolate environmentally related materials from other materials. Disassembly of products into separate materials is just one of many possible end-of-life treatment options. Even though, complete disassembly may seem to provide a way of minimizing the damage to the environment.

Materials, which are not disassembled, can be recycled by mechanical processing activities. A full recovery from these waste products requires use of a sequence of different steps, for example, shredding, electromagnetic separation, and further size sorting and electrostatic separation. Shredding is the chopping of the different materials to achieve size reduction using hammer, cutting and cryogenic mills.

Compared to metal outlets the plastic recycling industry is at beginning stage. Economically recycling of plastics is not feasible now. This is caused by not being able to know what kind of different plastics are mixed in the recycling process, resulting in unknown chemical properties [9].

5. DESIGN FOR DISASSEMBLY

Design for assembly and design for manufacture and assembly are well known and widely applied concepts, established during the 1970 and which gained prominence in the following decade, principally because of the work by Geoff Boothroyd from the University of Massachusetts. They are structured techniques, which allow manufacturers to implement product designs with reduced numbers of parts, simplified parts handling and improved assembly. They are driven principally by economic considerations and allow the design of products that can be manufactured at minimum cost and with maximum quality and reliability.

However, other design considerations need to be developed, as manufacturers are coming under pressure from legislation and consumers want to minimize their impact on the environment. This defines all attitudes of issues, such as reducing in energy consumption, transportation, recycling and waste reduction, disposal and one discipline to emerge from these considerations is design for disassembly (DFD) [12].

Disassembly is the process of systematic removal of desirable parts from an assembly. There are both economic and environmentally sound reasons for disassembly.

A suddenly discontinued product line can lead to excess inventory of undesirable assemblies. Disassembly scheduling can be used to retrieve valuable components, which are common to other products still being produced. Certain products might have to be disassembled in order to recover some of their components, which are in urgent demand, by some other products. In this situation, supplying the components needed for the urgent demand products by disassembling other products may result in a substantial lead-time reduction for these urgent products. A plant may be forced to disassemble inventories in order to comply with recycling regulations imposed by governments [13].

The aims of DFD are to design a product that can be readily dismantled at the end of its life and thus optimize the reuse, remanufacturing or recycling of materials,

components and sub-assemblies. This is particularly critical today as low cost plastics are quickly being outpaced by more complex and costly products such as consumer electronics and household accessories as the dominant waste streams in the developed world [12].

End of life disassembly that has to be carried out completely, disassembly is not equivalent with inverse assembly. On the other hand, the disassembly process is strongly influenced by the demand for specific parts and materials. Also, there can be a demand on modules that consist of multiple parts. Table 5.1 shows the design rules for improving disassembly process. If materials recovery is aimed, shredding and subsequent separation is widely applied. Because the separation is imperfect and can only be carried out to a certain extent, an amount of shredder residue of an indefinite composition is left.

Table 5.1 : Design rules for design for disassembly [12]

Factors Affecting the Disassembly Process	Guides to Improve Disassembly
Product structure	Create a modular design Minimize the component count Optimize component standardization
Materials	Minimize the use of different materials Use recyclable materials Eliminate toxic or hazardous materials
Fasteners, joints and connections	Minimize the number of joints and connections Make joints visible and accessible, eliminate hidden joints Use joints that are easy to disassemble Mark non-obvious joints Use fasteners rather than adhesives
Characteristics of components for disassembly	Good accessibility Low weight Robust, minimize fragile parts Non hazardous parts
Disassembly conditions	Design for automated disassembly Eliminate the need for specialized disassembly procedures DFD with simple and standard tools

Due to environmental legislation aimed at the reduction of emissions of heavy metals, this residue is a principal challenge from both an economic and an environmental point of view. To deal with this, one of the basic tasks is to investigate selective disassembly, which is an incomplete disassembly process that is carried out for meeting a multitude of purposes. Such as, recovery of parts and materials,

materials recovery, removal of hazardous parts and materials, reduction of the amount of shredder residue and improvement of the quality of the shredder residue [13].

The most important point of this research is optimizing the product for design for recycling with prudence of design for disassembly. To do this, it is needed to plan of disassembly and generation of disassembly sequence. An optimum sequence represents the best way for carrying out selective disassembly at a given product structure, disassembly costs, material revenues, and external constraints. In this research, design for recycling and design for disassembly will be embedded to each other with concurrent engineering approach to prevent defaults at design stage.

5.1 Issues and Research Needs on Design for Disassembly

There are many issues and research needs in the area of disassembly. These can be classified into two common categories; these are technical and operational disassembly.

5.1.1 Technical problems

Designing a product in according to easy disassembly constraints is a very difficult task. The current maturity level of product designs is mostly limited to assembly manufacturing

In the past, products and machines were designed with only the assembly operations in mind. Now, designers have to think in terms of disassembly and parts recycling as well [13]. Some of the design problems that need specific attention are:

- Design for ease of separation, handling, and cleaning of all product components.
- Design should aim at reducing energy usage for assembly as well as disassembly.
- New two-way snap-fit or pop-in pop-out fasteners should be developed.
- The variety of material types has to minimize in order to realize volume advantage.
- The product design should minimize the total number of stations and operations.

5.1.2 Operational problems

Once the product was manufactured and sold, it rarely came back to the plant. Instead, it ended up in a landfill at the end of its useful life. In a disassembly environment, however, old products will have to come back to a disassembly plant, and the components recovered will be re-sold or reused in the assembly plant or recycled at a separate recycling plant. The major operational problems that are likely to arise when dealing with disassembly are:

- Gathering: There will be accumulations of certain kinds of materials. This is because of the difference between the demand for components and their yield from the assembly.
- Location problems: When dealing with assembly, disassembly and then recycling, a certain product and its components will have to be present at different locations at different times because of transportation costs.
- Added confusion: Disassembly increases the operational scope of a company and makes the system more complex. If disassembly were to be performed in the same assembly plant, the potential for added confusion on the manufacturing floor is significant.
- Implementation and transitional problems: While companies may have a clear idea of where they want to be, they may not know what the most efficient way to get there. Transitional and implementation problems, when going from assembly to disassembly need very careful examination since they have the potential of adding significant cost [13].

5.1.3 Disassembly constraints

The basic principle of the method of generation is to examine the feasibility of all the operations relating to the disassembly. The aim of the feasibility of the operations is realized using operative constraints. The operative constraints allow formalizing the conditions via an operation can or cannot be realized. Operative constraints may be classified in three categories. These are the geometric constraints, the stability constraints, and the material constraints.

According to geometric constraints, to implement an operation of disassembly, there must be at least one track that allows extracting an object from another without any

interference between the two considered objects. The geometric constraint related on the subassembly.

The stability constraints are considered when an operation is not restricted by a geometric constraint; it is advised to be ensured of the stability of the objects that are achieved after the realisation of the operation.

Unstable subassemblies can be prohibited, which produced by an operation. Actually, stability must be ensured to facilitate transport, to avoid destruction of reusable components [14].

5.2 Disassembly Types

There are several possible disassembly methods for removing a component from a given assembly. Followings are methods for disassembly operations.

5.2.1 Sequential and parallel disassembly

In sequential disassembly, only one component is removed from the assembly at a time. But in parallel disassembly, several components or a sub-assembly are removed from the assembly at the same time.

5.2.2 Non-Destructive and destructive disassembly

In nondestructive disassembly, none of the components of an assembly are destroyed. However, if one or more components are destroyed then the disassembly method is destructive disassembly. Disassembly method selection is carried out by analyzing all the possible disassembly methods for the given assembly. Then the disassembly method that best fits the user's requirements is selected for disassembly analysis.

5.2.3 Selective disassembly and total disassembly

Total disassembly is not economically feasible in most cases. It is way to disassembling all the parts of a product. Because of its style, hazardous and useless parts are disassembled. So the companies lose money and time. Selective disassembly is generally used either for repair and maintenance of a product or for end-of-life disassembly. Here selective disassembly is always followed by reassembly. The selective disassembly process results in three types of outputs:

- Homogeneous components, which cannot further be physically separated.
- Complex components consist of several discrete homogenous subcomponents but they are normally not disassembled because they are often connected via fasteners that require destructive disassembly for separation.
- Modules can normally be disassembled, but sometimes are not as they possess their own functionality.

The presence of nonreversible connections in complex components one of the reasons why disassembly cannot be carried out to its full extent. A second reason is that the modules might be more valuable intact.

Selective disassembly serves many purposes for environment and lower product costs. These purposes are following:

- Recovery of modules and components used for remanufacturing.
- Removal of hazardous modules, components, and materials.
- Regulatory requirement for removal of hazardous and nonhazardous components.
- Recovery of valuable materials.
- Increase of the quality of shredder residue.

It is obvious from Figure 5.1 that the process of selective disassembly influences the subsequent end-of-life processing steps [15].

5.3 The Disassembly Process of Complex Products

A complex product is considered as a functional unit that consists of components that are related to each other with connections. Components and connections are less complementary to each other.

A component is a material entity that can be separated from a product via disassembly operations. A connection forms a relationship between two components that restricts their relative movement. Material objects that are used to restrict the movements of two components are called fasteners.

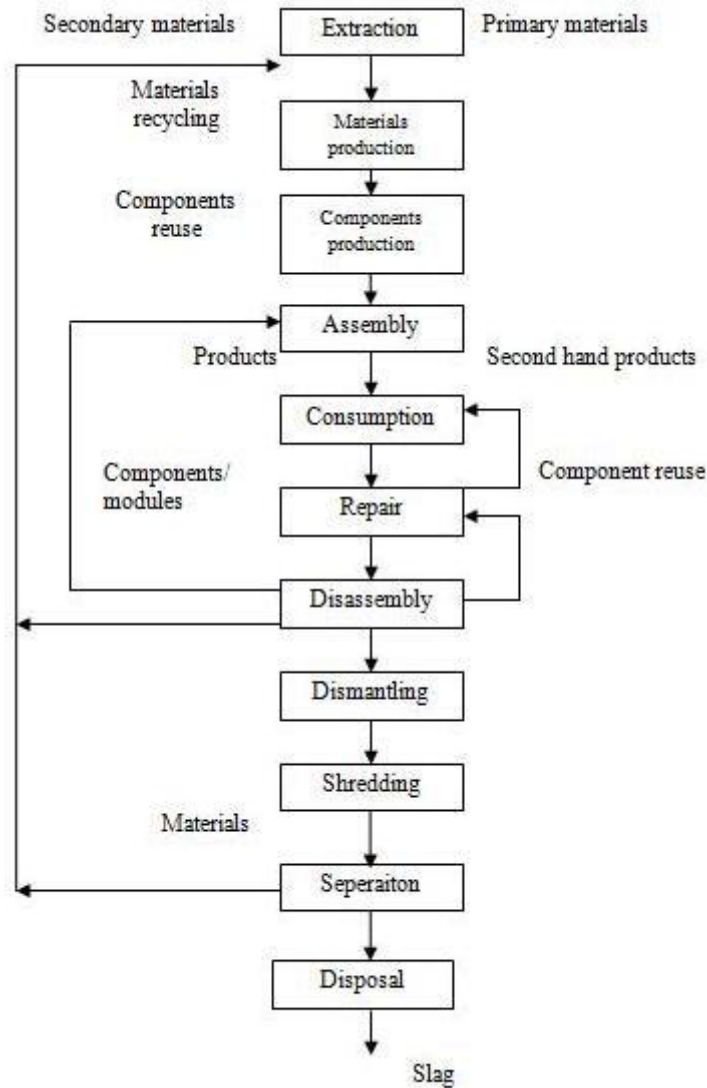


Figure 5.1 : Product-process chain of a complex product

5.3.1 Components

Identifying a component introduces some arbitrary action, as disassembly may include some semi destructive actions. The following types of components are recognized: 1. Homogenous 2. Composite, 3. Complex components

Homogenous components consist of homogenous materials, which may be a mixture or an alloy. Minor parts of different materials could also be present.

Composite components consist of multiple materials that are linked in an irreversible way, such as in sandwich structures. Complex components are units that consist of a set of irreversibly connected homogenous components. Components are linked to each other with connections. A connection is a relationship between two components that restricts their movement or detachability. A component is moveable with respect

to a subassembly if it can be displaced with respect to this subassembly over. This motion can be translational or rotational. If infinite displacement is possible, the component is considered detachable. Many products have some internal degrees of freedom, as movement of components with respect to each other might be essential for the product's functionality [15].

5.3.2 Connections

The separation of components or disassembly is closely related to the disestablishment of connections. However, prior to getting into disassembly task analysis, an exploration of connections and fasteners is needed.

There are considerable variety of connection types that are used in complex products. These connection types offer varying degrees of difficulties in their ability to release the fasteners, the amount of force required to undo the connections, the restriction in movement and the type of fasteners used. The following are some types of connections that are present in different products:

- Mating connection: In this type connection, motion is restricted by mating surfaces.
- Screw Connection: Bolt and nut connection etc. are reversible connection types that usually completely restrict the motion of the components involved.
- Snap Fit Connections: This type of connections can be either reversible or irreversible.
- Press fit connection: This type connection is implemented with pressure that is implemented by a deformation of the components involved. For disassembly the connection, a definite friction force has to be handled.
- Rivet connections: These type connections are implemented with fasteners that are deformed during the process.
- Glue and seal connections: These type connections are implemented with an agent that is applied to the components to be connected.
- Solder connections: These type connections are implemented with an agent that undergoes a phase transition
- Weld connections: In these type connections, the phase transition takes place in the materials of the components that are welded together [15].

According to VDI 2243, Table 5.2 presents separability ratings of connections. Also in this table, a few examples are presented.

Table 5.2 : Separability ratings of connections [12]

Rating	Description	Examples
A	May be disassembled easily by manual techniques in less than 1 minute	Pull-apart plastics
B	May be disassembled manually with effort in less than 3 min	Instrument cluster, radio
C	May be disassembled with effort and some mechanical separation or shredding to separate. Process fully proven.	Engine, sheet metal, uncorroded screws
D	May be disassembled with effort and some mechanical separation or shredding to separate.	Instrument panels, corroded screws, adhesives
E	Cannot be disassembled, no known separation process	Heated backlight

5.3.3 Fasteners

Fasteners can be discrete components such as screws, or nondiscrete material object such as snap fits.

When designing a product, designer should consider a few rules for fasteners. These are, minimizing the number of fasteners used within an assembly, minimizing the types of fastener used within an assembly, standardizing the fasteners used, not compromising the structural qualities of the assembly by using too few or inadequate fasteners, using snap-fits where possible to eliminate the need for a fastener, considering work-hardening, fracture, fatigue failure and general wear when designing snap-fits, considering the use of destructive fasteners. Table 5.3 shows fasteners and their features for ease of design for disassembly.

Ideal assembly is one in which there is only one fastener, and that is released by a single linear action. This provides the easiest disassembly situation, and a plan with only one-step [14]. For any pair of mating parts we identify three possible mating relationships as follows:

Type 1 mating: Parts are assembled with separate fasteners.

Type 2 mating: Parts are assembled with fasteners integral to one of the parts.

Type 3 mating: Parts are mating but there is not direct fastening involved.

Because the use of plastics is so prevalent in product design, the following Table 5.4 plastic-to-plastic joint design with respect to disassembly has been included.

Table 5.3 : Table of fastening guidelines

GUIDELINE	REASON
Minimize the number of fasteners.	Most disassembly time is spent on fastener removal.
Minimize the number of fastener removal tools required.	Changing tools costs time
Fasteners should be easy to remove.	Saves time during disassembly.
Fastening points should be easy to access.	Awkward movements slow down disassembly process.
Snap fits should be obviously located and able to be opened using standard tools.	Special tools may not be available.
Try to use fasteners of material compatible with the parts being joined.	Allows disassembly operations to be avoided.
If parts cannot be produced of compatible materials, make them easy to disassembly.	The parts must be separated in order to recycle.
Eliminate adhesives unless compatible with material of both parts being joined.	Many adhesives cause contamination of parts for material recycling
Minimize the number and length of wires and cables used.	Flexible elements are slow to remove, copper contaminates steel in recycling
Connections can be design to break as an alternative to removing fasteners.	Fracture is a fast disassembly operation.

5.4 Operational Impacts of Disassembly

Incorporating disassembly impacts lots of factors such as product cost, maintenance, and financial decisions.

The cost of labour, energy and overheads represents a large portion of the total cost of a product. In a disassembly environment, this cost will be incurred twice: once during assembly and another time during disassembly.

Since this will result in products that are more expensive in the future, manufacturers will start designing products with longer lives so that they are more attractive to consumers. Since longer life products will be of prime importance, quality and reliability will be more important than ever.

Table 5.4 : Fastener types and their disassembly methods

Fastener Type	Disassembly Method
Mechanical Joints	
Hook	Slipped Loose
Snap Fit	Snapped Out
Press Fit	Ripped Out/Pressed Out
Screw	Unscrewed
Screw Insert	Unscrewed
Welded Joints	
Welded Compatible Materials	No Separation Needed
Solvent Bonded Compatible Materials	No Separation Needed
Stud Welded	Chiseled off/Milled Away
Molded In(Insert)	Ripped Out/Pressed Out/Drilled Out
Glue Bonded	Economically not feasible

Maintenance and servicing of products are essential ingredients in ensuring longer product lives. Often these activities require partial disassembly in order to replace or repair parts that are embedded deep in the product structure. The inclusion of design for disassembly considerations in the product design process can greatly simplify the performance of these activities [13].

5.5 Design for Disassembly Sequence Planning

The optimal sequence generation is an important task for the end of the product life cycle. Sequence generation for material recovery must be based on maximizing the value of material recovered.

Disassembly sequence planning (DSP) is a sequence of disassembly tasks that begins with a product to be disassembled and terminates in a state where all the parts of the product are disconnected.

Identifying DSP is not an easy task since disassembly sequence planning in a complete problem. The number of alternative sequence plans increases exponentially with the number of parts in the product, which are disassembled. The number of

feasibility constraints may reduce the number of disassembly sequences required to be analyzed for optimality. This number is still expected to be large for a complex product [16].

5.5.1 Guidelines for determining EOL options for components

The most suitable EOL options for materials are represented in Table 5.5 [10].

5.5.2 Defining of disassembly sequence number

Disassembly sequence number depends on the part's number. It increases with the increase of parts number. Therefore, we must eliminate unsuitable disassembly sequences by using some constraints. Allowing designers to decide if other constraints should be given or not. Precedence constraints for disassembly can be represented by graphics as shown in Figure 5.2.

For ease, these graphics are classified as following:

Type (a): out-tree graph, Type (b): in-tree graph, Type (c): disconnected graph that consisting of other types, Type (d): others.

Table 5.5 : Recommended EOL options for various materials

	Sub Material	Recommended EOL Options
Metals and Alloys	Cast Iron	Primary Recycle
	Aluminum	Primary Recycle
	Copper	Primary Recycle
	Nickel	Primary Recycle
	Zinc	Secondary Recycle or Landfill
	Stainless Steel	Secondary Recycle or Landfill
	Alloy Steels	Secondary Recycle or Landfill
	Brass	Secondary Recycle or Landfill
Polymers		
	PE	Secondary Recycle
	PP	Secondary Recycle
	PA	Secondary Recycle
	ABS	Landfill
	Nylon	Landfill

We consider only precedence constraints that can be represented by type (a) after they are transformed into a non-transitive graph as shown Figure 5.2(a). Type (a) graph can be transformed into a transitive graph as shown in Figure 5.2(b). The

graph shown in graph in Figure 5.2(c) is a subgraph of the transitive graph as shown in Figure 5.2(b) where the P1 is the initial node.

So precedence constraints between P1 and all the other parts, the number of them is r_1 , are determined. By the way, the number of disassembly sequences from graphics shown in Figure 5.2(c) is given in (5.1)

$$\frac{n!.r_1!}{(r_1+1)!} \quad (5.1)$$

where n defines the total number of parts. For Figure 5.2(d), P1 is the initial node of arcs whose terminal nodes are P2 and P3. This implies the sequences between P1 and the two parts are determined, whereas sequence between the two parts is not determined. The number of disassembly sequences becomes as (5.2)

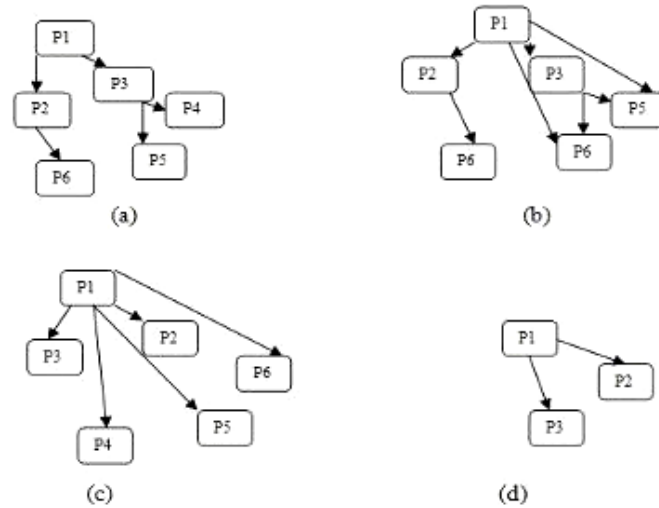


Figure 5.2 : Procedure to calculate disassembly sequence number

$$\frac{n!.r_1!.r_2!}{(r_1+1)!.(r_2+1)!} \quad (5.2)$$

We get the following equation (5.3) by repeating this procedure for all parts,

$$\frac{n!.r_1!...r_n!}{(r_1+1)!...(r_n+1)!} = \frac{n!}{(r_1+1)...(r_n+1)} \quad (5.3)$$

For example the Figure 5.2(a) has feasible disassembly sequence number as following formula (5.4);

$$\frac{6!}{6.3.2.1.1.1} = 20 \quad (5.4)$$

Firstly, we do not know how to calculate the number of sequences from figure 5.2(d). However, we can solve this problem by calculating the upper and lower boundaries of the sequences. The number given by equation (5.4) is smaller than the actual number for Figure 5.2(d). This smaller number is called lower boundary. Upper boundary is calculated by removing arcs from the Figure 5.2(d). By the way, upper and lower boundaries of disassembly sequences can be determined without calculation of possible motions or geometrical modifications of parts [17].

5.6 Reduction of Disassembly Sequence Number

If there are possible disassembly sequences actually, we should add some precedence constraints to a product. Increase of the number of precedence constraints leads to decrease of the number of disassembly sequences. To reduce the number of disassembly sequences added some constraints as following:

- Introduction of assembly feature
- Consideration of removing directions for disassembly
- Grouping parts

Firstly, the assembly feature is introduced. If a designer adds some information with respect to assembly feature to a product, the number disassembly sequences can be reduced.

After that, constraints between removing directions for disassembly are considered. Therefore, constraints with respect to removing directions can be given. Finally, by grouping parts the number of disassembly sequences can be reduced

By applying the operations, which are mentioned above, we can add some precedence constraints for disassembly to a product and it makes the number of disassembly sequences decrease [17].

5.7 Disassembly Considering Reuse and Recycle

Evaluating disassembly sequences of products is important to consider their reuse and recycle. Point of view for reuse and recycle influence disassembly sequences. If the life span of parts is considered, long-lived parts may be reused as parts but short-lived parts should be recycled as materials. Some parts can be melted together and

others should not. Thus, if some parts can be kept in a group or must be disassembled individually depends on viewpoints for reuse and recycle.

Disassembly sequences of products depend on their design. Assuming that the disassembly sequence for reuse and recycle is decided by considering the following evaluation viewpoints:

- 1)The kind of each part's material
- 2)The life span of each part
- 3)Whether each part should be melted or not
- 4)Whether each part should be clashed or not
- 5)Whether each part is expensive or not

Then, a matrix can be generated as shown Table 5.6. This example is very simple but also a database with respect to the kind of possible treatments for reuse and recycle of parts can be made.

Assuming that a designer thinks only expensive parts should be disassembled individually for reuse and recycle.

Table 5.6 : An example of database for a product for its reuse and recycle

No.	Material	Life span	Melted	Expensive
1	A	SHORT	NO	NO
2	B	LONG	YES	YES
3	C	LONG	YES	YES
4	D	LONG	NO	YES
5	E	SHORT	YES	NO
6	F	SHORT	YES	YES
7	G	LONG	NO	NO
8	H	LONG	NO	NO

By using this system, designers can evaluate their design related to a product's maintenance, repair, reuse, recycle [17].

6. DESIGN FOR RECYCLING

All of the products manufactured today have some adverse affects on the environment. For example, waste computer equipments are usually landfilled or the users throw them away. New electronic regulations require the use of very special materials that have not negative effects on humans and environment.

With the increasing public senses of environmental issues, governments have been forced to companies more strict environmental policies. Environmental policies have caused manufactures to take note of the environmental impacts created by not only their production process but also their product over its entire life cycle.

Subsequently, this has spurred the development of various programs, from both the government and individual manufacturers, to consider the environment when designing a product [18].

As shown at Table 6.1, 915.000 tons of waste products of electrical and electronic equipments are produced at 1998 in Britain. This number increased to 2 million tons at 2005 according to data which are taken from England Secretary of State for Industry.

Huge amount of WEEE are landfilled or incinerated. Environmental Protection Agency of United States of America claimed that 4.6 million waste electrical and electronic equipments are landfilled at 2000. Six source materials which used in EEE are defined by European Union. RoHS (2003) directives restrict these materials by using rates. Restricted materials and their usage areas are shown in Table 6.2.

End-of-life costs could be reduced and the material recovery and quality improved if already during product design material choices and structures are chosen that would favour future recycling.

This could be done by reducing the number of different materials in a single product, avoiding incompatible material combinations and use joints that easily disintegrate in a shredder. In this way a better liberation and consequently separation of the different materials can be achieved.

Table 6.1 : Electronic waste product production numbers

Country	Total WEEE Production (Tons/year)	Groups of Electronic Waste Products	Year
Switzerland	66.042	Telecommunication appliances, consumer entertainment electronic, home appliances, refrigerator	2003
Germany	1.100.000	Telecommunication appliance, consumer entertainment electronic, home appliances, refrigerator	2005
Britain	915.000	Telecommunication appliance, consumer entertainment electronic, home appliances, refrigerator	1998
USA	2.124.000	Multimedia systems, sound systems, computer and telecommunication appliances.	2000
Taiwan	14.036	Computer, home appliance (television, washing machine, refrigerator)	2003
Thailand	60.000	Refrigerator, television, washing machine, computer, air conditioner	2003
Denmark	118.000	Electrical and electronic products(Include refrigerator)	1997
Canada	67.000	Computer, printer etc. and consumer electronics (Television)	2005

Table 6.2 : Restricted materials with RoHS directive [19]

Restricted Material	Usage Areas	Usage Rate in Homogenous Material
Lead	Solder, active and passive electronic material,	Maximum %0.1 by the weight
Mercury	Batteries, keys, sensors, roles, fluorescent lamps	Maximum %0.1 by the weight
Cadmium	Electrolysis coatings, plastic materials, NiCd batteries,	Maximum %0.01 by the weight
Hexavalent Chrome	Chrome coatings	Maximum %0.1 by the weight
PBB(High Bromine biphenyl)	Flame retarder at plastics	Maximum %0.1 by the weight
PBDE (High Bromine biphenyl ether)	Flame retarder at plastics	Maximum %0.1 by the weight

Design for Recycling (DfR) is a product design practice in which the fitness of the product for recycling is one of the criteria for making design choices. Recycling has two very basic goals: first, to eliminate or reduce the use of hazardous materials that create danger to the environment and second, to reduce the use of materials that are

non-recyclable. The result is an improved potential for material recovery from the product after it has reached its end-of-life stage.

Electrical and electronic equipments are classified to groups and each group has different recycling rates. Lower limits of reuse and recycling are defined to maximize the environmental benefits. Products, which are scope under directive and recycling rates of these materials, are given Table 6.3 [19].

Table 6.3 : Gains obtained from steel and ferrous wastes with recycling process

Benefit	Rate (%)
Decreasing of consumer wastes	105
Gained obtained from raw materials usage	90
Decrease of water pollution	76
Decrease of water usage	40
Decreasing at mineral wastes	97
Energy gain	74
Decreasing at air pollution	86

6.1 Design for Recycling Motivation

The pressure on the industry to produce economically and recyclable products comes from three directions: The legislation, need for cost reduction and the marketplace.

6.1.1 Cost reduction

The main cost benefit of recycling is usually the cost reduction for the scraps. The serious deficiency of landfill capacity increased the dumping fees for landfilling process. However, the value of regained materials and components itself could be increased, if they could be regained intact and pure enough for further utilisation at the same level for tasks as demanding as their original ones. While raw copper costs approximates 2000€/ton, copper from shredding residues and cables can be sold only for approximately 300€/ton, hardly covering separation and transportation costs. A major key to cost reduction in recycling lies in enhanced purification of the regained materials and a higher degree of regained reusable components [20].

6.1.2 Marketplace

Increased public awareness of environmental issues is also reflected in consumer demands for environmentally friendly products. Many companies have already responded to that development by offering to collect and recycle their used products

and by stressing the ecological orientation of their company in their marketing strategy.

Other companies have suffered serious setbacks that had until now been unimaginable, because their products were seen as an offence to the rule of sparingly using natural resources. Offering products that are economically sound and easy to recycle becomes a necessity in market competition [20].

6.1.3 Legislation

All of the European countries are preparing their legislation for environmental protection. Germany is currently discussing a proposal for an act regarding “The Avoidance of Residues, the Exploitation of Used Materials and the Disposal of Waste”. It provides the legal frame for the German government to encourage the industry and importing companies to recollect their products after usage at no cost. The legal frames will force the industry to take financial as well as organizational responsibility for recycling plants. Most European car manufacturers have to set up prototypical disassembly plants on the other hand electronic equipment and home appliance producers are so far behind these projects [20].

6.2 Design for Recycling Options for End of Life Products

Design for recycling have three types of options for end of life products. These are reuse, recycling and incineration (energy recovery).

6.2.1 Reuse

Using of a part or subparts when a product come to its end of life with the same designing aim. This scenario is true when the product came to end of its physical life. Reduction of waste mass by this operation is the fundamental aim of reuse. That aim is provided by the extending the product’s using life.

One of the purposes of reuse is saving from material and energy by using waste products instead of new produced products. Economically, reuse has more benefits then other actual end of life scenarios.

For example, developing countries have about 5 million computers. Major parts of these computers are old-fashioned computers. These computers are good options for reuse but these will be waste at a short time at developing countries.

When not possible to completely reuse of product, reusing subparts of the product is another convenient method. These parts can be applied to subassembly directly for remanufacturing or they can be used for service purposes [19].

Reuse is very practical method if compared with another end of life scenarios. Reuse technique effects directly and decreases the necessary energy amount.

6.2.2 Recycling

Nowadays, recycling is the most common technique for appreciation of waste products. Recycling is applied to white goods and automobiles for years.

Recycling method has three fundamental stages. These are: 1. Disassembly for preliminary; 2. Depreciation of product's parts; 3. Separating of product's material and characterizing procedure.

Disassembly method was mentioned previous section with its details.

Separating of product's material and characterizing procedure is applied to obtain pure materials from parts that are in product. Impure materials decrease the material quality in recycling method. It directly affects the quality of product and decreases the value of product.

Depreciation of product's parts method is used to obtain liberalization of grains and separation procedures for get to parts to necessary dimensions. Liberalization of grains corresponds to forming a grain that has only one type material in it.

Dimension depreciation machines consume huge amount energy. Little part of this energy is converted to job. Because of energy loss this process is not very efficient.

The product that has different types of grain dimensions is subjected to classification of elimination to respond to separation process for demanded grain dimensions. Separation process has options according to materials conductibility and density purposes.

Separation according to conductibility has three types; electrostatic separation, eddy current separation and triboelectric separation. Electrostatic separation is used for separation of nonferrous metals. Eddy current separation techniques separate metal and nonmetallic parts. Triboelectric separation method is used for nonconductor different type of plastics separation.

Separation according to density is used to separation of materials that have different densities. If grain dimensions are between 50cm-6 μ m, this method can be used. Most common method is floating product on fluid. The materials, which have different densities from each other, are put in fluid with defined density. The materials are evaluated according to floating or sinking. This method is the cheapest way to recycling. If the material has more than two types, more than one pool is needed.

At present, economically metals have highest recycling volume. Metals are suitable for recycling because of separation easiness and high economic value.

Using of recycled materials has many benefits. Process of preparation materials consume substantial amount of energy. Hazardous wastes occur with the result of consumed energy. Hazardous materials can be reduced by recycling. Table 5.4 about gains obtained from recycled materials [19].

6.2.3 Incineration

Incineration is used to obtain energy and this process sometimes applied for recycling of domestic waste. Usage of incineration at Waste Electrical Electronic Equipments has begun to separate copper from cables and recover metals by recuperator and mini recycler. On the other hand, dioxin that is one of the most hazardous chemical occurs with incineration process and accumulates in incineration ashes. Because of leaving dioxin without control, it mixes in soil and water.

Incineration in end of life process is considered as an option for reduction of the volume of waste. Also, natural gases-driven incineration systems are used to reduce toxic wastes resulted in incineration and low thermal values of Waste Electrical Electronic Equipments. Wastes are incinerated at high temperature such as more than 500 °C. Incineration is not good enough for gained utility when compared with another end of life product options. If incineration compared with the landfilling, it is more gainful alternative than the landfilling operation [19].

6.2.4 Priority of design for recycling options

Design for recycling options, which are mentioned above, have priorities in themselves. Table 6.4 shows the recycling and reuse rates and Figure 6.1 shows the priorities of these options and the option priorities are given follow:

- Re-use: Highest priority refer to reuse because reuse affects environment directly. Raw material resources and energy consumptions for a product is minimized. Reuse can be done by selective disassembly.
- Recycling: At recycling process, materials are preserved. Recycling process need to energy and that decreases its priority. Only destructive disassembly is allowed in recycling.
- Incineration: Only the energy is preserved embodied in product.

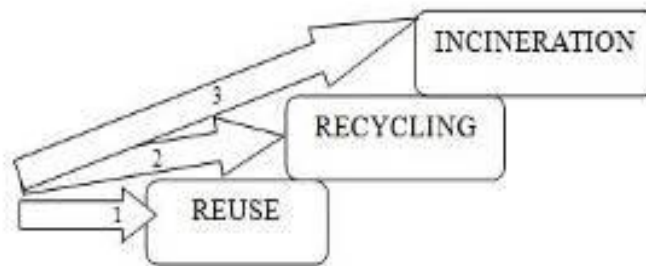


Figure 6.1 : Design for recycling priorities

Table 6.4 : Reuse/Recycling rates with WEEE directive

Product Category	Products	Directive Aims
Large Home Appliances	Large cooling devices, refrigerators, deep freezer, washing machine, dish washer, oven, microwave oven	reuse/recycling rate %70
Mini Home Appliances	Vacuum cleaner, iron, toaster, coffee maker, watches	reuse/recycling rate %50
Telecommunication Appliances	Mini computers, printer units, desktop computers, portable computers, printers, mobile phone	reuse/recycling rate %65
Consumer Products	Radio systems, television systems, video camera, sound systems	reuse/recycling rate %65
Electrical and Electronical Devices	Driller, saws, sewing machine, lathe, stoning, drilling machines for metals, spraying, repulsing equipments for gases or liquids.	reuse/recycling rate %50
Toy, hobby and sport equipments	Electrical trains and car racing sets, game consols, video games, sport equipments which contains electrical and electronic components.	reuse/recycling rate %65

6.3 Types of Recycling

Recycling aims at closing the loop of materials or components after usage by reusing them for new products. Three loops can be considered, during recycling activities.

The renewed use of production scrap is by the most developed form of recycling. This is due to the fact that production scrap usually occurs in large quantities of pure materials.

Since recycling of production scrap is already, and recycling during usage is limited by the obvious restraints of the products shape, the highest potential for future development lies in the area of recycling after usage.

During all loops, different forms of recycling are possible. If the functions of original and recycled products differ, we define the process as using on or utilizing on. Examples for the different forms of recycling are given in Table 6.5 [20].

Table 6.5 : Examples for different forms of recycling [20]

Loop	Form of Recycling	Original Product	Recycled Product
Recycling during product usage	Reusing	Bottle	Refilled bottle
		TV Set	Repaired TV set
		Car Tire	Remoulded car tire
	Using on	Milk Bottle	Flower vase
		Shopping Bag	Waste bag
		Old Tire	Ship fender
Recycling after product usage/ Recycling of production scrap	Reutilization	Glass Bottle	Bottle from recycled glass
		Aluminium Can	Can from recycled aluminium
		Sheet Metal Scrap	Sheet metal
	Utilizing on	Glass Window	Bottle from recycled glass
		Aluminium Cans	Aluminium window frame
		Sheet Metal Scrap	Wires

6.4 Rules for Design for Recycling

A specific problem lies in the complexity of the problem, as most design decisions are influenced by many factors. The target of this section is making easy the designer's study with a set of guidelines, which are simple and easy to apply.

6.4.1 Product recycling

The first priority for recycling is extending the products life span by recycling during usage. It aims at ensuring that the product can fulfill its function for a longer period using minimal this can be achieved by the following aims:

- A modular structure of the product allows modernizing components that are outdated without having to change the whole product.
- To design those sections of a product which are subject to heavy wear as separate elements allow having them exchanged easily and thus extend the products life resources.

6.4.2 Ease of design for disassembly

One of the most important design for recycling rules is the ease of disassembly, since the disassembly process allows regaining components intact and materials of higher purity than the alternative shredding process.

While taking a system approach the design for disassembly and design for recycling activities should be done concurrently in order to achieve a global optimum of the system. For ease of design for disassembly, the designer has to implement some basic rules, which are mentioned previous section extendedly.

6.4.3 Ease of design for recycling

Design for recycling considers the products that are manufactured which material, how these materials are assembled and how these products will disassemble. These approaches are described by the a few design for recycling rules that follow. If applied during a product's conception and carried through to its design, assembly, and disposal, these criteria can be an effective design for recycling tool to minimize waste.

- Using Recyclable Materials; Designing products using materials that can be recycled and for which materials collection and recycling. Technologies currently are available and commonly used.
- Using Recycled Materials: Select materials that contain a high percentage of recycled content, because this supports the recycling process for which a product is being designed.

- No matter what material is considered, the less that is used, and the more functions incorporated into a part.
- Mark a material identifier into parts wherever practical.
- If something wears out, you can replace a component rather than an entire product [20].

6.4.4 Material selection issues for design for recycling

The amount and types of materials used in products are very important for designers who working on design for recycling. Recycling world has four material categories, these are: Metal, glass, paper and plastic

Various compatibility tables exist for outlining what materials in a specific class can be recycled together. The majority of these lists, however, are oriented to plastics. One such example is shown in Figure 6.2. Thermoplastics such as low-density polyethylene, polypropylene, polyvinyl chloride, and polyethylene terephthalate are generally easy to recycle. On the other hand, thermosets are harder to recycle.

Since coatings are a major source of contamination in recycling, uncoated materials are much easier to recycle than their coated counterparts. It should be noted that coatings not only encompass plated metals but also include various laminates and paints that are typically used for both metals and plastics. Metals with high alloy content are harder to recycle because of their large residual elemental concentration. These elements represent another source of contamination especially when other low alloy metals are included in the feed material. Due to advancements in material separation technologies, steel, aluminum, and magnesium can be separated quite easily. However steel contaminated with copper, tin, zinc, lead, or aluminum is more difficult to recycle. Similarly, iron, chromium, zinc, lead, copper, or magnesium contaminants in aluminum also lower its apparent value and recyclability.

Therefore, in the material selection process of the design stage, recycling compatibility should be a major consideration. In addition, exotic materials should be avoided, especially ones that pose a risk to humans and the environment.

Moreover, plastics should be adequately marked so that they can be readily identified during normal dismantling practices. Misidentification of recyclable plastics is the number one reason why plastics have such a low recyclability [18].

		Additive												
Basic material	Important synthetic design materials	PE	PVC	PS	PC	PP	PA	POM	SAN	ABS	PBTP	PETP	PMMA	
	PE	●	○	○	○	●	○	○	○	○	○	○	○	● Compatible ● Limited compatibility ● Compatible in small quantities ○ Not compatible
	PVC	○	●	○	○	○	○	○	●	●	○	○	●	
	PS	○	○	●	○	○	○	○	○	○	○	○	○	
	PC	○	●	○	●	○	○	○	●	●	●	●	●	
	PP	●	○	○	○	●	○	○	○	○	○	○	○	
	PA	○	○	●	○	○	●	○	○	○	●	●	○	
	POM	○	○	○	○	○	○	●	○	○	●	○	○	
	SAN	○	●	○	●	○	○	○	●	●	○	○	●	
	ABS	○	●	○	●	○	○	●	○	●	●	●	●	
	PBTP	○	○	○	●	○	●	○	○	●	●	○	○	
	PETP	○	○	●	●	○	●	○	○	●	○	●	○	
	PMMA	○	●	●	●	○	○	●	●	○	○	○	●	

Figure 6.2 : Material comparison chart for plastics [19]

6.4.5 Fastener selection table for design for recycling

The most appropriate fastener selection options generally recommended as Table 6.6. In this table A shows good, B shows average, and C shows bad.

6.5 Recyclability Assessment in Design for Recycling

To make a recyclability assessment a few step approaches must be applied. This approach provides to designer easiness at design stage or for only recycling process.

These steps can be put in order as following: Collection of data, rating the components, calculation of recyclability by weight.

6.5.1 Collection of data

Collection of data refers to finding information about product, product's material, recycling options of product and fastener types, which are used at product.

With the information given below, a table can be made to organize recycling options. Mostly, for data collection materials and fasteners are considered.

Table 6.6 : Fastener rating system for both product and material recyclability [18]

Connection Characteristics		Material Connection		Frictional Connection					Positive Connection			
		 Plastic/metal Adhesive bonding	 Welding	 Magnetic Con.	 Velcro Fast.	 Bolt/ nut	Plastic Bolt/ nut	 Spring Con.	 Snap joint	 Turnoff fastener	 Press- tup fastener	 Press- press fasten er
Detaching Behavior	Detaching Expenditure	C	C	A	A	B	B	A	C	A	A	A
Detaching Behavior	Destructive Detaching Expenditure	B	B	-	-	B	A	-	A	B	B	B
Recyclability	Product Recycling	C	C	B	B	B	A	A	C	A	A	A
Recyclability	Material Recycling	B	A	B	B	B	A	A	A	A	B	B

A certificate of the materials, which are used in product, essential because define its recyclability. Some of the materials can be recycled easily but some of them cannot. To solve this problem at design stage designer needs to know the recyclability of materials.

A certificate for fasteners is necessary, because that define the separation process needed in case two components need to be separated for recycling. The fastener material must be identified also for ease of data collection [21].

6.5.2 Rating the components

Generally rating the components are organized according to rating schemes, which are given Table 6.7 and Table 6.8. Two types of rating systems are available in component rating system. These are: 1. Recyclability rating; 2. Material separation rating.

Rating scales have values A to F for their properties. Material recyclability and remanufacture categories are mentioned below:

- A.Parts can be remanufactured.
- B.Parts can be recycled completely.
- C.Technically feasible for recycling process.
- D.Recycling process technically can be done however; material has to develop.
- E. These types of materials can be used for energy recovery.
- F.There is no technology for recycling these types of materials.

The values of A to D refer to values for material separation in a component and these characters are classified below:

- A.A refers to easily disassembly in material separation rating scheme.
- B.B requires to effort for disassembly.
- C.The parts and materials need to mechanical separation techniques for separation.
- D.D refers to material or parts cannot be disassembled [21].

Table 6.7 : Recyclability ratings of materials

MATERIAL	RECYCLABILITY RATING	CAUSE
Metal	A	Technology available for recycling
Thermo-plastic	B,C	Technology available but substructure not available
Thermosets	D,E	Technology under development
Metal with thermo-plastic	C,D	Shredding process is required to separate the materials, resulting plastic can be recycle
Multiple Thermo-plastics (compatible)	C,D	Technology under development and mixture of plastic can be recycle
Multiple Thermo-plastics (incompatible)	D,E,F	Incineration can be possible for these material types
Multiple Thermosets	D,E,F	Incineration can be possible for these material types

Table 6.8 : Separability ratings of fasteners and materials

STATUS	SEPERABILITY RATING	CAUSE
Fasteners made from same materials with parts which joined together	A	Disassembly process not necessary
Fasteners material made of compatible with joined part's material	A	Disassembly process not necessary
Fasteners incompatible with joined parts, however removal by force	C,D	Parts and fasteners materials can be separated manually.
Ferrous fasteners joined with compatible plastic parts.	A,B,C	Fasteners can be separated by shredding or magnetic operations.
No removable ferrous fasteners joined with incompatible fasteners.	C,D	Plastics are separated by density differences. Other parts are separated by shredding.
Fastener dimensions are so small actually no contamination will occur	A	Components are recycled as a whole product.
Non-removal fasteners and part materials are not suitable with fastener materials	D	Part materials and fastener materials are incompatible also fasteners are non-removable

6.5.3 Calculation of recyclability by weight

A product's recyclability can be calculated according to its weight. To implement this process total weight of the product and recyclability and separability ratings of the products must be known.

To apply this method to product recycling process instructions must be followed given below (6.1).

- The weights of all components with a recyclability rating of A-C and separation rating A-C are summed.
- The letters, which are given Table 6.7 and 6.8 A, B, C are taken values 1-3.
- The number of resulting weight is divided by the product's total weight of all components in the assembly.
- The resulting number shows the percentage of the recyclability.
- The calculation is quantitative value but generally, system components are more informative than resulting value [21].

$$\text{Recyclability by weight} = \frac{\text{Total weight of components with the rate of 1-3}}{\text{Total weight of all components}} \quad (6.1)$$

6.6 Cost Factors for Design for Disassembly

In design for recycling approach cost factors depends on disassembly, shredding and separation, energy recovery, material recycling, equipment operation costs, equipment investment costs and waste and hazardous substances. A product's cost and profit calculations are based on its weight. Generally in manual disassembly cost is calculated from disassembly time directly and additionally the cost of tool used in process. Separating and shredding costs change according to operational cost and operation tool cost. On the other hand, profits from the recycling of end of life products generally includes, profit from parts or materials yielded from disassembly and profit from reclaimed materials recovered after shredding.

Profits of substances yielded from disassembly and materials reclaimed after shredding need to be considered separately because parts and materials reclaimed from disassembly often have higher prices than the materials that are reclaimed after the shredding process. Materials reclaimed from shredding are in a bulk form and are mixed with other materials, which must be further processed prior to reuse.

By defining the parts differentiation disassembly, shredding and disposal, the cost of each can be calculated accordingly. That accommodates changes in unit prices and costs so that estimates of recycling costs can be recalculated easily. It is useful for computing the costs or profit from recycling a product in different units and market prices [21].

6.7 Limiting Factors for Design for Recycling

Design for recycling can be applied all of the product's design, however design for recycling approach has a few restricts for implementation. Designers consider product's valuable parts firstly and if the product is made with same material at ever components designers should consider about weight. If recyclability and recycled content are defined by weight, the heaviest parts should be considered first. Improving of a 5kg component's recyclability has a larger affect than 1kg component.

At previous section, a recycling rate and a separability rate schemes are mentioned. According to these schemes, designers should not use the materials, which have rating D to F. The components with a recyclability rating D must be changed easily to C rate. Shortly, the designer should consider the material rating and separability rating targets.

Breaching the design for recycling guidelines is another limiting factor. A fastener, a component or a material, which breaches some of the design for recycling guidelines, may be a limiting factor. These problems must be solved design stage so probable time losses are prevented [21].

7. CASE STUDY WITH DESIGN FOR RECYCLING APPROACH

In the previous chapters, concurrent engineering, end of life stage, design for disassembly, design for recycling approaches have been presented to increase a product's economic performance, recyclability and quality.

In this chapter, the main concepts of the previous chapters will be summarized by implementing an experimental study for computer equipment. In the following section, one of the most important computer equipments, mouse will be analyzed according to design for recycling approach. An old model mouse and a new model mouse will be compared with their fastener types, connection types, materials types and disassembly times.

7.1 Introduction to Case Study

Every year companies from the entire world pay land costs for waste computer equipments. In addition, these companies pay transportation money to carry waste equipments. These problems encouraged the computer and computer equipment manufacturers to improve design for recycling techniques. Recycling computers and their equipments can be lengthy process and some companies find reuse is much easier than recycling operations. Reuse has the first priority in recycling options. Hazardous materials such as, mercury, lead and nickel cadmium are landfilled generally.

Improvements in technology effect the computer environment directly. Changing in computer equipments is required because of new technological changes in computer environment. Mice are impressed mostly from these technological changes. For example, old-fashioned mice had three buttons and a ball to direct the mouse's cursor. Nowadays almost all the mice are optic and most of all are cordless mice. When considered the invention time of first mouse and today date interval, a huge amount of waste mouse landfilled or incinerated. To decrease of the number of waste mice design for recycling approach is required.

Design for recycling efforts in the computer and electronics industry. DfR can be used to by a manufacturer to reduce its environmental impacts, to enhance its prestige, or to comply with the DfR requirements of major product eco-labels (i.e. Blue angel for electronics).

This study summarizes the implementation of end of life strategies with DfR strategies for plastic personal computer equipments. The framework, which modeled with respect to EOL, DfD and DfR, is shown in Figure 7.1. This framework applied to case study with a mouse that is recycled using manual disassembly and putting in order the process. Mice represent one of the highest value applications for plastic in electronic industry. Only in 2004, 145 million desktop PC's are manufactured. According to this information approximately 145 million mice are manufactured so. If the technological improvements considered, that amount can be more than 145 million nowadays.

The electronics manufacturers not be interested in design for recycling strategies until today, however, decreasing at raw materials amount, legislations, and environmental pollution will trigger the manufacturers to deal with design for recycling and the other subjects like DfR.

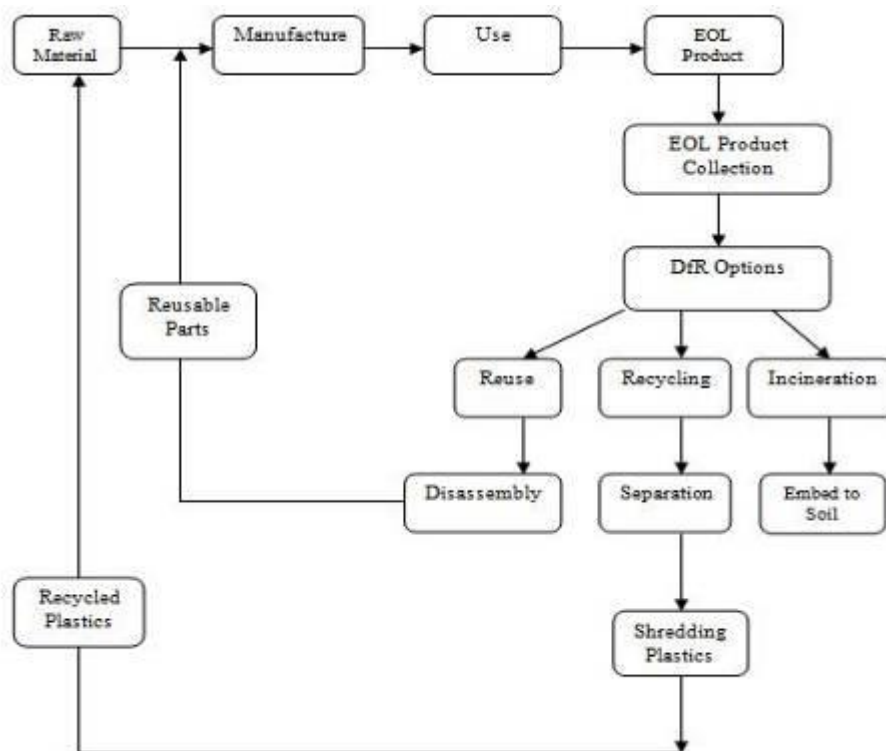


Figure 7.1 : The framework of case study

7.2 Ball Mouse Assessment

In this section an old-fashioned ball mouse, which is shown in Figure 7.2 will be examined. The mouse will be disassembled manually and disassembly times each part will be determined. To implement this process easily disassembly sequence will be determined firstly. Numbers, which are seen in Figure 7.2, identifies the each part of ball mouse.

The ball mouse has 10 parts. These parts are upper cover, lower cover, left/right/middle button with their holder, ball, PCB, ball cover, rotary encoder wheel (1), rotary encoder wheel (2), opposite movement scroll and Ps2 connection cable.

The goals of this study are to find out the product parts recycling options, recycling rate and disassembly times. The reason to use a mouse is simple and easy to understand. A more complicate product that comprises many parts and different joint types can be modeled by using the same system following the same procedure. However, implementing system a complex product very difficult and expensive. Because, for such a product disassembly, designer only has a one chance to implement.

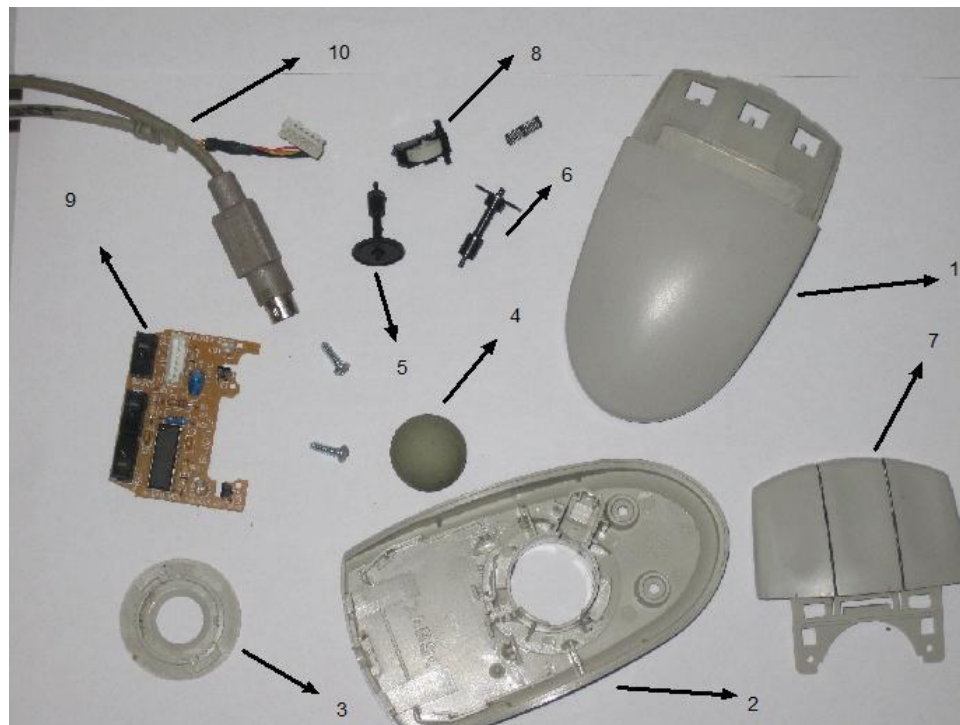


Figure 7.2: Exploded view of ball mouse

7.2.1 Disassembly process of ball mouse

Disassembly sequence defining is very important process to start disassembly operation. So, to determine the disassembly sequence all the parts of ball mouse must be disassembled in a optimum sequence. Table 7.1 shows the disassembly sequence of ball mouse. Following figures are belongs to ball mouse and these figure are put in order to optimum disassembly sequence.

In disassembly process, firstly the ball is taken out. To do this ball cover is turned to the left and opened. After these steps, to separate the upper and lower cover, a screwdriver must unscrew two screws. Left, right and middle button is belongs to upper cover and they are connected to upper cover with snap fits. Button holder firstly disassembled from snap fits and then each button is disassembled.

After disassembling of upper side, lower cover can be disassemble. To make easy lower side disassembly firstly connection cable can be removed from its socket. With the cord out of the way, rotary encoder wheels can be disassembled. Each one of rotary encoder wheels is beared by press fits. These connections are disassembled easily with help of a mini crank. As seen in the Figure 7.3 there is an opposite movement scroll to help the ball movements. This has a spring connection for stability.

Table 7.1: Disassembly sequence of ball mouse

Part No	Part Name	Disassembly Sequence No
1	Upper Cover	3
2	Lower Cover	10
3	Ball Cover	1
4	Ball	2
5	Rotary Encoder Wheel(1)	6
6	Rotary Encoder Wheel(2)	7
7	Left/Right/Middle Button	4
8	Opposite Movement Scroll	8
9	PCB	9
10	Connection Cable	5



(a)



(b)



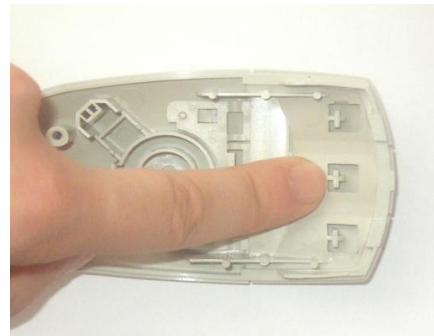
(c)



(d)

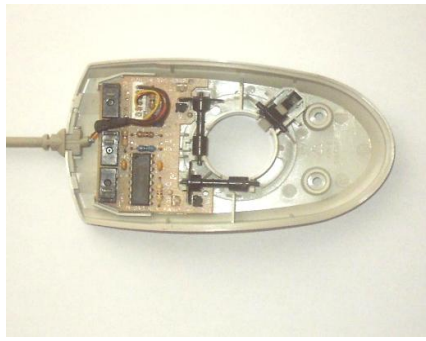


(e)

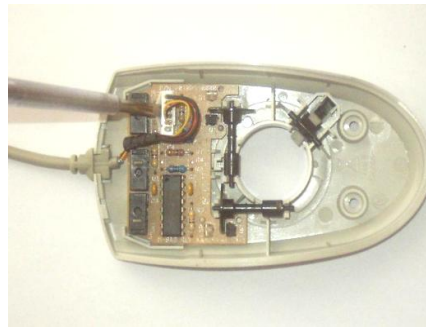


(f)

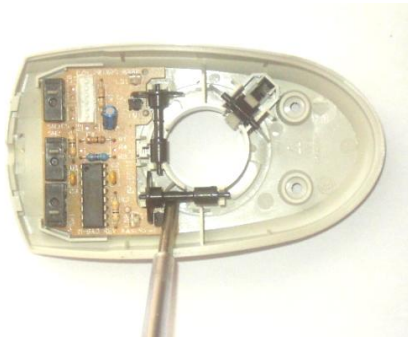
Figure 7.3: Disassembly process of ball mouse



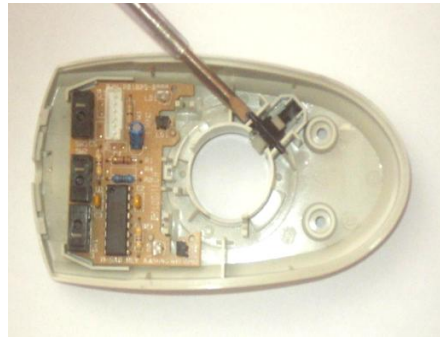
(g)



(h)



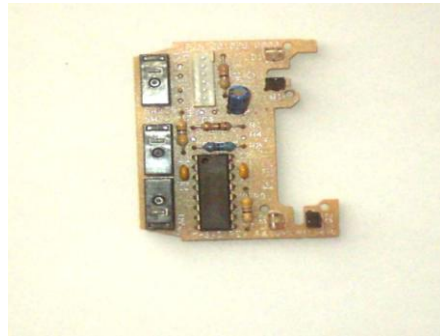
(i)



(j)



(k)



(m)

Figure 7.3: (Contd.) Disassembly process of ball mouse

In order to optimum disassembly sequence, disassembly times are given in Table 7.2. Also, this table give information about fastener types and disassembly tools.

Table 7.2: Disassembly times for each part of ball mouse

No	Part Name	Fastener Type	Disassembly Tool	Disassembly Time (second)
1	Ball Cover and Ball	Snap Fit	Handmade	3.1 s
2	Upper and Lower Cover	Screw(1)	Screwdriver	6 s
3	Upper and Lower Cover	Screw(2)	Screwdriver	6 s
4	Button Holder	Snap Fit	Handmade	3 s
5	Left Button	Snap Fit	Handmade	2 s
6	Right Button	Snap Fit	Handmade	2 s
7	Middle Button	Snap Fit	Handmade	2 s
8	Connection Cable	Close Fit	Screwdriver	2.5s
9	Rotary Encoder Wheel(1)	Press Fit	Mini Crank	3.5s
10	Rotary Encoder Wheel(2)	Press Fit	Mini Crank	3.5s
11	Opposite Movement Scroll	Press Fit	Mini Crank	3s
12	PCB	Contact	Handmade	2s
			TOTAL	38.6 s

7.2.2 Design for recycling assessment of ball mouse

To assess the ball mouse's recycling design following all of the parts of mouse must be check over with the aspect of design for recycling. The following Table 7.3 shows summary of assessment of ball mouse for design for recycling.

Table 7.3: Parts and material features of ball mouse

No	Part Name	Weight (g)	Accessibility	Dimension (mm)	Material
1	Ball Cover	2.5	Excellent	35	Plastic (ABS)
2	Ball	32	Poor	10	Rubber
3	Upper Cover	23	Excellent	110*55	Plastic (ABS)
4	Lower Cover	16	Excellent	110*55	Plastic (ABS)
5	Button Holder	5	Average	20*40	Plastic (ABS)
6	Left Button	3	Average	30*20	Plastic (ABS)

Table 7.3: (contd.) Parts and material features of ball mouse

7	Right Button	3	Average	30*20	Plastic (ABS)
8	Middle Button	3	Average	30*20	Plastic (ABS)
9	Connection Cable	26	Excellent	1800*3	Insulated Wire
10	Rotary Encoder Wheel(1)	2	Poor	25	Plastic (ABS)
11	Rotary Encoder Wheel(2)	2	Poor	25	Plastic (ABS)
12	Opposite Movement Scroll	2.5	Poor	15	Plastic
13	PCB	10	Excellent	50*35	Plastic (Composite)

When designing a product with design for recycling approach recyclability rating guide to designer to decide right way. Table 7.4 shows recyclability rating of the ball mouse.

Table 7.4: Recyclability rating for ball mouse

No	Part Name	Material Rating	Fastener Rating	Disassembly Rating	Recyclability Rating
1	Ball Cover	B	C	C	B
2	Ball	C	A	A	C
3	Upper Cover	B	C	C	B
4	Lower Cover	B	C	C	B
5	Button Holder	B	B	B	B
6	Left Button	B	B	B	B
7	Right Button	B	B	B	B
8	Middle Button	B	B	B	B
9	Connection Cable	A	A	A	A
10	Rotary Encoder Wheel(1)	B	B	B	A
11	Rotary Encoder Wheel(2)	B	B	B	A
12	Opposite Movement Scroll	C	B	B	B
13	PCB	D	A	A	C

With the design for recycling assessment, some of the parts can be reuse. These parts are generally inside of the ball mouse. Connection cable, ball, PCB, rotary encoder

wheels can be reused. Especially rotary encoder wheels can be reuse in other electronics, such as tachometers. Ball and connection cables are standardized products so they can be use in other mouse or they can keep such as spare part. Also opposite movement scroll can be use in other mouse or can be kept.

Ball cover, upper cover, lower cover, button holder, PCB and buttons can be recycled. Because they cannot be use in other mice or in other options. Using them as raw material by recycling is the best option.

7.3 Optical Mouse Assessment

With improve of technology old type ball mice have given their place to new technology optical mice. In this time interval, new type mice developed more ecofriendly. They are designed to suitable for ease of disassembly and recycling by computer equipment manufacturers.

The optical mouse has 9 parts. These parts are upper cover, left and right button with button holder, upper cover safety plate, wheel (scroll), optic sensor guard, led lamp guard, PCB(printed circuit board), lower cover and USB cable.

To get better understanding exploded view of optical mouse is shown in Figure 7.4.

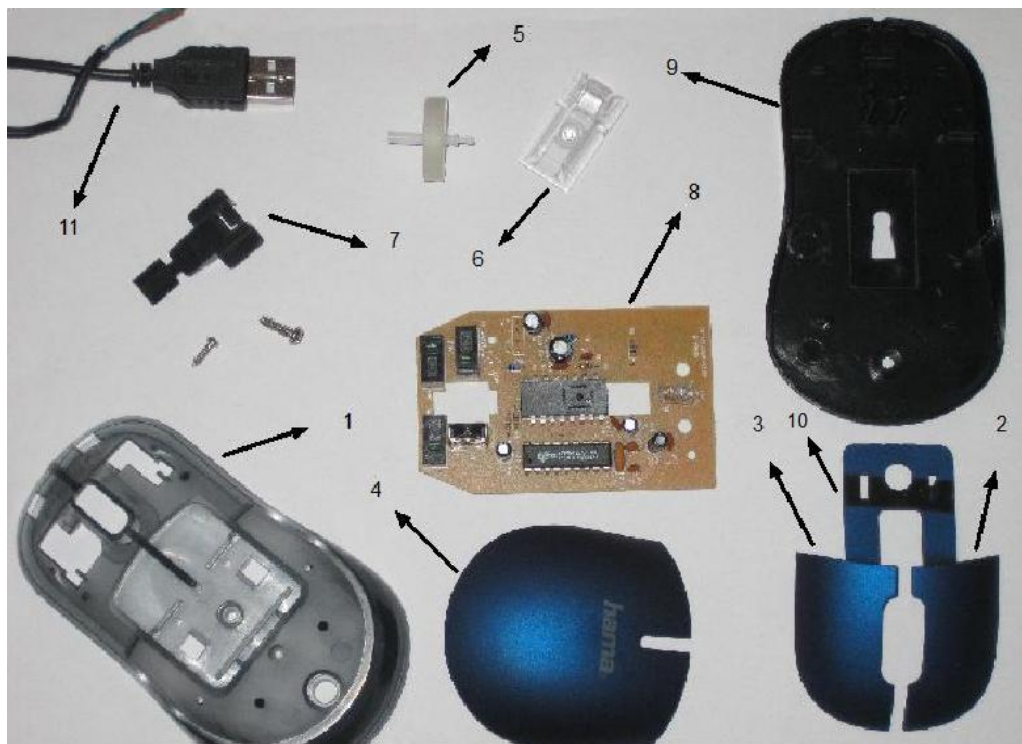


Figure 7.4: Exploded view of optical mouse

7.3.1 Disassembly process of optical mouse

The following figures put in order according to the disassembly sequence of optical mouse. Figure 7.5 shows the disassembly of optical mouse in order to optimum disassembly sequence.

The figure, which is shown below, represents the disassembly steps of top of the mouse. Firstly, lower and upper covers of screw connection are disassembled by screwdriver. These covers are separated from each other by pulling them apart. A screwdriver is used to separate from the upper cover unscrews left and right button holder. Left, right button and button holder part connected to upper cover by a snap fit so they are required to press them out by hand.

In Figure 7.5, PCB is taken from the lower cover by pulling the lower cover and it. A press fit required to pull it to opposite position to unfasten the wheel (scroll). After that, optic sensor guard is separated easily by pulling them apart. Led lamp guard fastened by a press fit so firstly, it will be pulled perpendicular to PCB and then it is required to press from press fits at the lower side of PCB as shown in the figure. Finally, a scissors must cut connection cable because connection cable is soldered. Disassembly sequence of optical mouse is summarized in the Table 7.5.

Table 7.5: Disassembly sequence of optical mouse

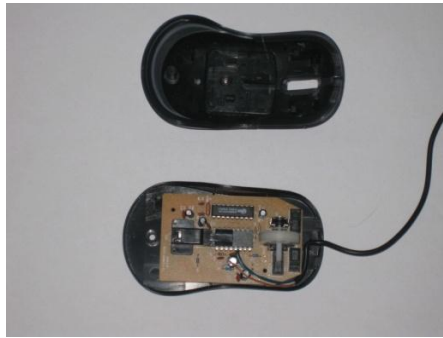
Part No	Part Name	Disassembly Sequence No
1	Upper Cover	1
2	Left Button	4
3	Right Button	5
4	Upper Cover Safety Plate	3
5	Wheel (Scrool)	8
6	Optic Sensor Guard	9
7	Led Lamp Guard	10
8	PCB	6
9	Lower Cover	7
10	Left/Right Button Holder	2
11	Connection Wire	11



(a)



(b)



(c)



(d)

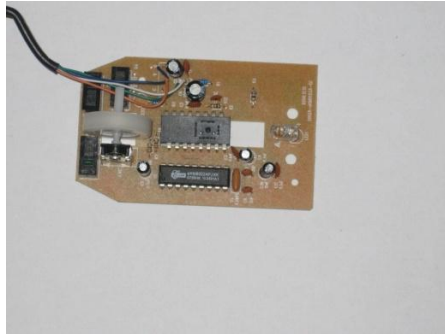


(e)

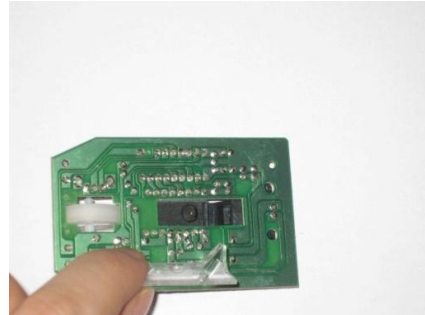


(f)

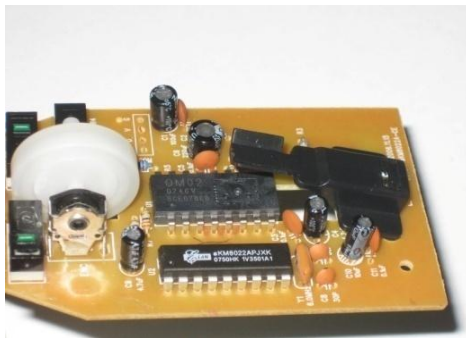
Figure 7.5: Disassembly process of optical mouse



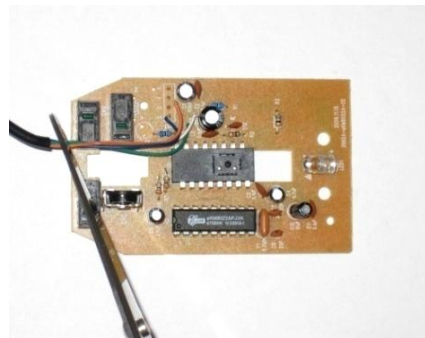
(g)



(h)



(i)



(j)

Figure 7.5: (contd.) Disassembly process of optical mouse

Finding the optimum disassembly sequence provides to decrease of disassembly times. Such a basic product disassembly sequence and disassembly times cannot be very urgent but when designing more complex products then this mouse, incorrect disassembly sequences causes unnecessary time loses.

The disassembly times of optical mouse is presented in the Table 7.6. This table put in order respect to disassembly sequence of optical mouse.

Table 7.6: Disassembly times for each part of optical mouse

No	Part Name	Fastener Type	Disassembly Tool	Disassembly Time (in second)
1	Upper and lower cover	Screw + Press Fit	Screwdriver + Handmade	7.2 s
2	Upper cover safety plate	Contact	Handmade	1.2 s
3	Left and right button holder	Screw	Screwdriver	6 s
4	Left Button	Snap Fit	Handmade	3 s
5	Right Button	Snap Fit	Handmade	3 s
6	PCB	Contact	Handmade	2 s
7	Lower Cover from PCB	Contact	Handmade	2 s
8	Wheel	Press Fit	Handmade	2.5 s
9	Optic Sensor Guard	Contact	Handmade	1 s
10	Led Lamp Guard	Press Fit	Handmade	3 s
11	Connection Cable	Soldered	Scissors	2 s
			TOTAL	32.9 s

7.3.2 Design for recycling assessment of optical mouse

Design for recycling assessment considers product's material, recyclability rating of parts, ease of disassembly, and ease of recycling. Fastener type also is necessary for design for recycling because type of fastener affects the ease of disassembly rules.

In Table 7.7 each parts of optical mouse is considered with their purposes such as shape, dimension, and material. The accessibility assessment rating is given respect to experiment of disassembling optical mouse.

In the Table 7.8, a design for recycling rating system is summarized. Material types, fastener types and their connection types affect this table directly. This table is prepared experimentally.

All of the information, which is used in tables, is taken from the previous sections. Material rating values are taken from Table 5.7, fastener-rating values are prepared respect to Table 6.6 and disassembly rating is taken from Table 5.2.

Table 7.7: Parts and material features of optical mouse

No	Part Name	Weight (g)	Accessibility	Dimension (mm)	Material
1	Upper Cover	21	Excellent	105*60	Plastic (ABS)
2	Left Button	2.5	Poor	40*20	Plastic (ABS)
3	Right Button	2.5	Poor	40*20	Plastic (ABS)
4	Upper Cover Safety Plate	6	Excellent	55*60	Plastic (ABS)
5	Wheel (Scrool)	4.5	Average	10	Plastic
6	Optic Sensor Guard	4	Excellent	30*15	Plastic
7	Led Lamp Guard	3.5	Poor	30*18	Plastic (ABS)
8	PCB	22	Excellent	75*46	Plastic (Composite)
9	Lower Cover	14	Excellent	105*60	Plastic (ABS)
10	Left/Right Button Holder	3	Excellent	30*35	Plastic (ABS)
11	Connection Wire	20	Excellent	1400*3	Insulated Wires

Table 7.8: Recyclability rating for optical mouse

No	Part Name	Material Rating	Fastener Rating	Disassembly Rating	Recyclability Rating
1	Upper Cover	B	B	B	B
2	Left Button	B	C	B	B
3	Right Button	B	C	B	B
4	Upper Cover Safety Plate	B	A	A	B
5	Wheel (Scrool)	C	A	B	C
6	Optic Sensor Guard	B	A	A	B
7	Led Lamp Guard	B	B	B	B
8	PCB	D	A	A	C
9	Lower Cover	B	B	B	B
10	Left/Right Button Holder	B	C	B	B
11	Connection Wire	A	C	A	A

As mentioned in previous sections, the design for recycling approach has three options (reuse, recycling and incineration). The disassembled parts are separated according to their end of life options. Reusable parts are; Upper cover, wheel, led lamp guard, left and right button holder, connection wire.

Outside parts of mouse are getting more wear out when compared with the inside parts of mouse. Recyclable parts are left and right button, upper cover safety plate, optic sensor guard, lower cover, and PCB (if it is not broken). Finally, none of the parts is required to incinerate.

7.4 Comparison of Ball Mouse and Optical Mouse

Until today, designs of mice changed lots of time. In the previous sections, a ball mouse and an optical mouse were examined. Ball mouse produced about 90's, and optic mouse produced about in 2000's. The following tables are prepared to compare these two mice in order to design for recycling rules. Table 7.9 shows fastener differences. According to Table 7.9, total joint quantity did not change by the time, however, types of fasteners changed. Snap fastener quantity decreased until today's design, although, number of contacts increased. Increasing in number of contacts provides decrease on disassembly time. In other fastener types, there is no significant change. Number of screws and press fits remained the same quantity.

From past to today, there is no significant material type changes at mice. Both of the examined mice use plastic (ABS) as material generally. Therefore, it is not necessary to compare material types.

Table 7.9: Comparison of ball mouse and optical mouse about joints

Mouse Type	Number of Snap Fastener	Number of Screws	Number of Contacts	Number of Press Fits	Number of Soldered Joints	Number of Close Fits	Total Joint Quantity
Ball Mouse	5	2	1	3	0	1	12
Optical Mouse	2	2	4	3	1	0	12
Difference	-3	0	+3	0	+1	-1	0

The most significant difference can be seemed for disassembly times. Common part's disassembly times are given in Table 7.10. Time differences between disassembly processes of each mouse are one of the goals of this study. As shown in the table, there is a difference about 6.3 seconds for a mouse and this provides to manufacturers to easiness for design for recycling.

Table 7.10: Comparison ball mouse and optical mouse about disassembly

Mouse Type	Upper and Lower cover	PCB	Connection Cable	Buttons	Button Holder	Total Disassembly Time
Ball Mouse	12s	2s	2.5s	6s	3s	38.6s
Optical Mouse	7.2s	2s	2s	6s	6s	32.9s
Difference	+4.8	0	+0.5	0	-3	+6.3

When the design for recycling ratings compared we could say there is no difference generally. Recycling ratings and materials ratings are same, because both of the mice are produced from plastic (ABS). Table 7.11 shows the common parts comparison with respect to design for recycling rating system. Only the disassembly rating has a few differences. The reason of this difference is, ball mouse upper cover and lower covers connection type. Also, recyclability ratings of each mouse is compared in the table.

Table 7.11 Comparison of design for recycling ratings for common parts

Parts	Recycling Rating		Material Rating		Disassembly Rating		Recyclability by weight	
	Ball Mouse	Optic Mouse	Ball Mouse	Optic Mouse	Ball Mouse	Optic Mouse	Ball Mouse	Optic Mouse
Upper Cover	B	B	B	B	C	B	%40	%41,74
Lower Cover	B	B	B	B	C	B		
PCB	C	C	D	D	A	A		
Con. Cable	A	A	A	A	A	A		
Buttons	B	B	B	B	B	B		
Button Holder	B	B	B	B	B	B		

8. CONCLUSION

Sequential engineering became unable to meet requirements of today's rapid technological changes, marketing pressure, improving quality and decreasing production costs. Therefore, manufacturers developed concurrent engineering approach.

To meet concurrent engineering requirements, companies have to use a few basic principles such as multidisciplinary setup, teamwork and global participation. These basic principles are not sufficient by themselves. However, design processes in concurrent engineering are needed to at design stage of a product.

Easiness in rapid technological change with concurrent engineering causes to increase the amount of electrical electronic products. Reasons of increasing levels are, fashion changes, product's end of life and low quality of products. To prevent waste electrical electronic products design for recycling approach is developed.

First step to design for recycling is design for disassembly process. Design for disassembly is systematic removal process of parts from an assembly. For implementing design for disassembly to complex products, designers have to consider components, connections and fasteners of products. Designing these provides ease of disassembly in complex products.

Companies firstly thought that design for recycling is unnecessary at development stage. Therefore, they are directed to use this approach by legislations. In addition to, cost reduction and market pressure encouraged companies to implement DfR on their product development stage.

The main goal of this study was examination electrical electronic products, which have rapid fashion changes. Thus, two computer mice were examined with respect to design for recycling and their results were compared.

Finally, that could be said there is no significant difference in mouse material types, but visible changes occurred at fastener types and disassembly times.

This study represents that, DfR approach has not been applied yet on mouse design sufficiently. Because, expected changes such as material type change, reductions in quantity of fasteners are not implemented in new type optical mouse significantly. Optic mouse's disassembly time is lower than the ball mouse's disassembly time. But the optic mouse disassembly time could be decreased by reducing the mouse part quantity. In addition, recyclability by weight values was so close to each other. The reason of this value is material type's sameness of each mouse.

In the next studies, designers can be work on material type. The ABS, the plastic material that is used in mouse, is suitable for recycling options, but possible material changes or new type material selection reviews could be done for easiness of design for recycling. Moreover, new studies could be done about fastener type selection such as, reducing fastener type quantity or total number of fasteners.

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