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Demanufacturing metrics for industrial fasteners and disassembly process

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ABSTRACT

DEMANUFACTURING METRICS FOR INDUSTRIAL FASTENERS AND DISASSEMBLY PROCESSES

by
Narendra P. Raj

As the society progresses towards ecological maturity, the issue of reducing the environmental burden imposed by used products becomes increasingly important Environmental issues are becoming increasingly relevant for product designers and manufacturers. Public awareness of the value and fragility of an intact ecology is constantly growing, and the traditional assumption that the cost of ecological burdens to be shared by a society, as a whole is no longer accepted. Environmental protection legislation requiring manufacturers to "take back" and recycle used products will be a commonplace throughout Europe and the U.S. in the near future.

Demanufacturing involves separating and disassembling a 'product' into its smaller 'subassemblies' and 'components'. Unfastening carries out the physical separation itself and other separation techniques are also used to separate the unfastened component. There are two types of Disassembly methods they are destructive disassembly and non-destructive. The term 'product' means a complete entity, such as an automobile, a washing machine, etc. 'Sub-assembly' refers to a product .A 'component' is a subassembly that cannot be disassembled any further.

The principle aims and objectives of this research are to analyze the mechanical aspects of demanufacturing a component with respect to fasteners and disassembly

Processes. This research involved developing Disassembly Effort Index Metrics (DEIM) for a wide variety of industrial fasteners, destructive and non destructive disassembly processes.

The industrial Fasteners were separated into four categories i.e. One Piece Fasteners, Two Piece Fasteners, Integral Fasteners and Miscellaneous Fasteners. They were analyzed with respect to the accessibility of a fastener with respect to the part, tools necessary to disassemble them, time needed to unfasten them, part hold and fixturing issues ,forces needed to unfasten them and instructions to the dissemblers to dissemble the fastener. A scoring pattern was developed .

The Disassembly Processes were categorized into Non-Destructive Disassembly and Destructive Disassembly. The Non-Destructive Disassembly methods like Magnetic Separation, Suction and Drainage, Self Removal, Separation of both Fastened and Unfastened Components, and only two of the Destructive Disassembly methods i.e. Weld Breakage and Impact breakage were analyzed using Disassembly Effort Index Metrics (DEIM) parameters. The DEIM parameters, for the Disassembly Processes are, time needed to disassemble the component, tools needed to separate them, Forces (both human and Machine) , Part hold , Process Instructions and Hazard Tools. The scoring pattern was developed.

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FOR
INDUSTRIAL FASTENERS AND DISASSEMBLY PROCESSES

by
Narendra P. Raj

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APPROVAL PAGE

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FOR
INDUSTRIAL FASTENERS AND DISASSEMBLY PROCESSES

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This thesis is dedicated to my
beloved parents, sister and other family members

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Finally, I thank my friends for their continuous help, support and encouragement.

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CHAPTER 1

INTRODUCTION

1.1 Background

As the society progresses towards ecological maturity, the issue of reducing the environmental burden imposed by worn out products becomes increasingly prominent. Environmental issues are becoming increasingly important for product designers and manufacturers. Public awareness of the value and fragility of an intact ecology is constantly growing, and the traditional assumption that the cost of ecological burdens to be shared by a society, as a whole is no longer accepted. Environmental protection legislation requiring manufacturers to "take back" and recycle used products will be a commonplace throughout Europe and the U.S. in the near future.

Environmental life-cycle analysis (LCA) has emerged over the last several years as a key tool for the environmental management of production systems. [5] It forms part of a novel orientation in environmental management towards pollution prevention, and from old-style "end of pipe" approaches. Within this paradigm, the concept of product stewardship is gaining acceptance: it encourages producers to take responsibility for all their product's interactions with the environment, including pollution resource consumption, and safety.

Life-Cycle analysis has been and continues to be developed as a tool to systematically measure and assess any environmental impact attributable to a product and supporting product system. During each of the cycle stages materials are explicitly analyzed from an environmental perspective: materials production, product manufacturing as affected by material composition and processing, product use as related to materials performance and properties, and product disposal in terms of materials processing. The LCA of products is fundamentally dependent on the LCA of materials. As such both concurrently and interdependently analyzed and assessed according to their environmental characteristics.

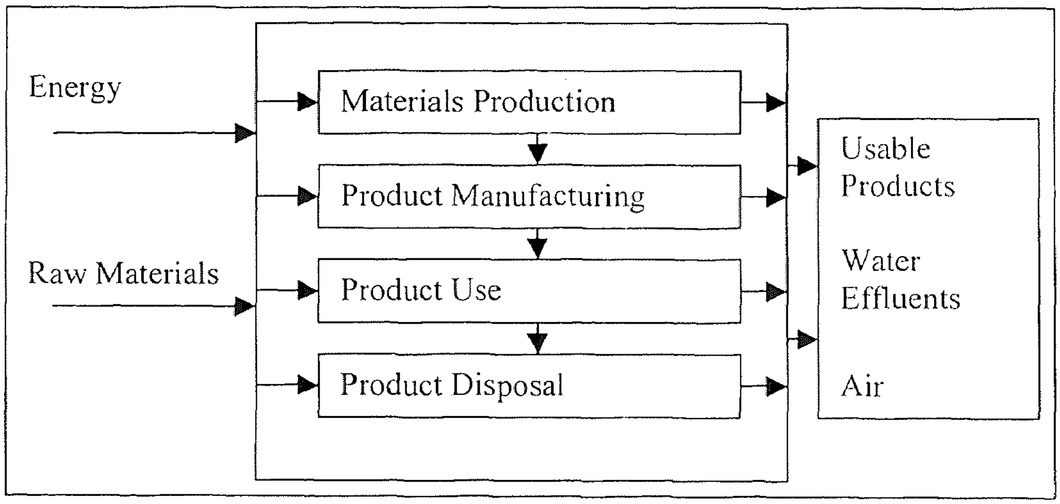

Figure 1.1 Life Cycle Assessment.

Life-Cycle engineering seeks to maximize a product's contribution to society while minimizing its cost to the manufacturer, the user, and the Environment. Life-Cycle Engineering seeks to incorporate various product lifecycle values into the early stages of design. These include functional performance, manufacturability, serviceability, and environmental impact.

Demanufacturing involves separating and disassembling a 'product' into its smaller 'subassemblies' and 'components'. Unfastening carries out the physical separation itself and other separation techniques are also used to separate the unfastened component. There are two types of disassembly methods they are destructive disassembly and non-destructive. The term 'product' means a complete entity, such as an automobile, a washing machine, etc. 'Sub-assembly' refers to a product .A 'component' is a subassembly that cannot be disassembled any further. When a product reaches the end of its original useful life, the following options exist,

- Re-using it for its original task. A further distinction is sometimes made between strict re-use, namely, using it 'as is' and remanufacturing, namely re-using after some repair or renovation has been done.
- 'Using on' for a purpose other than its original use, while retaining its original form.
- Utilizing it as a source of raw material, where it loses its original form. A distinction is made between high-level utilization, where the properties of the original material are retained, and a low-level utilization, where the utilized material is inferior to the original. Energy recycling, the burning of waste for energy, is usually considered a special sub-category of utilization (typically the lowest).
- Dumping the used product in some publicly approved site. This category can be further classified according to the 'level of toxicity' of the dumped material.

'Recycling' refers to all of the above, excluding dumping.

Often before a product/ subassembly can be recycled, it must go through certain preliminary ' recovery processes'. Two types of such processes can be distinguished:

- Disassembly separates two or more part types, each different label.
- Shredding and sorting cuts the product randomly into pieces, which are then sorted in order to get pure material pieces. [3].

1.2 Aims and Objectives

The principle aims and objectives of this research are to analyze the Mechanical aspects of demanufacturing a component with respect to fasteners and disassembly processes. This research involved developing Disassembly Effort Index Metrics (DEIM) of a wide variety of industrial fasteners, Destructive and Non Destructive Disassembly Processes.

The industrial Fasteners were separated into four categories i.e. One Piece Fasteners, Two Piece Fasteners, Integral Fasteners and Miscellaneous Fasteners. They were analyzed with respect to the accessibility of a fastener with respect to the part, tools necessary to disassemble them, time needed to unfasten them, part hold and fixturing issues ,forces needed to unfasten them and instructions to the dissemblers to dissemble the fastener. A scoring pattern was developed .

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Using the scoring pattern the DEI or the Disassembly Effort Index Calculator is being developed using Visual Basic 5.0 as front end and MS Access as back end .

1.3 Thesis Format

The remainder of the thesis is comprised of four chapters.

Chapter 2 presents the current environmental problems, a brief overview of Demanufacturing and the research and the software being developed to assist demanufacturing.

Chapter 3 evaluates the fasteners with respect to the Disassembly Effort Index parameters and describes a scoring mechanism for the fasteners.

Chapter 4 evaluates the Disassembly Processes with respect to Effort Index Parameters and describes a scoring mechanism for the Disassembly processes.

Chapter 5 concludes the thesis by summarizing the DEI software and the analysis of a TV Monitor with respect to the Disassembly Effort Index Metrics.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The space flights of 1960's enabled human beings for the first time to actually look at our planet from outer space and perceive it as an integrated whole. The perception of the Earth in all it's beauty-a- blue-and-white globe floating in the deep darkness of space provided the most powerful symbol for the global ecology movement [1].

Pollution prevention has become the environmental mantra of the 1990's.The rhetoric is easy but practice is difficult [2]. As the society progresses towards ecological maturity, the issue of reducing the environmental burden imposed by worn out products becomes increasingly prominent. Environmental issues are becoming increasingly important for product designers and manufacturers. Public awareness of the value and fragility of an intact ecology is constantly growing, and the traditional assumption that the cost of ecological burdens to be shared by a society, as a whole is no longer accepted [3].

Environmental protection legislation requiring manufacturers to "take back" and recycle used products will be a commonplace throughout Europe and the U.S. in the near future. The European Union, for example, has introduced a set of guidelines: the Eco-Management-and Audit Scheme (EMAS). Although still voluntary, EMAS signals that environmental responsibility lies with the industry. In Germany, this attitude is already being enforced with legislation guided by the 'originator-principle' (Verursacherprinzip); 'He who inflicts harm on the environment should pay for fixing the damage'. Public concern about diminishing natural resources, limited landfill space, and hazardous waste disposal has prompted legislators to place the responsibility for product recycling on the producers. In order to remain competitive, manufacturers must create products which are safe for the environment and facilitate the efficient recovery and reuse of materials and components [3].It has been noticed that the biggest environmental impact at the present time comes from such products such as disposable diapers, cosmetics packaging and food packaging, Nevertheless, the current disposal rates and recycling procedures for mass produced appliances (including automobiles) represent a waste to society that probably cannot continue [4].

2.2 Life Cycle Assessment

Environmental life-cycle analysis (LCA) has emerged over the last several years as a key tool for the environmental management of production systems. [5] It forms part of a novel orientation in environmental management towards pollution prevention, and from old-style "end of pipe" approaches. Within this paradigm, the concept of product stewardship is gaining acceptance: it encourages producers to take responsibility for all their product's interactions with the environment, including pollution resource consumption, and safety.

Life-Cycle analysis has been and continues to be developed as a tool to systematically measure and assess any environmental impact attributable to a product and supporting product system. During each of the cycle stages [Figure 2.1], materials are explicitly analyzed from an environmental perspective: materials production, product manufacturing as affected by material composition and processing, product use as related to materials performance and properties, and product disposal in terms of materials processing. The LCA of products is fundamentally dependent on the LCA of materials. As such both concurrently and interdependently analyzed and assessed according to their environmental characteristics.

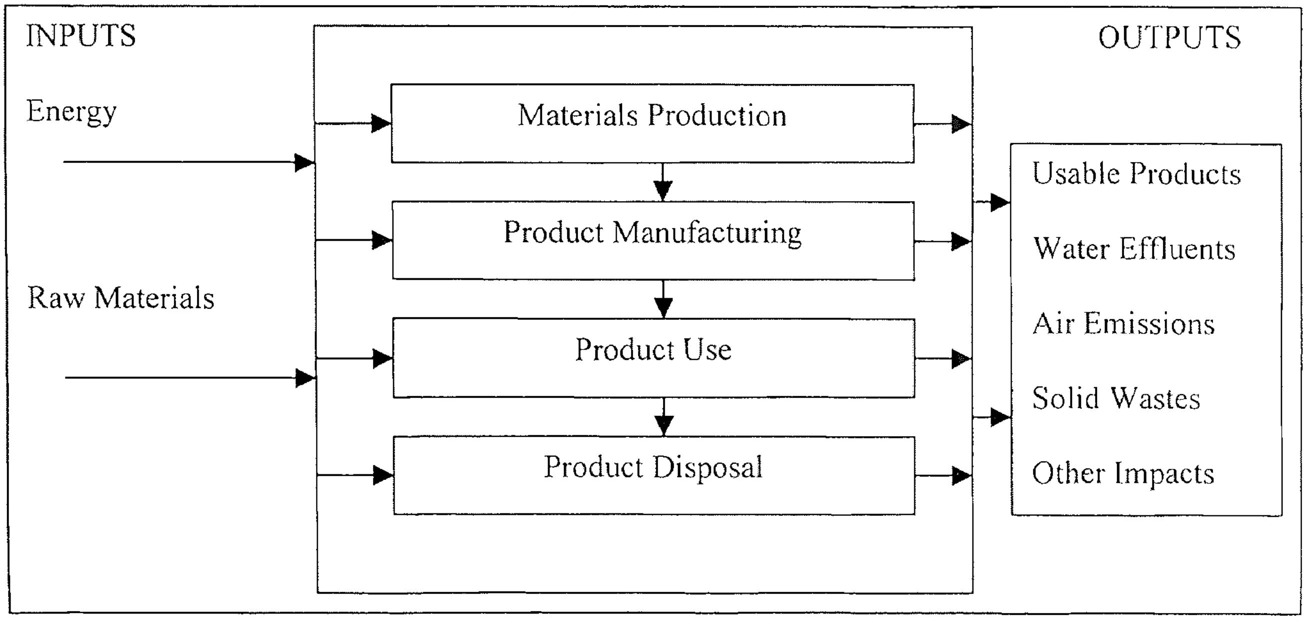


Figure 2.1 LCA, a product system defined by the system boundary

Life-Cycle engineering seeks to maximize a product's contribution to society while minimizing its cost to the manufacturer, the user, and the Environment. Life-Cycle Engineering seeks to incorporate various product lifecycle values into the early stages of design. These include functional performance, manufacturability, serviceability, and environmental impact [figure 2.2].

2.3 Design for X Approach

The term DFX is used to sum up all tools which provide a methodology that is focussed on part of a product's lifecycle or focuses on one of a number of ways to improve an aspect of the product [6].

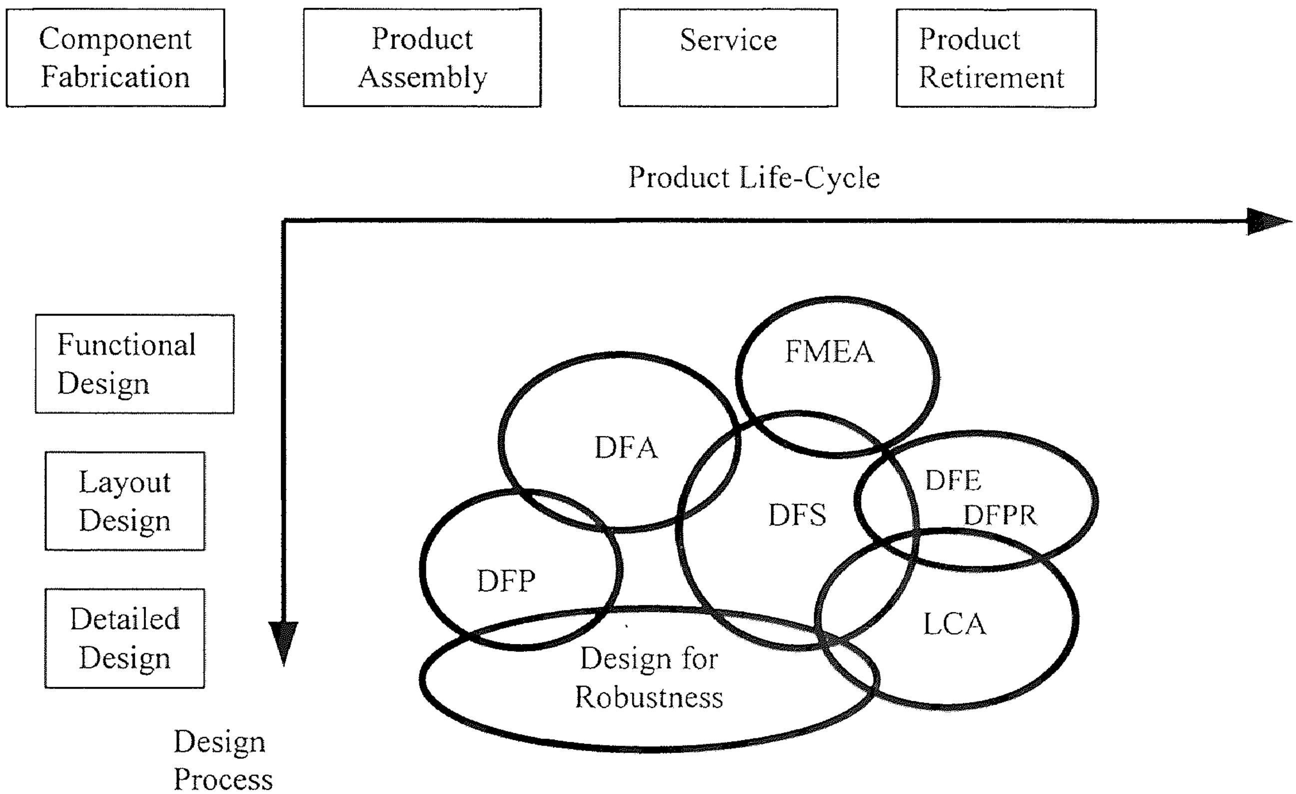


Figure2.2 Life Cycle design methodologies, Product Life cycle, and Design cycle

2.3.1 Design for Manufacturing and Assembly (DFMA)

DFX [6] is again divided into Design for assembly (DFA)[7], Design For Life (DFL), Design for Disassembly or End of Life (DFD).

Design for Assembly: Assemblability is a measure of how easy it is to assemble a product. The assemblability the higher the product quality in terms of fewer parts and simpler assembly operations. Fewer parts lead to breakdowns, fewer workstations, less time to assemble and less overheads. Simpler assembly operations imply that the product fits together easier, leading to shorter lead times and less rework. It may even become easy enough for machines to assemble them.

The tenets of DFA are:

- Reduce part count and types.
- Modularize the design.
- Strive to eliminate adjustments.
- Design parts for ease of feeding or handling.
- Design parts to be self aligning and locating.
- Ensure adequate access and unrestricted vision.
- Design parts that cannot be installed incorrectly.
- Use efficient fastening or fixing techniques.
- Minimize handling and reorientation's.
- Maximize part symmetry.
- Good detail design for assembly.
- Use gravity.

More specific tools in this area are Design for Manufacture (DFM), Design for Manufacturing and Assembly (DFMA). DFMA provides a systematic procedure for analyzing proposed design from the point of view assembly and manufacture. This DFMA procedure produces a considerable reduction in part count, resulting in simpler and more reliable products which are less expensive to assemble and manufacture.

2.3.2 Design for Life and Serviceability (DFL & DFS)

Design for Life (DFL) tools are directed towards improving the products during its life phase, by either decreasing its impact or by increasing the length of its life. The more specific tools of DFL are Design for Maintainability (DFMAIN), Design for Serviceability (DFS) focuses on the improvement of the design of a product so as to reduce the disassembly effort while servicing the component .The service community has developed a process to measure the serviceability of a vehicle, system, assembly, subassembly or component; the Serviceability Task Evaluation Matrix (STEM) process. The STEM process measures six criteria in every procedure being evaluated. The six criteria are Time, Cost, Diagnosis, Tool Requirements, Training Requirements, and Availability of parts [8].

2.3.3 Design for Disassembly (DFD)

The Design for Disassembly or End of Life focuses on the end or disposal stage. This is where they try to improve the product's performance by simulating reuse of certain components and materials and if possible further use of the complete products by giving them a second life. The tools in this group are Design for Recycling (DFR). Design for Environment (DFE) [9]. There is a growing interest in product design for disassembly and in life cycle analysis for environmental impact evaluation. Factors which should be considered in the design of products for ease of disassembly are:

(i) the financial aspects, including costs of disassembly process, the cost of benefits of item reuse or recycling costs of disposal and

(ii) Environmental impact

The reduction of automotive "fluff", the nonmetallic waste that is the bane of recyclers and environmentalist, was the aim of a 14 week, senior transportation design project at the Art Center College of Design (ACCD), Pasadena, California). They all illustrate how lighter- weight, stylish, production vehicles can be manufactured with less glass and plastic and fewer parts using a design-for-disassembly approach. Students presented a hybrid electric, sport luxury sedan equipped with a small gasoline engine for battery recharging. Half of the car's exterior, which features stainless steel panels, is designed with gradually curved steel sides to decrease tooling and simplify die stamping. A combination of adhesives bonding and Velcro® -like bonding systems would speed assembly and disassembly. This project really demonstrated to students that recycling must be part of design process, and that style and sturdiness do not have to take back seat to environmental friendliness [10].

2.3.4 Design for Environment (DFE)

Design for Environment (DFE) has now come to be called *Green Engineering Design* .The aim is to identify, develop, and exploit new technologies that can bolster productivity without costing the environment. The idea is to inject concerns about environmental friendliness into the design process; where, the assessment of environmental friendliness is based on a life-cycle view of the product. This includes the product's manufacturing process, distribution, use, and final disposal. The *Green Engineering design* has two parts: (1) the development of special *green indicators* that measure environmental compatibility, and (2) tools that use the green indicators to help designers assess, compare, and make design decisions.

Traditionally, products have been designed to satisfy only functional requirements and specifications. Recently, interests has been generated in designing products that not only satisfy functional specification, but are also easy to manufacture, assemble, diagnose and maintain. This new approach to design is also called concurrent design. Including environmental considerations in to it. Some of the questions that arise are: How should a product be designed to reduce hazardous wastes? Can ease of recyclability be engineered into a product's form and materials? What de-commissioning methods should be considered during the design process? How does one evaluate the hazardousness of various products and processes? What are the implications of environmentally motivated design decisions on other aspects of a product? How should the tradeoffs be addressed? These questions point to some important issues that have not traditionally been considered during product design and development, they represent a new are of design that is called green design. Green Engineering is defined as a study of, and an approach to, product/process evaluation and design for environmental compatibility that does not compromise product quality or function. In this framework, a "green" product is both environmentally compatible and commercially profitable [11].

2.3.5 Design for Recyclability (DFR)

Design for Recyclability (DFR) is one approach where recycling begins with design. Auto-makers in USA not only use materials that can be recycled, but also design the assembly process to make it easier to dismantle a vehicle and separate useful materials. Generally, the fewer materials used the easier to identify and disassemble them for reprocessing. Automakers are working hard to find new increasing uses for the separated materials. Increasingly, current and future recycling considerations, including designing for parts reuse and recyclability are influencing vehicle design decisions. In designing a vehicle, many consumer needs must be met, including safety, fuel efficiency, quality, comfort, performance, and affordability. Automakers use recycled and recyclable material carefully to ensure that the safety and reliability of the finished vehicle are not compromised. Auto manufacturers work with parts suppliers and industry engineers to develop recyclable components that will not sacrifice consumer needs.

The recycled materials in a car are, Brake shoes 75%, Undercarriage 28.5%, Engine Block 51.7%, Springs 57.1%, Outside Shell 28.5%, Axle 28.5%, Drive Shaft 100% [12].

Environmentally Conscious Manufacturing (ECM) has emerged as a strategic and competitive practice for the electronics industry. One of the results of the scramble for viable alternatives to chloroflurocarbon (CFC) solvents in the electronics industry and the ban on CFC solvent usage has been a push to incorporate the environmental impact analysis into the design stages of a product and process.

The paradigm shift from reactive end-of-pipe treatment to integrated, multidisciplinary, proactive design for environment planning requires new analysis tools. A total system perspective from manufacturing strategies and engineering practices is shown in [figure 2.3]. A traditional perspective is shown below for contrast in [figure 2.4][13].

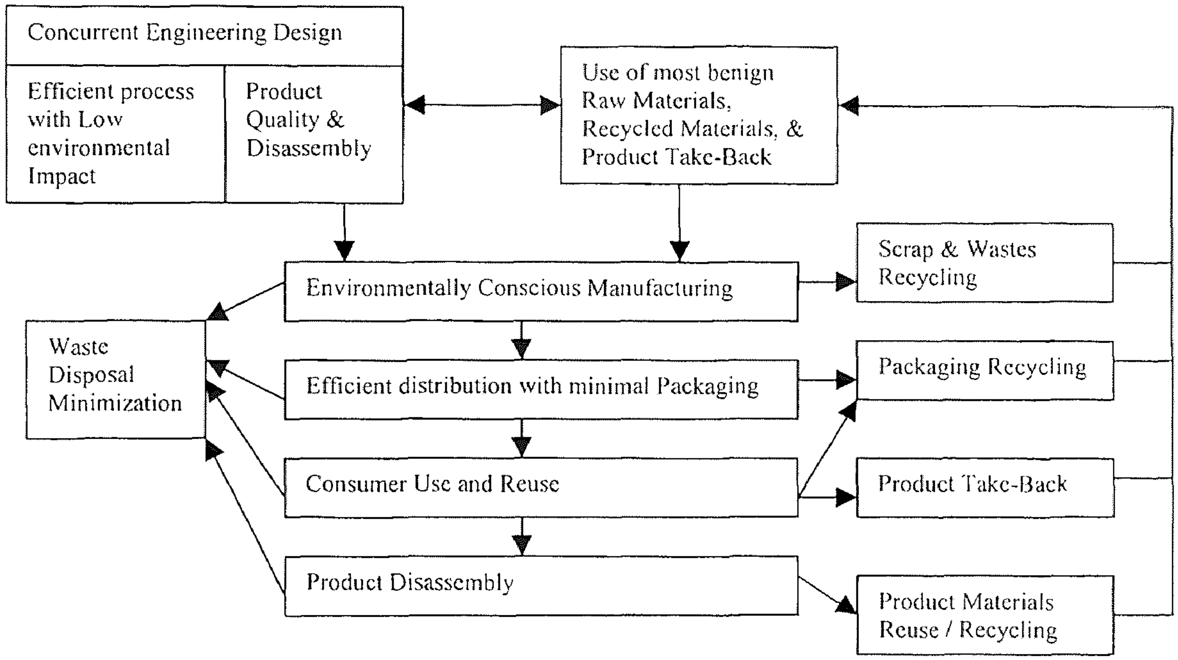


Figure 2.3 Environmentally Conscious Manufacturing

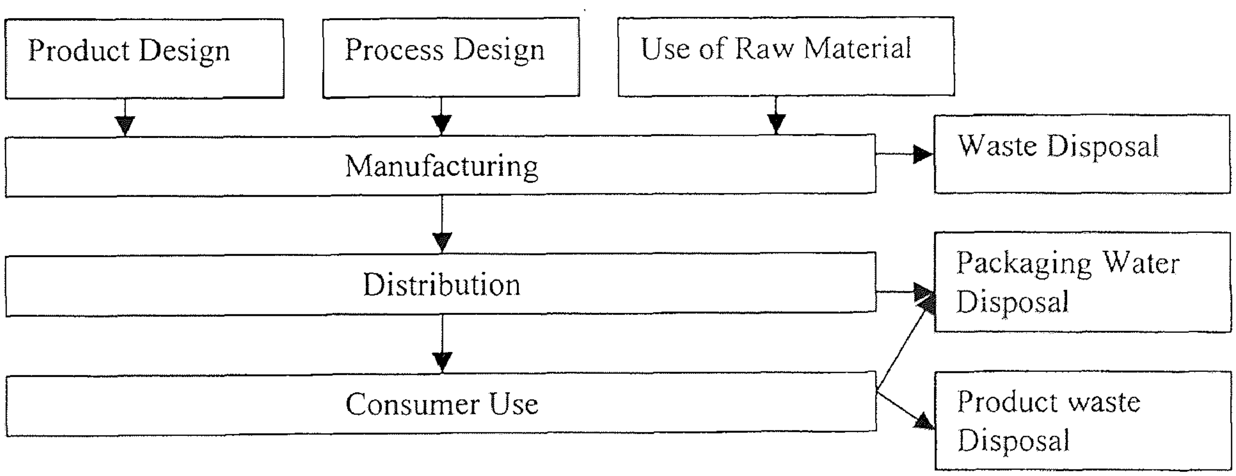


Figure 2.4 Traditional Manufacturing System

2.3.6 Comparison between DFMA and DFD

Comparison of Design for Manufacturing and Assembly and Design for Disassembly: The Minimize parts principle of DFMA is most concurrent with DFD principles. Optimize part Handling, Improve Assembly Access, and Avoid separate Fasteners all share an equal level of support in DFMA. The principles of Design for Top-down Disassembly and Provide Parts with Self-Locking Features fall in the Middle of the ordering. A drop off in concurrence occurs for Maximize Part Symmetry and Drive toward Modular Design because neither of them have much effect on DFD principles. Minimize Assembly Surfaces is least supportive of DFD, in part because it conflicts with Design without fasteners or Adhesives. From the DFD perspective, Design Parts for Ease of Separation, Handling and Cleaning of Components is most in agreement with DFMA processes. Reduce Energy Consumption also strongly supports DFMA. Design Two-way-Snap Fits ;Design without Fasteners or Adhesives; and Reduce the Number of Parts are all of above average value to DFMA, while Make Necessary Screws Obvious; Identify Separation Points and Materials ; and Use More Expensive Materials if it Reduces Material Types all are below average. Specify the Best fits Possible between Parts and Do Not Use Sonic Welding have no net effect on DFMA, partly because of conflicts with Maximize Part Compliance and Avoiding Separate Fasteners, respectively. Many of the principles of DFD and DFMA support one another. The strongest agreement occurs for principles that are related to minimizing activity: minimizing activity: minimizing parts reduces assembly time , as do optimizing part handling, improving assembly access and avoiding fasteners among DFMA principles. The DFD principles of designing for ease of separation, handling and cleaning and reducing energy consumption by eliminating unnecessary steps also minimize activity.

The principles that do not highly support one another are those that are concerned with more detailed aspects of each area of concern. For example maximizing part symmetry will decrease assembly time and difficulty, but will not affect assembly times. These are principles that do not support one another, but do not create any conflicts either. Conflicts do occur in instances, where making a product easy to take apart hinders assembly. The use of sonic welding for assembly is advantageous because it eliminates fasteners, but this principle makes separating dissimilar materials impossible. High part compliance makes parts easy to put together, but leads to products that can be loose fitting. For successful DFD, products must be tight fitting in order to maintain their perceived quality.Given this perspective, a design team, when seeking to address both DFMA and DFD issues, should focus on :

1. Minimizing parts.
2. Optimizing part handling and separation of components.
3. Reducing energy consumption in manufacturing and assembly by eliminating unnecessary steps and.
4. Improving assembly access.

In terms of design activities, the design team should focus on:

1. Assembly processes.
2. Structure.
3. Manufacturing process selection and.
4. Tooling Processes [14].

2.4 Demanufacturing Tools and Techniques

Demanufacturing involves separating and disassembling a 'product' into its smaller 'subassemblies' and 'components'. Unfastening carries out the physical separation itself and other separation techniques are also used to separate the unfastened component. There are two types of Disassembly methods they are destructive disassembly and non-destructive. The term 'product' means a complete entity, such as an automobile, a washing machine, etc. 'Sub-assembly' refers to a product .A 'component' is a subassembly that cannot be disassembled any further. When a product reaches the end of its original useful life, the following options exist, [figure2.5]

- Re-using it for its original task. A further distinction is sometimes made between strict re-use, namely, using it 'as is' and remanufacturing, namely re-using after some repair or renovation has been done.
- 'Using on' for a purpose other than its original use, while retaining its original form.
- Utilizing it as a source of raw material, where it loses its original form. A distinction is made between high-level utilization, where the properties of the original material are retained, and a low-level utilization, where the utilized material is inferior to the original. Energy recycling, the burning of waste for energy, is usually considered a special sub-category of utilization (typically the lowest).
- Dumping the used product in some publicly approved site. This category can be further classified according to the 'level of toxicity' of the dumped material.'Recycling' refers to all of the above, excluding dumping[3]

2.4.1 End of Life Process Flow

Often before a product/ subassembly can be recycled, it must go through certain preliminary ' recovery processes'. Two types of such processes can be distinguished:

- Disassembly separates two or more part types, each different label.
- Shredding and sorting cuts the product randomly into pieces, which are then sorted in order to get pure material piece's [figure 2.5],[3].

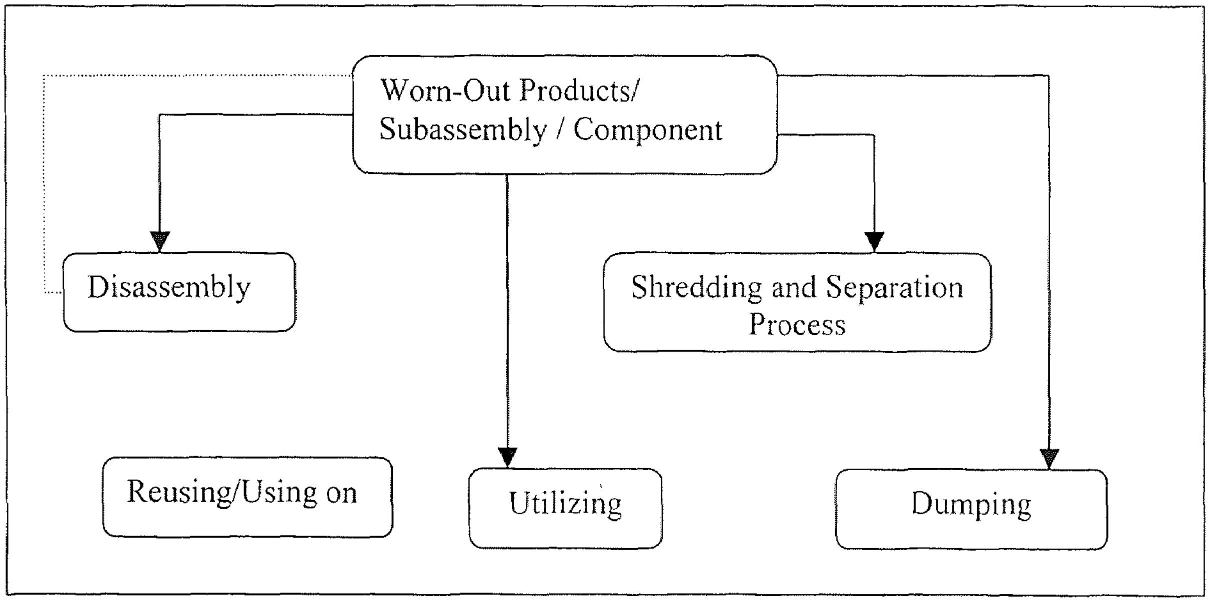


Figure 2.5 End-of-Life-options

In 1994, IBM established a Reutilization and demanufacturing line for IBM owned information technology equipment at its' Endicott, New York facility. The objectives of the line were to provide asset protection, insure proper environmental disposal of any residual material after dismantle, and maximize recovery to IBM. Recovery was to be achieved through reuse of machines and parts for IBM field service programs, by reselling recovered parts and material, and by recycling commodities by material content.

To date, the Reutilization line has processed over 70 million pounds of equipment and parts. It has saved IBM over $50 million through machine and parts reuse. Additional $10 million has been recovered by selling industry standard parts and over $5 million through recycled commodities. Endicott's process consists of 6 basic steps [figure 2.6]. They are:

- Customer shipment
- Receipt acknowledgement/ Inventory verification
- Staging
- Disassembly/Parts Reuse
- Commodity sorting / Grading Shipment to Vendor(s) for recovery

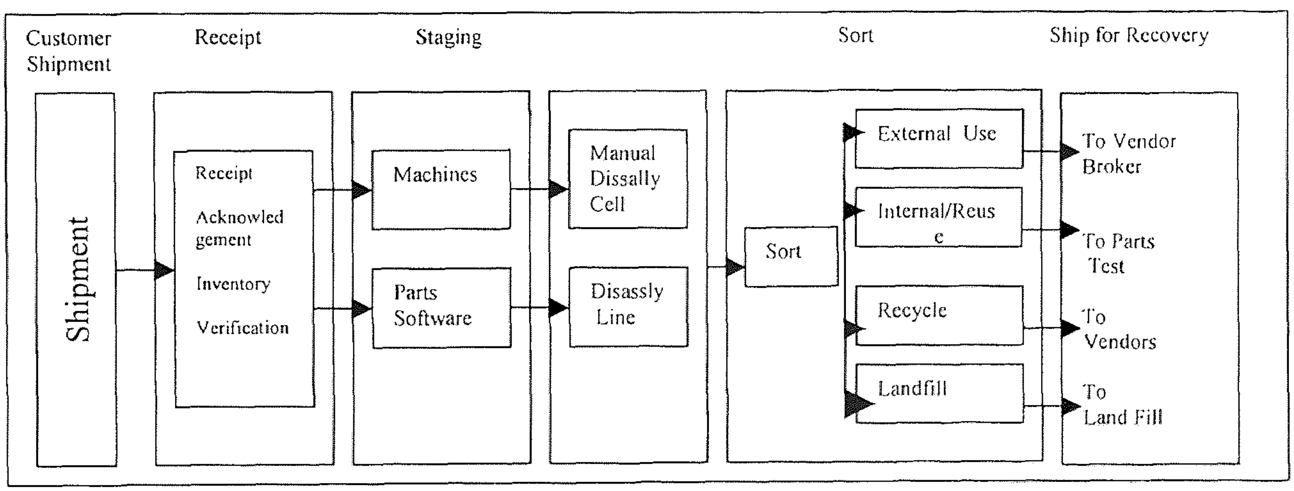


Figure 2.6 The Reutilization Process Flow

Disassembly is the center of the Reutilization process. At the macro level, this operation breaks down electronic equipment to prescribed reuse, recycle, or scrap levels. The objectives of the area are to :

- Obtain a high return from the sale of machines and parts (reuse)

- Achieve the optimum balance between commodity separation and separation expense
- Maximize the amount of material being reused or recycled.

And

- Render IBM products unusable (impairment)[15].

2.4.2 Reverse Fish Bone Diagram

Most of the research being carried out is on optimizing the disassembly process itself by disassembly planning. In the past decade, graphical representation of assembly process called the assembly process called the assembly fish bone diagram, has effectively assisted engineers to conduct design for assembly (DFA) and process failure modes and effects analysis (FMEA). On the other hand, environmentally conscious manufacturing requires engineers to make advanced planning for product retirement. One of the most effective ways to enhance product design for ease of assembly is to plan in advance the assembly process. To facilitate this advance planning, these procedure forces the designers to identify cost driving assembly tasks and step that may lead to defects. The new disassembly analysis tool that is being used in close concert with design for manufacturability tools is the reverse fishbone diagram, the reverse fishbone is most effective when implemented at the layout design stage, when designers can identify disassembly complications and difficulties and ensure that product retirement concerns are addressed up front. The reverse fishbone method of describing and dissecting such sequences promotes a structured approach to advance planning of the disassembly and sorting process. The diagram encourages the designer to qualitatively "walk through" the disassembly process, identify difficulties, focus on cost driving disassembly tasks and steps that may lead to defects, and iterate towards solutions.

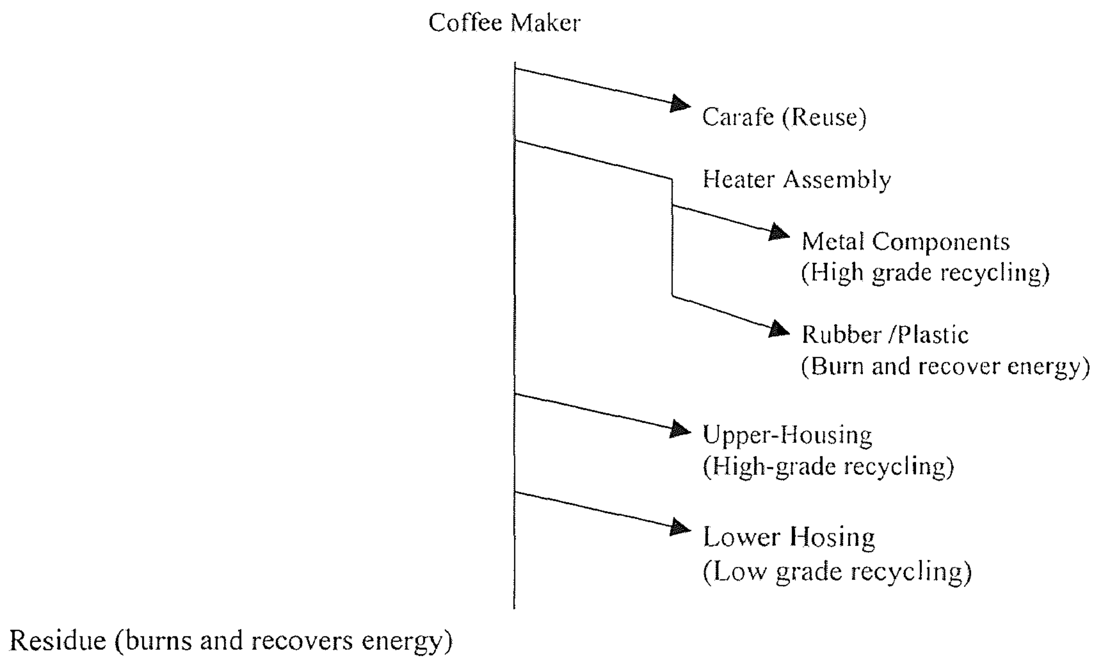


Figure 2.7 Concept of Reverse Fishbone Diagram

[Figure 2.7] shows the core idea of a reverse fishbone diagram using the coffee maker. As with assembly fishbone, reverse fishbone schematically describes the disassembly steps for the product and specifies the retirement intent for each clump thus the reverse fish bone diagram is emerging as an essential analytical tool in the design and evaluation of product retirement processes for minimal environmental impact. The Examination of the reverse fishbone diagram permits the designer to generate additional qualitative and quantitative information about his/her designs' performance under product retirement scenarios. Used together with disassembly time data and clump reprocessing cost projections, fishbone analysis can provide the designer with early guidance in the following areas:

- Retirement clump identification /refinement

- Projections of fate category load levels, i.e., matching the retirement scenario with market demand of reused components and recycled materials
- Identification of inter-component connections that pose disassembly difficulties
- Retirement cost/revenue stream projections
- Identification of special disassembly tooling and fixturing requirements

The reverse fishbone helps engineers to identify the strategic retirement clumps and determine the fate categories early in the design process. In short, reverse fishbone is a motivator and documentation method for retirement scenarios including disassembly and fate specification. This analysis leads to an estimation of the relative volumes of traffic (system load) for each of the fate categories (e.g., keep, recycle, etc.). Engineers can also aggregate this analysis for the entire product family's projected product retirement facilities and "reverse" supply chain. This in turn is useful for assessing revenue and cost streams associated with the sale and processing of each fate category. Improvements in the disassembly steps and procedures are another important goal of reverse fishbone analysis [16]

2.4.3 Linker

A new methodology to evaluate layout designs for manufacturing and lifecycle is being developed. The method uses a graph called Linker to represent the layout designs [figure 2.8]. The Linker uses icons to represent components and subassemblies, and links to describe various relationships between icons. These relationships are geometrical and topological characteristics that are pertinent to life cycle evaluation. The icons and links connect to object oriented product data, such as materials and other geometrical characteristics of the components. Linker was modified in 1993 to support design for product retirement, DFPR, by introducing "clumping" of components. A "clump" is a collection of components that share a common characteristic based upon the designer's post-life intent: reuse, primary or secondary recycling (depending on the purity of recovered materials), incineration and energy recovery, or land filling. Linker allows users to define product retirement clumps, then estimate the disassembly and reprocessing costs of the product. For a given system, as the number of individual clumps increases, the disassembly cost rise, and the reprocessing costs fall. Large, complex clumps, while easily removed from the system, require more complexes reprocessing techniques. A large number of simple homogeneous clumps may require more time to disassemble, but are simpler to reprocess. If results of the analysis fail to meet expectations the designer can examine two

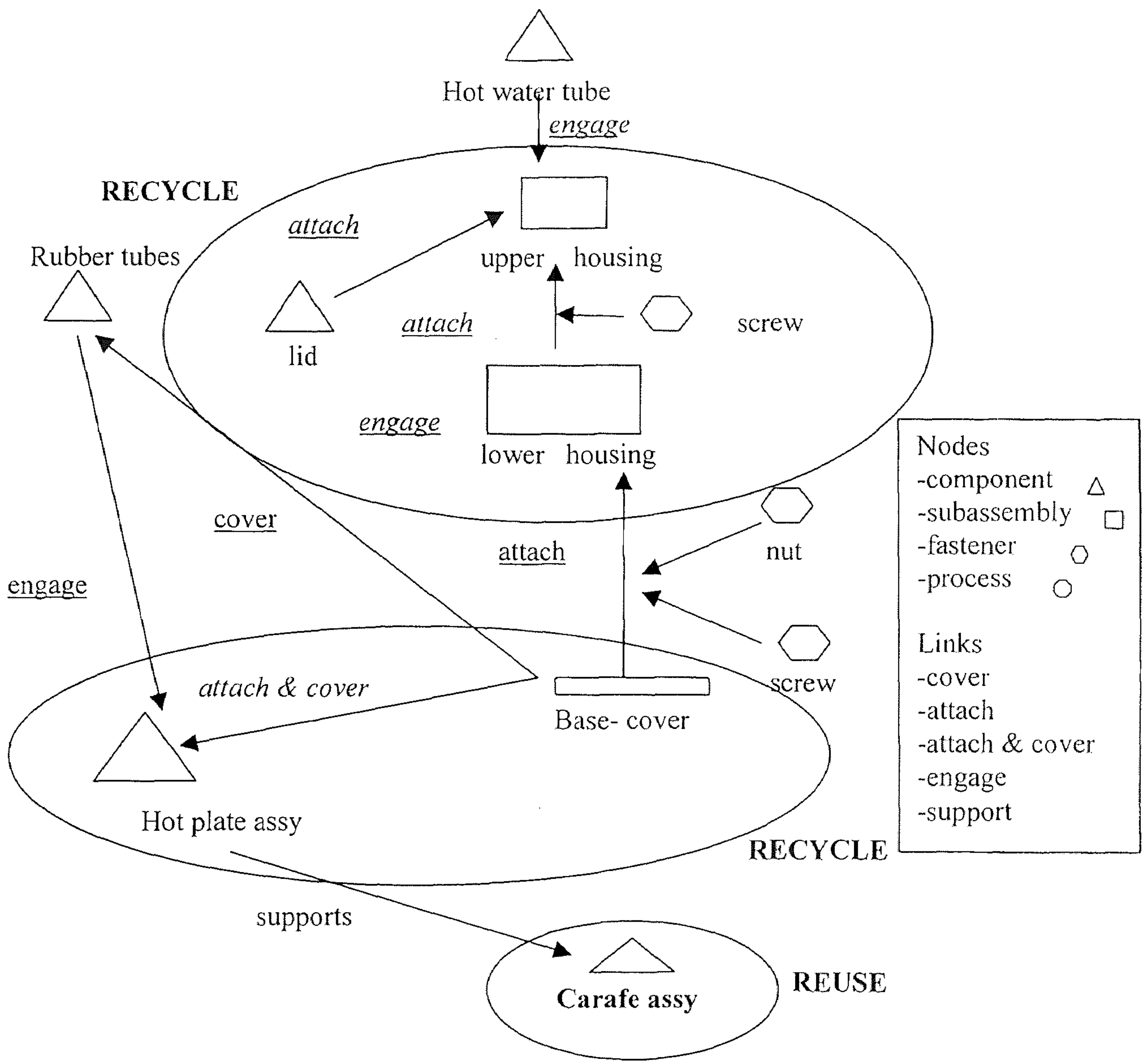


Figure 2.8 LINKER Structural Representation

options: 1) redesigns the product structure (configuration, materials, etc.), or 2) rethink the retirement strategy.

Using the industry provided time standards for the disassembly costs and the concept of design compatibility analysis [figure 2.9]to evaluate the retirement cost of each clump, by checking the knowledge base for any compatibility information dealing specifically with a component's material and post-life intent for the clump [figure 2.8]. The above concepts have been incorporated into a preliminary life-cycle design tool, LASer (Life-cycle Assembly, Serviceability, and Retirement). The approach in DFPR is to 1) use the Linker to capture product layout design and retirement plan and to 2) is use knowledge-base technique to evaluate the retirement cost .

The 'end-of –life' (EOL) value can be realized in two ways: (1) improvement of the recycling process, and (2) improvement of product design. It is widely believed that only 10-20% of the recycling cost depends on the recycling process optimization. The rest is already determined at product design stage. The 'product- independent' approach focuses on the EOL value of individual materials, components, and joining elements outside the context of a specific product. This is done either quantitatively, producing systematic EOL value classification schemes, or qualitatively. The benefits of the product-independent approach are easy assessment and wide applicability (each element is considered separately and the results apply to all products), it is clearly an over-simplification, since the context in which an element is embedded is often dominates its EOL value. In order to be able to assess or influence the EOL value of a complete product one, has to integrate such a product-independent information into a coherent 'product recovery plan' - a plan which specifies in detail how to disassemble the product and what to do with each of the resulting subassemblies.

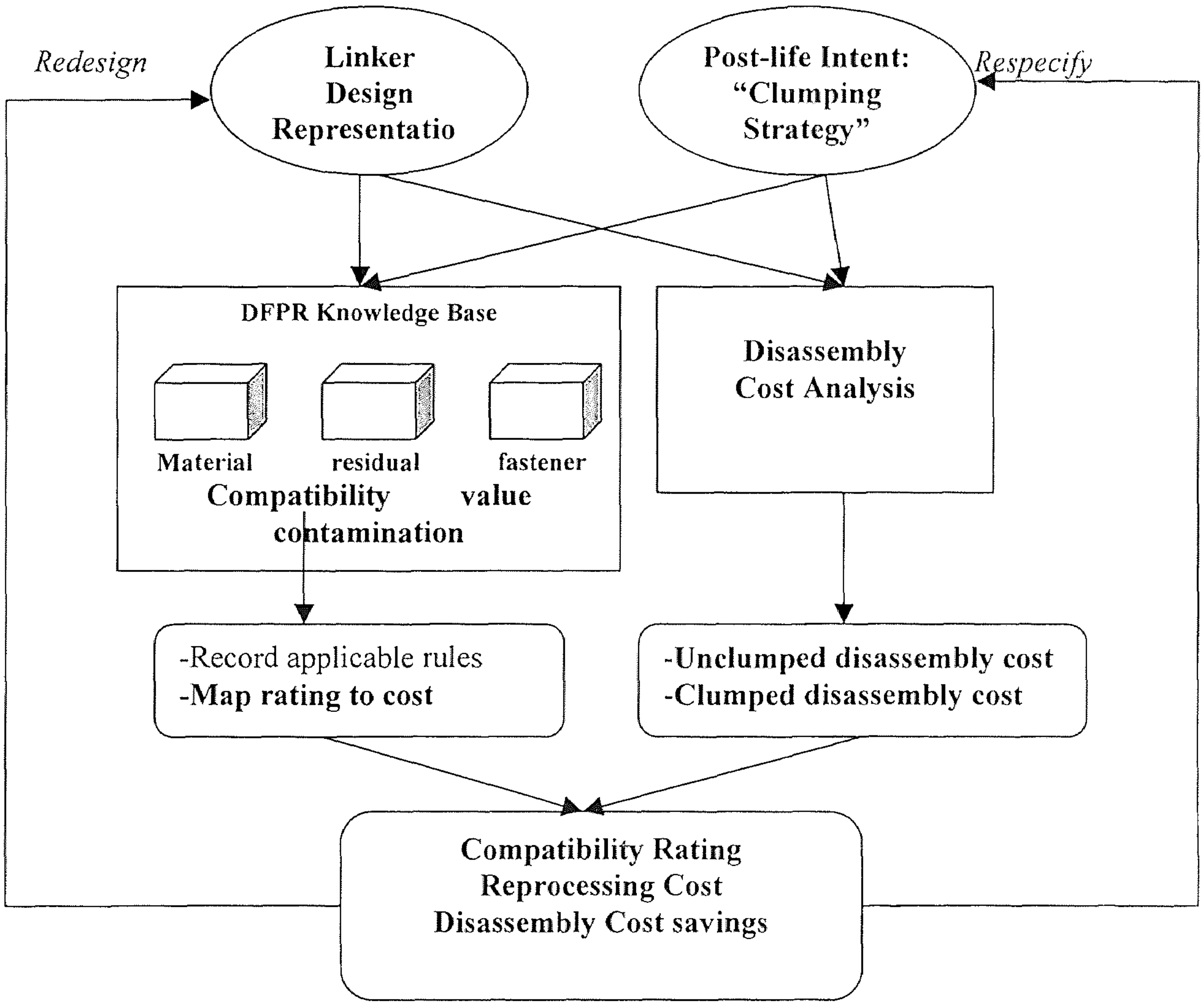


Figure 2.9 Clump Evaluation using DCA.

The first algorithmic method for generating such plans (and hence the first true EOL evaluation algorithm) was developed at Carnegie Mellon University. It was a modification of the 'optimal disassembly path for serviceability' algorithm developed at the University of Rhode Island in 1991. The recovery plan based on a quantitative assessment of the EOL value of a product is achieved by integrating EOL factors into product design. These tools include the following:

- A new algorithm for computing the EOL value of a product and for obtaining the optimal option out of all possible EOL recovery options. Unlike previous algorithms, this one always finds the global optimum and does so in a computationally efficient manner.
- An algorithm to identify 'weak spots' in the design, namely, those aspects that are least 'EOL friendly', and hence require improvement.
- An automatic generator of hints, namely, design modifications that can lead to an improvement in the EOL value. [3]

2.4.4 MoTech

MoTech is software that evaluates the End-of Life value of a mechanical design [fig 8] . First the user describes a structural design of a product along with recovery cost/benefit of components and disassembly costs. The program determines the recovery and the disassembly steps needed to accomplish the optimal recovery plan [figure 10]. Further on, the user can redesign the product and change the product characteristics, which will affect the End –of-Life value. An assembly is described by a set of nodes corresponding to separate parts and by a set of links (arcs) connecting between the nodes, when each link corresponds to topological connectivity existing between two parts. The part description data includes part name, recovery cost /benefit (dumping of a battery Ni Cd will be C=-30, utilizing of ABS plastic C=23,) and the weight in Kg. The connectivity characteristic or the "Joint properties" is also entered (disassembly cost of a screw joint d=1,disassembly cost of snap-fit by milling d=2.5). There are two algorithms that can be run by the user. One of them prepares information required by the other. The first algorithm to be executed is AOG (And-Or-graph) generation and the second is algorithm for finding optimal disassembly sequence using the generated AOG. The final end-of-Life value (disposability value) is also displayed. The third algorithm finds the minimum-length path from the root node in the generated AOG to each of the AOG leaves (single elements). Minimal Assembly Cost is also generated. The AOG generation process is interactive the user participate in it by defining feasible decomposition of a subassembly that is currently displayed by the application [17].

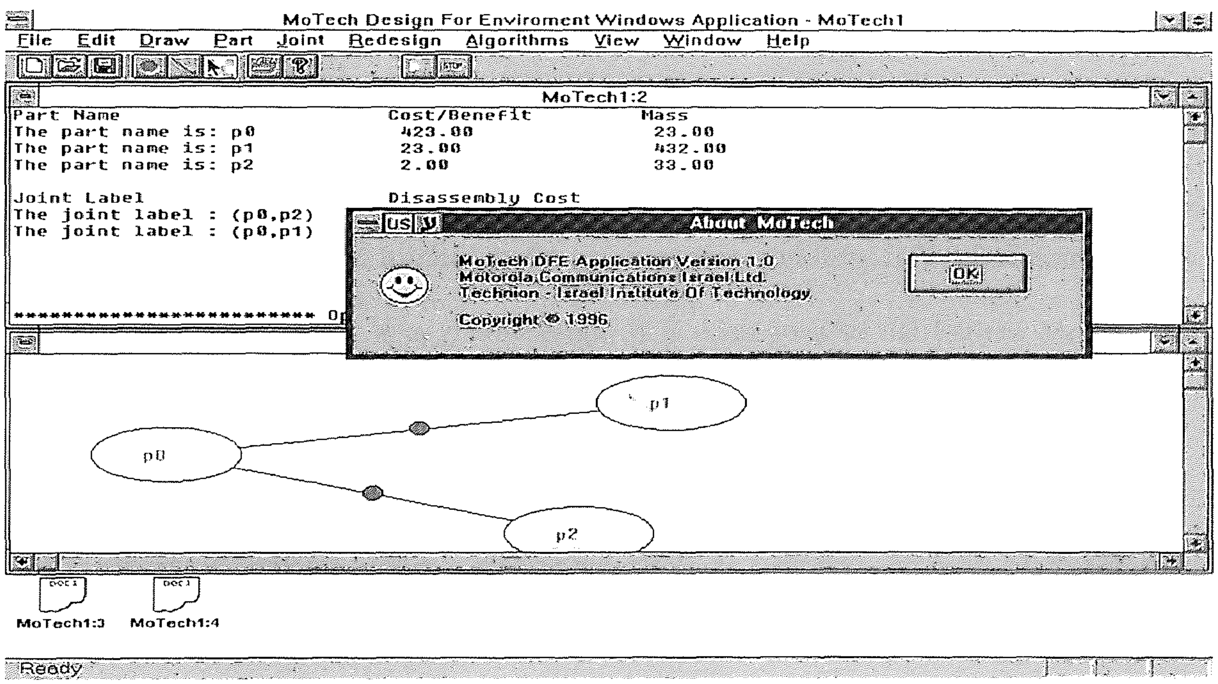


Figure 2.10 MoTech Design For environment Windows Application –MoTech 1

2.4.5 LASer

LASer/Linker is a Windows-based prototype program, developed at Ohio State University's Life Cycle Engineering Group, evaluates the serviceability, and assembly of mechanical designs. First, the user describes a structural design of a mechanical system along with cost, labor, and material data. The user can then return to the navigation page and invoke the analysis routine he/she is interested in . for assembly analysis , the user selects "evaluate" to view the results of a GE-Hitachi Assembly Evaluation . For service analysis the user selects labor operations. The program determines the labor steps needed to accomplish the repairs and computes associated service costs. For product retirement, the user selects groups of compatible components. The software analyzes these groups, or "clumps" and determines the disassembly and reprocessing costs associated with the given clumping strategy [18].

2.4.6 Environmental Impact Factor Analysis (EIFA)

Environmental Impact Factor Analysis (EIFA), spreadsheet tool is a new methodology that examines the potential hazards to the environment posed by individual components or clusters of components in a given design. It is analogous to the Failure Modes and Effects Analysis (FMEA), but has been restructured address environmental issues instead of component failures. Based on individual components in the design, the EIFA breaks down the environmental hazards and ranks them in terms of severity of effect and likelihood of occurrence. A non-dimensional scoring system is used so that results can be more easily compared. Once the ratings are established, the resulting list of components and environmental impacts can be sorted and addressed in order of importance. Typically, at this point a Pareto analysis of the ratings may reveal that only a few parts are contributing majority of the environmental impact of the product. Then a systematic method of evaluating the current design and potential redesign options (if applicable) is employed, again using a non-dimensional scoring system, to explore the merits of each design alternative. The EIFA structure is as follows

- Item/ functional Identification: The EIFA is split into a number of columns, the first of which is a listing of all the components in the product. The components can be broken down in whatever level of detail is appropriate. For example, it may be desirable to clump all printed circuit boards together as a single entry, or it may be desirable to go into extremely fine detail by listing each and every individual component. In some cases it may be appropriate to list multiple times using different clumping methods in order to gain multiple perspectives of their environmental impact and potential methods of design/redesign. This column can be used to clump together components, which are known to have similar hazards to identify not only the worst offending components, but also the top hazards introduced by the product.
- Function: A very brief description of function of each item or clump of items is given for reference purposes. Having the functionality of the parts will be considered in the event of a redesign. If a part is specifically present for environmental reasons (i.e. vapor guard on gas pump nozzle), then its function will closely tied to the local and end impacts of its failure and its EIFA analysis will closely follow the pattern of a traditional FMEA.
- Environmental Factor: For each item, a number of environmental factors can be identified. Each factor is entered on a separate line. This section refers to issues such as "Health hazard" and "contributes to landfills." If a particular part within a clump presents an environmental factor, which is independent of other parts in the clump, then the clump should probably be broken up.

- Environmental Impacts –Local: For the environmental factor, this column identifies the immediate effect. This can range from getting light headed from the presence of carbon monoxide to leaking chemicals poisoning a lake.
- Environmental Impacts –End: the end impacts of the environmental factor indicate what the final untreated problems are. For example, carbon monoxide poisoning could result in sickness or even death; lake poisoning could result in damaged ecosystem (fish, water supply, local vegetation, etc.).In many cases, such as with landfill space, the end impacts are not always clear. It may be unclear whether or not disposing of an item in a landfill will contribute to environmental hazards such as contaminated ground water. There can be many hidden end impacts associated with a given local impact so serious attention should be given to this column.
- Impact analysis: Evaluates and scores the impact for each item and factory line entry. Scoring is done on a non-dimensional scale of 1-10 with 10 representing the most severe environmental impact. It is important to note that this scale is the opposite of the scale for the design evaluations. Both scales are setup such that a more intense emotional reaction, of "feeling," gives a higher numerical score. This makes the scoring more intuitive for the person filling out EIFA.
- Severity of Impact: For the identified environmental factor, estimate the severity of the effect due to the particular item or clump of items. A score of 1 represents a minimal impact, 10 a very severe impact. This scoring can take into account the quantity or concentration of an offending material or process. The scoring can also reflect impacts resulting from manufacturing and retirement programs, costs in terms of dollars to the user or manufacturer, and other factors. The severity of Impact

should not take into account the likelihood of extent of the impact – simply consider what could happen.

- Probability of Maximum Impact: This weighting factor which reflects the probability (10 = high) that used the maximum impact will be achieved. It van also be used to estimate the percentage of an item that will be reused, recycled, or otherwise protected from producing an undesirable environmental impact. This score provides a means to scale the severity, taking into account such qualitative factors as peoples' willingness to participate in recycling programs, the mortality rate of diseases, randomness effects, etc.
- Overall Impact Severity: This column provides a combined scoring of the Severity and Probability by multiplying the two previous columns. The score is computed by the spreadsheet and does not require additional input from the designer. The result is a computed score between 1 and 100.
- Evaluation of Current Design: It is important to understand the environmental shortcomings of the current design before attempting to evaluate the options for redesigning it. The evaluation of the current design is used as a benchmark with which to compare the redesign options. Again, scoring is done on a non-dimensional scale of 1-10, except this time 10 represents the most environmentally friendly end of the spectrum. This is done to provide a more intuitive correlation between the purpose of the EIFA (achieving maximum environmental friendliness) the emotional response involved in the scoring process. Reduce, reuse, and recycle are the three primary goals of an environmentally friendly design considered in this EIFA – other goals can be incorporated in a similar manner. Of these, "reduce" is not applicable to the

current design since it already exists (it is included in the redesign section). The other factors, reuse and recycle, do et scored based on their current level of applicability to the design. If a totally new design is being considered, as is the hope of authors, this section is not directly applicable. However, in this case it can be used to evaluate similar products or components, which can then act as a competitive benchmark for the new design.

- Reusability: The item or clump is scored for reusability based on a scale of 1 to 10, 10 being completely reusable and 0 being totally non-reusable. This value indicates the amount of a particular item that can be removed and reinstalled in another product. The score may be weighted if the item has "reconditioned" prior to reuse. For example, an automotive started or alternator can be reused but first has to be "factory reconditioned." This number is often high even though it is unlikely to occur. For example , small screws, fasteners, clips, and wires may be reusable, but it may not be worth the effort involved to directly reuse them.
- Probability of Occurrence: This is a weighing factor which accounts for how likely it is that a given part will be reused. It takes into account the ease with which an item can be reused , but can also include any issue which affects the likelihood of reuse. For example, it may be possible to reuse screws but their market value may be so low it isn't worth the salvaging them. Alternatively, a screw may be entirely reusable and desirable to do so, but a bracket welded across the head of the scre might make its removal impossible.
- Reusability Score: This column provides a combined scoring of the reusability and probability by multiplying the two previous columns. The score is computed by the

spreadsheet and does not require additional input from the two previous columns. The score is computed by the spreadsheet and does not require additional input from the designer. The result is a computed score between 1 and 100. Recyclability: The item or clump of items is scored for recyclability based on a scale of 1 to 10, 10 being fully recyclable and 0 being totally non-recyclable. This value indicates the amount of a particular item that can be both removed (separated) and recycled. For example, an item may receive a less than a perfect score if it can't be completely removed, even if it's material fully recyclable, and vice-versa. Probability of Occurrence is a weighing factor, which accounts for how likely it is that a given part will be recycled. It takes into account the ease with which an item can be removed and the inherent recyclability of the material, but can also include issues which affect the likelihood of actually entering the recycling process. For example, the material may be easily removed and fully recyclable, but if the type of material can't be easily identified it is unlikely that it will ever reach a recycling center.

- Recyclability Score: This column provides a combined scoring of the Recyclability and probability by multiplying the two previous columns. The score is computed by the spreadsheet and does not require additional input from the designer. The result is computed between 1 and 100.
- Potential for Improvement Through Redesign: Once the current design has been evaluated the possible redesign efforts can be examined to determine the optimal approach to minimizing environmental impacts. The redesign options are categorized into three principle classification redesign: Reduction of material, Reuse of parts, and

Recycling of material, upon final retirement. It is felt that the priorities should be prioritized in this order to achieve a maximum overall environmental gain.

- Reducibility: The first redesign approach is to reduce material usage. To reduce material, the designer can identify excess material, discover alternate means of providing bulk structural support or volumetric presence. This can include redesigning the adjoining parts to require and/or allow a reduction in material for the part.

- Recyclability: This redesign approach aims at simply making the item under consideration more recyclable. An obvious approach is to favor materials, which can be recycled. A less obvious approach is to make sure that all material types can be easily identified, including any filler material which affect the recycling process. Other factors which could make an item more recyclable are to reduce the material mix within the product, make items of different materials easily separable, eliminate contaminants such as exotic coatings and fillers, etc.

The process of scoring the redesigns for each category is similar. The main difference is the scoring for this section of the EIFA is that you are actually scoring the redesigned items and then comparing them to the base-line current design to quantify the improvement. If the product being analyzed is a new product and there are no benchmarks to work against as previously discussed, then this section is scored on an absolute scale instead of a relative scale and references to the "current design" may be ignored. The scoring process is as follows:

a) Nature of Redesign: Here the redesign tact used to achieve an improvement in environmental friendliness. If there are several tact's under consideration for each category. For example "reduce wall thickness" and "reduce number of stiffening ribs" would be entered separately.

b) Ease of Redesign effort: Rank the level of effort which will be required to do the redesign on a scale of 1 to 10, where 10= difficult. This score should factor in the magnitude of the redesign effort required to overcoming political resistance, etc. Cost should not be included. Cost issues can be more effectively factored in to the EIFA analysis in a post-processing operation.

c) Reducibility/ Reusability/ Recyclability after redesign: Score the redesigned item in the same manner as the base-line design. The Reduction category must be scored on a relative scale, through a comparison to the base line design (you are quantifying the amount by which the material can be reduced from the original design). The reusability and recyclability categories are scored on an absolute scale without consideration of the original design.

d) Probability of Occurrence: Score the probability that the item is likely to be used or recycled. This step is identical in approach to the evaluation of the current design. For the Reducibility category this value is virtually always 10, although there are isolated situation when this will not be true. For example, if the manufacturing process is subject to high levels of dimensional variability. The probability is included in Reducibility so that the scores for the three categories can be directly compared.

e) Score: As in the evaluation of the current design, this is a multiple of the previous two columns. No input is required from the designer.

f) Potential: This is the key output of the EIFA methodology. It compares the environmental friendliness scores for the design and redesign, and then weights the potential for improvement by the ease of the redesign effort. The potential is computed automatically from the following formula Potential = (Score design-Score current) X Ease

The improvement in environmental friendliness of the redesigned product can be quantified by dividing the Total Potential column by 10 (to reverse the Ease of Effort scaling factor), summing the Reusability and Recyclability scores for the Current Design evaluation section, then subtracting the two numbers to obtain the difference. The equation is as follows:

(Total Potential/10)- (Reusability Score + Recyclability score) = I E F*

- I E F is Improved Environmental Friendliness.[18]

2.4.7 Autonomous Disassembly by Advanced Shape Recognition (ADAS)

The Autonomous disassembly by Advanced shape Recognition focuses its efforts on developing an autonomous system for the identification and disassembly of electromechanical products such as TV sets or computer monitors. ADAS aims to combine these elements to form a disassembly line for the dismantling of different devices of a product family (e.g. TV monitors). This line will be designed to be as flexible as is required to enable the identification of and adaptation to different product types. It's therefore highly desirable that the sensor can detect the 3D co-ordinates of monitors without the restriction to diffusely scattering surfaces of smooth curvature.

Also, for the objects of interest (diameter between 0.5 and 1m), the required resolution that allows the identification of small components such as screws must be better than 1 mm. The use of the chirped lasers radar technique offers a promising way to overcome these well-known restrictions. As the disassembly process requires image-processing rates of higher than one 3D image per second, a fast image processing technique is required. Neural network s have also been proven suitable for a number of image processing tasks, but fast neural network implementations are necessary in order to perform online image processing. A trainable neural network PC expansion board with supporting software will be developed within the framework of this project. The implementation of the disassembly process will also require a graphical interface in order to enable users to develop strategies on their own.

Among the results to be expected are:

- Strategies for the disassembly process
- Integration of a sensor for fast 3D shape measurement
- Development of fast image-processing software and hardware for shape recognition
- Definition of a database for various electromechanical appliances
- Development and implementation of disassembly tools.[19]

2.4.8 REMPRODUSE

REMPRODUSE project is a current European initiative towards re-designs of electromechanical products for reuse and recycling sponsored by the European Commission. The project REMPRODUSE aims at in a comprehensive way of grasping all the difficulties found in the analysis of the end-of-life phase of electromechanical products, exemplified with electric motors of medium and large size. The primary objective of the REMPRODUSE project is to make future copper rich electric motors and future disassembly oriented recycling systems adapt to each other. Work, thus, proceeds on essentially two fronts: Firstly, the analysis and re-design of the functional unit, the electric motor. Secondly, the development of a sensor based robot disassembly cell that can perform full or partial disassembly of the new electric motor design. The project in its totality has 11 tasks, as also shown in [figure 2.11]. Tasks 2, 3, 5, 6 and 9 have to do with the life cycle engineering of the functional unit, the electric motor. Tasks 4, 7 and 8 have to do with the development of the future robot assisted disassembly cell. Task 1 is a start up task in which general issues are defined and analyzed. Tasks 10 and 11 are where the dissemination of results takes place.

- Task 1:Analysis of present situation/selection of model functional unit and model products containing the functional unit and model products containing the functional unit/ analysis of the copper recycling problem.
- LCA of present product selection. In task 2 full life cycle assessments are carried out on model products containing the targeted functional unit, assuming current recycling practices. This in order to see how large ,a part of the overall environmental load of the model product can be assigned to the functional unit, and get to the basis for the subsequent evaluation of the effect of re-designing the functional unit. on the environmental and resources performance of the model product.
- Task 3: New design methodology. In task 3 an innovative, environmentally oriented design methodology is developed to facilitate the re-design of the functional unit.

The design methodology is developed in close co-operation with the industrial partner carrying out in re-design.

- Task 4: Special sensor systems for reuse and disassembly. The objective is to develop multisensory systems which, when coupled to knowledge systems, can be used to support the reuse of the functional unit and to support automated disassembly.
- Task 5: Conceptual and embodiment design of the functional unit. In this task the concept and structure of the re-designed functional unit are laid out, based on the evaluation of environmental consequences of different solutions for concept and structure.
- Task 6: Detailed design of the functional unit. In task 6 the functional unit design is finalized concerning materials and process choices. In this case also supported by environmental assessments of the consequences of choices made.
- Task 7: Robot Aided disassembly demonstration. The viability of the chosen re-design for the functional unit is demonstrated with a laboratory scale disassembly cell.
- Task 8: Improved sensor systems, test phase. The disassembly of a wider group of functional units facilitated by sensor systems is implemented.
- Task 9: Final life cycle assessment of the model product(s) with the re-designed functional unit, taking into consideration the new disassembly oriented recycling scenario. The objective in this task is to verify the environmental and resource recovery benefits of the concurrent innovative design of functional unit and disassembly system.

- Task 10: Improved design methods, guidelines and design tools. The objective of this task is to collect the experiences gained throughout the project in the form of guidelines, design methodology and tools, for implementation into participating industrial enterprise.
- Task 11: Final report and presentation of results. The overall conclusions of the project are finalized in a report.

The REMPRODUSE project is essentially a demonstration project, aiming at showing that it is indeed possible to develop products/functional units and disassembly/recycling systems that fit to each other. The present project focuses on the copper recycling loop, but could in principle focus on different functional units/product groups and the recycling of other scarce resources [20].

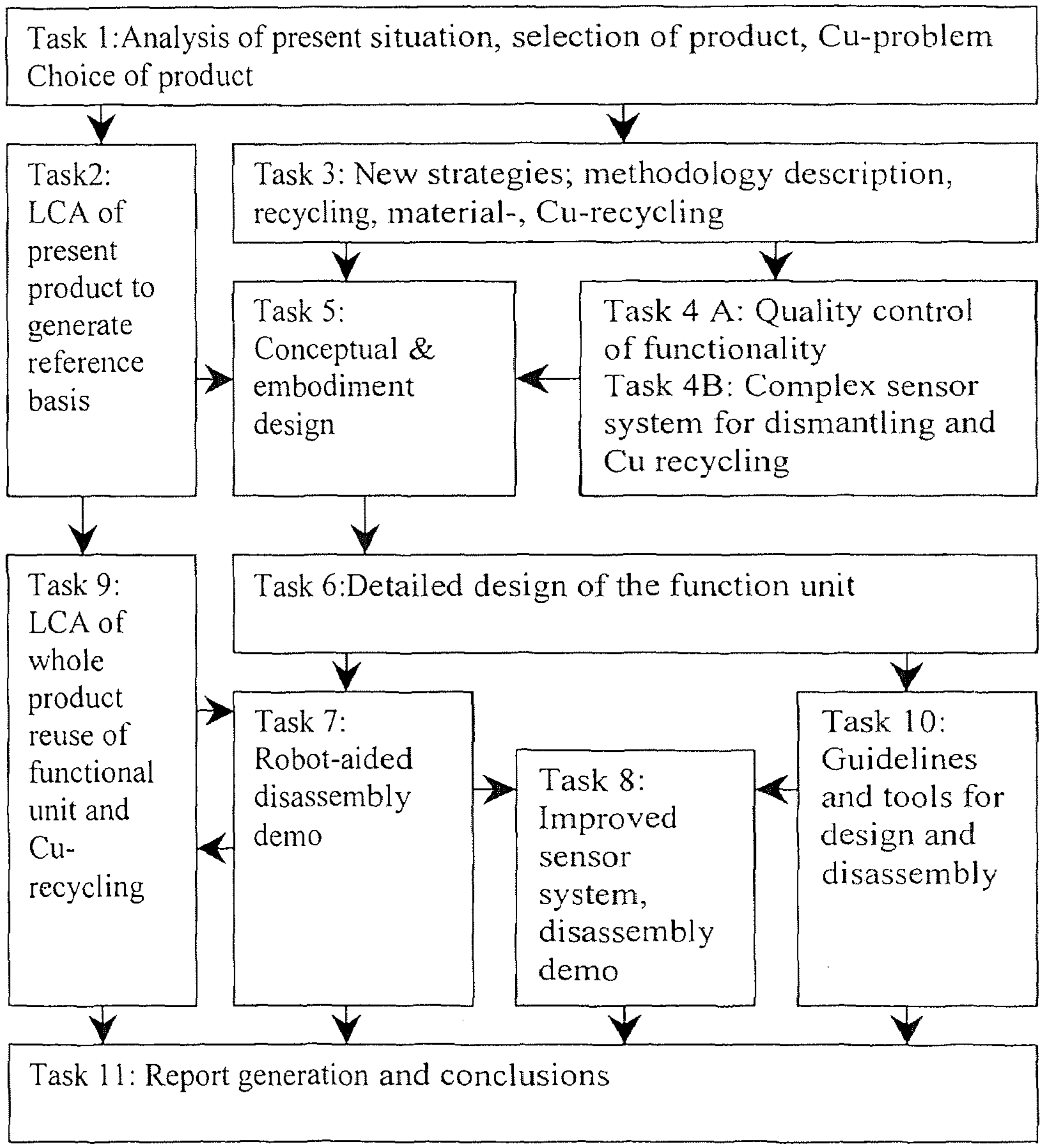


Figure 2.11 The REMPRODUSE project plan

2.4.9 Disassembly Model Analyzer (DMA)

Disassembly Model Analyzer (DMA): Recycling of automobiles involves two principal stages: disassembly and shredding. This work addresses both stages and explains a systematic approach to model them. The first part is focussed on the detail complexity of the disassembly problem. The second deals with the industry as a whole including the shredding operation and the price dynamics governing the systems' behavior. The

Disassembly Model Analyzer tool is an optimization program based on a genetic algorithm. This tool is capable of interpreting the complex economic and physical information associated to the disassembly problem of a large product (more than 500 parts). The DMA interprets this information and then returns, among other information, the profit-optimizing disassembly plans. The DMA can also be used on several dismantling drivers—design, prices and costs—on dismantling prices. The potential impacts were structured in the form of empirical equations. The other part of this work includes the description and use of the Automobile Recycling Dynamic Model (ARDM). This industry model captures part of the most relevant interactions among industry and evaluates the effect of policy changes (such as weight , and vehicle composition), in the environmental impact of disposing and recycling automobiles. The ARDM uses the empirical equations generated by the DMA to model the dismantlers' behavior. The ARDM includes optimization decisions (profit maximizing) within a dynamic context. The ARDM has to be dynamic because prices depend on the different industry participants' decisions, which in turn depend on prices. In the ARDM, the environmental impact of disposing automobiles is traced by determining the Automobile Shredder Residue (ASR) generation and the number of cars being left out of recycling loop (abandoned cars) [21].

2.4.10 Virtual Prototyping and DFD

The use of virtual prototyping is proposed to aid the assessment of product disassembly by enabling the designer to virtually disassemble the product .A virtually prototyping is defined as the generation of a virtual prototype and its simulation or assessment. Factors involved in generating product disassembly processes include determining the disassembly sequence of a product, the disassembly paths of components, tool change sequences, etc. Disassembly processes have been generated either by using interactive or automated approaches, these have limitations combining the two approaches, disassembly processes of complex sub assemblies can be generated without extensive user input. Combining virtual prototyping and a virtual environment can generate the disassemblies of complex processes of complex assemblies. Disassembling virtual prototypes in a virtual environment provides insightful observations about product dissemblability, which can be used to determine required design changes [22].

2.4.11 Disassembly Evaluation Worksheet

The systematic estimation of disassembly involves a procedure for disassembling the actual product or simulating the design's disassembly into a formal worksheet called disassembly evaluation chart [figure 2.12]. The various entries are

1. Part Number: The serial number of each part in the product is recorded. Identical parts that are disassembled at the same time and have disassembly process characteristics are assigned the same number.
2. Theoretical Minimum Number of Parts. Each part disassembled undergoes an evaluation to determine whether it is theoretically required to exist as a separate component. However, a subassembly that needs no further disassembly is regarded as a single part.
3. Number of Repetitions: The number of times each disassembly task is performed is recorded. This column counts for identical parts that are

disassembled at the same time for example, with three identical screws, the 'unscrew' disassembly task is repeated three times.

4. Task Type: There are currently 16 different task types to choose from which to choose. Only the five shown below with their corresponding letter codes were used in Push/Pull, Unscrew, Remove, Cut, and Flip operation. An unscrew operation implies a 'remove' as well, so only the former operation is noted. A remove task implies that the part can be gripped and removed without any additional operations.
5. Direction: This is an introduction of the axis along which the tool or hand accesses the part. An XYZ coordinate system with the positive Z-axis pointing upward is fixed to the table upon which the product is located. These coordinates are rigid and do not change when the product is reoriented during disassembly. Multiple directions for a single task are possible and listed in the order in which they occur.
6. Required Tool: There are 28 common tools that are used to disassemble example Phillips Screwdriver (PS), Pliers (PL), Wire Cutter (WC). Unassisted operations carried out by hands are not noted. Tool manipulation picking up and putting down is implied by the presence of different tool codes.
7. Difficulty Rating. These are subjective judgements of the difficulty of performing each disassembly task, which are broken down into five categories. Each is scored on a scale of 1 to 4 according to:

    1. No difficulty in performing the disassembly task
    2. Some difficulty in performing the disassembly task

3. Moderate level of difficulty in performing the task

4. Considerable difficulty in performing the task.

Accessibility: A measure of the ease with which a part can be accessed. It mainly indicates if adequate clearance exists and how easily the part can be maneuvered during disassembly.

Positioning: A measure of how precisely the tool or hand needs to be positioned and oriented in order to perform the task. For example, a higher accuracy is required when fitting a screwdriver blade in the screw head compared to a simple gripping and removal task.

Force: A measure of the amount of force required performing the task. For example, the force to remove a part that is press-fitted is higher than the force to remove a loosely fitted part. A greater force is also required for separating glued parts or breaking a part.

Additional Time: While each of the previous difficulty sources is related to time, this category has to do with additional time penalties. For example, the removal of a long screw would score higher (more difficult) than a shorter screw. Only those time considerations that are not accounted for in the other categories are considered here.

Special: This is a provisions to note special problems encountered that do not fit in any example, when the exact location of loose wires is unknown, it is noted in this category.

Subtotal: The sum of the individual difficulty ratings for columns 7 through 11.

Total: The product of columns 12 and 3 is entered here to take into account multiple repetitions of a task. This is the total difficulty rating of the disassembly task.

Comments: This space is reserved for explanations of circumstances that result in either special task performed, 'special' difficulty rating. To aid in subsequent redesign, it is also desirable to indicate the reasons for high ratings in column7 through 10.

After completing a disassembly evaluation chart, the following steps may be taken to improve the design for easier disassembly or to compare design alternatives:

$$Overal - Efficiency = \frac{5 \times \sum Column - 2}{\sum Column - 13} \times 100$$

The overall efficiency is a percentage rating that indicates how far the current design is from a reference design of the same product, which consists of the theoretical minimum number of parts with each part disassembled with minimal effort.

DISASSEMBLY EVALUATION CHART													
1	2	3	4	5	6	7	8	9	10	11	12	13	14
						DIFFICULTY RATING 1(EASY)....4(DIFFICULT)							
Part No.	MIN No PARTS	No of Repetitions	TASK TYPE	DIRECTION	REQUIRED TOOL	ACCESSIBILITY	POSITIONING	FORCE	ADDITIONAL TIME	SPECIAL	SUB TOTAL	TOTAL	COMMENTS
1	0	1	Pu	-X	PS	1	2	2	3	4	11	11	(Multiple Actions required to work subassembly tree)

Figure 2.12 Disassembly Evaluation chart for Monitor

The systematic method of disassembly evaluation constitutes a useful framework for a design tool. It offers a scheme to organize pertinent information and highlight design weaknesses [23]

2.4.12 ECO-Fusion

ECO-Fusion is an integrated environmental software tool to support the manufacture of electronic products. When the environmental impact of manufacturing and use of an actual product needs to be determined, the main problems are description of product composition and product composition and product life cycle, storage of these data, and correspondence of various environmental techniques. To solve these problems, ECO-Fusion features product-centered description, an object-oriented product databases, and multifaceted environmental evaluation. The product-centered description is created using the input system, the product list window, the composition window, and the life-cycle flow window. Product composition is represented by a tree structure with a product root in the composition window, and the product life-cycle flow is represented by a coupled-tree structure with a product root in the life-cycle flow window. This input system allows simple modeling of complicated compositions and life-cycles for actual products. The object oriented product database is suitable for storing relationships of components, and attributes of the components, relationships between processes, attributes of the components, relationships between processes, and attributes of the processes. Multifaceted evaluation is achieved by implementing three evaluation techniques: environmental product assessment, life cycle assessment (LCA) , and assembly/disassembly evaluation [figure 2.13]. In environmental product assessment, a product is compared with a reference product using about 30 criteria on an environmental checksheet. LCA is employed to evaluate the global environmental impact of a product over its entire life-cycle. In assembly / disassembly evaluation , assembly and disassembly are simulated on a 3-D CAD system, to calculate assembly/disassembly time, obstacle points and operation points . This multifaceted evaluation results in an objective estimation of the product. Since environmental product

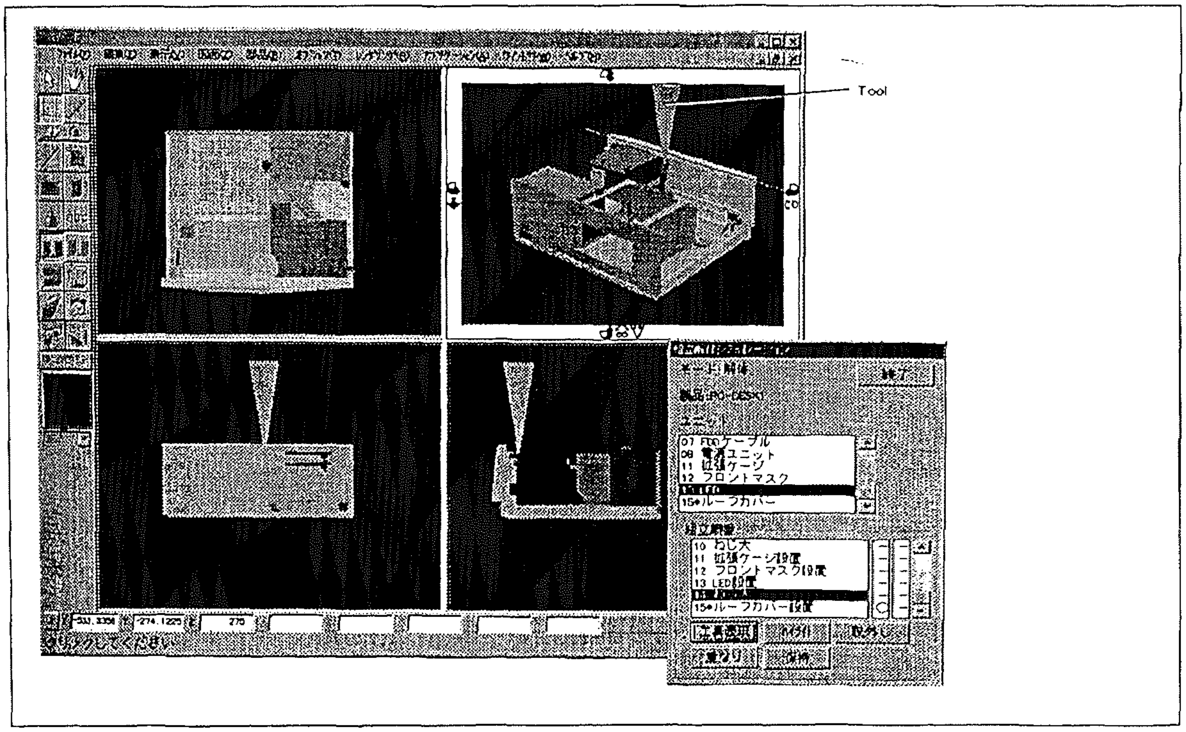


Figure 2.13 Disassembly Simulation for a Personal Computer

Assessment is a comprehensive and qualitative evaluation for the global environment , and assembly/disassembly is a qualitative method for product structure with a 3-D CAD system. This multifaceted evaluation can achieve relatively objective results since the characteristics of the evaluation technique of each unit are different. [24].

2.5 Performance Measurements of Fasteners for Disassembly

2.5.1Quantitative Disassembly Evaluation

Interconnections in assemblies are formed not only through mechanical fastening techniques, but also chemical joining techniques such as adhesive joining, soldering, or diffusion bonding. In general, chemical joining is thermodynamically irreversible and it is difficult to evaluate its dissemblability in the same way as that of mechanical fastening is evaluated. Two parameters a) energy for disassembly and b) entropy for disassembly defines quantitative evaluation of dissemblability.

2.5.1.1 Disassembly Energy: The disassembly energy for mechanical fastening is derived from the release energy of screws, the elastic deformation energy of snap fits, or the frictional energy of connectors. For chemical joining, de bonding energy , fracture energy or fusion energy is calculated over the bonded area. The total energy for disassembly can be calculated by summing up the contributions of each fastening point and the de bonding energy over the joining areas. The concept of the entropy for disassembly is based on the idea that the degree of difficulty of a disassembly depends on how many method's were used to make the interconnections, as well as the number of different directions in which the disassembly operations must be done. The randomness of the interconnection methods and disassembly operations, can be evaluated by the number of ways of classifying the methods and the disassembly directions. The logarithm of it is referred to as the entropy for disassembly.

Disassembly energy is concerned with the physical energy which is required merely for release or disconnect of an interconnection. Screw are tightened with a torque that generates a certain clamping force F_f This tightening torque is proportional to the clamping force and the diameter of the screw d, as follows:

$$T_f = 0.2.F_f.d$$

The coefficient a is called the torque coefficient, which depends on the friction coefficients and the pitch diameter shown in [figure 2.14] and is estimated about .2. 10 % of the tightening torque corresponds to the axial tension for joining. Since this axial tension in turn acts in the releasing direction on loosening the screw, the torque necessary for loosening the screw is 80 % of that for tightening torque. The energy for loosening the screw, E_n, is given by

$$E_n = T_f \ 0.8 \ \theta$$

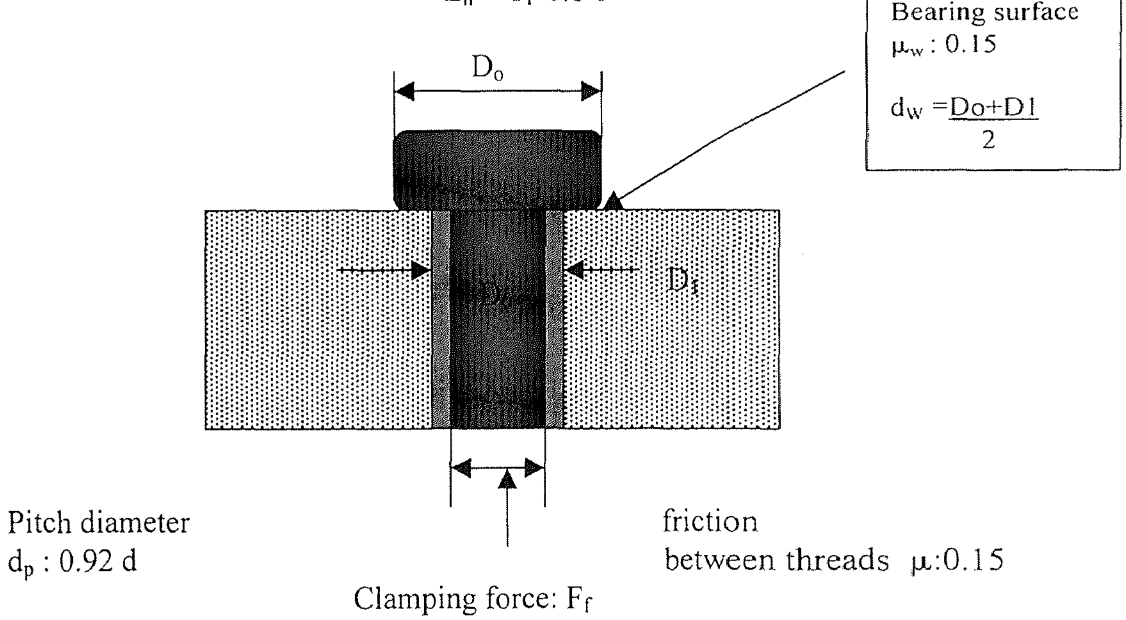


Figure 2.14 Fastener Analysis

Where θ denotes the rotational angle producing the axial tension. The disassembly energy for screws is defined by this energy for loosening the screws, assuming the clamping force of 5 kgf and the rotational angle of 1 radian for small screw used in PC's

The disassembly energy for a snap fit E_s , is defined as the elastic strain energy required for deforming the snapfit by the height of its hook. A simple cantilever gives the strain energy as

Where E is the modulus of elasticity of the material and the other parameters are shown in the [figure 15]

$$E_s = \frac{1}{8} Ewt^3 \frac{h_2^2}{h_1^3}$$

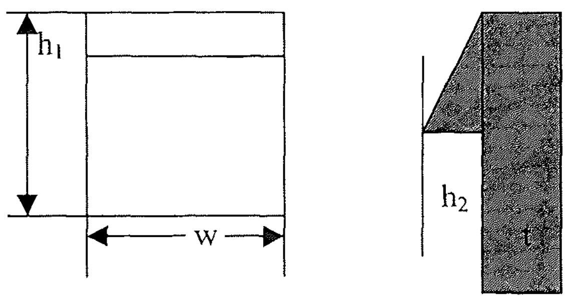


Figure 2.15 Simple model for snap fit

2.5.1.2 Disassembly Entropy: The degree of difficulty of a disassembly depends on how many methods were used to make the interconnections as well as the number of different directions in which the disassembly operations must be done. Certain assemblies may be constructed without interconnections. There are geometrical constraints on each part of such a structure. The dissemblability of such a constructions is affected and therefore characterized by number of disassembly paths , along which the parts are moved to be released from the construction as illustrated in [figure 2.16]. The main cost involved in disassembling such constructions would be for manipulating the tools and therefore directly related to the number of paths for removing the parts from the assembly. The randomness can be evaluated by the number of ways of classifying the methods and the disassembly directions for each interconnection, and the number of ways to classifying the removal paths for each part. The logarithm of the former is referred as the disassembly entropy for interconnection S_I, and the latter, the disassembly entropy for part S_p. These disassembly entropy are not exactly the same as the thermodynamic entropy or the entropy in information theory, it is analogously to the thermodynamic entropy by

$$S_I = \sum_k \left[\ln\left(\frac{N_{Ik}!}{\prod_i n_i!} \right) + \sum_i \ln\left(\frac{n_i}{\prod_j n_{ij}!} \right) \right]$$

Where N_{Ik} is the total number of interconnections belong to a part or an unit of the assembly k, n_I, the number of interconnections made by the method I for instance I=1 denotes the screw joints and I=2, the snap fits, and n_{ij}, the number of interconnections for the direction j (j=$\pm$1,$\pm$ 2, $\pm$3 for $\pm$x, $\pm$y, $\pm$z respectively) of the disassembly of the interconnection i. The symbol Σ_k denotes the summation in respect of the index k,Π the production in respect of the index I, N !, the factorial of N, and ln, the logarithm. The first term represents the contribution of the type of interconnections, and the second term the contribution of the direction of disassembly operations. The other entropy for disassembly path is defined similarly by

$$S_p = \ln\left(\frac{N_p!}{\prod_j n_{pj}!} \right)$$

Where the N_p is the total number of the removal paths for all parts, and n_{pj}, the number of the removal path for the direction j. The disassembly path is counted during the disassembly operations as shown in [figure 2.16] [25].

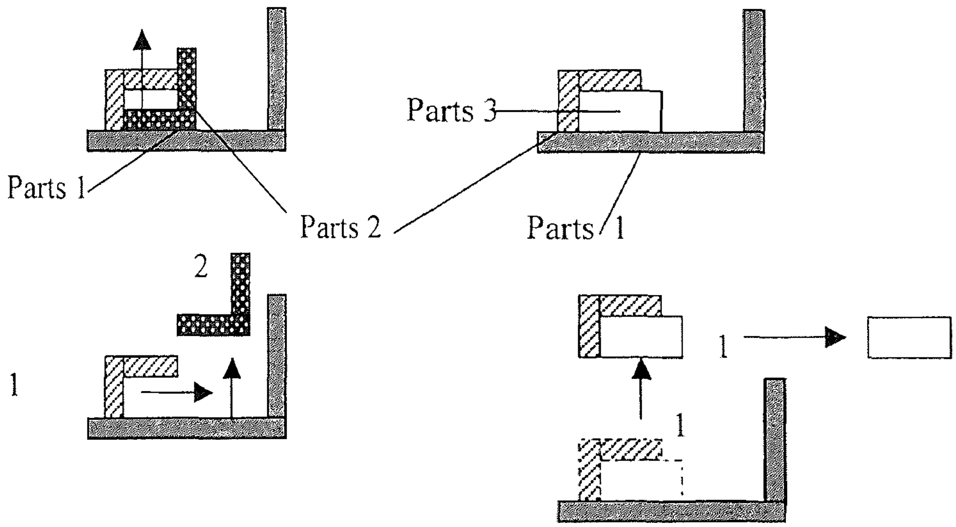


Figure 2.16 Definition of Disassembly path

2.5.2 Comparison of Fastening Techniques in Different Disassembly Process

The fastening techniques to assist disassembly have been tabulated [26]

Table 2.1 Comparison of Fastening Techniques

Phases directly effected	Cost	Time	Environmental Impact	Possible solution	Possible alternative /Recommendation
Disassembly for Recycling- (Manual and Non Destructive)			High	None	Joining with screws or disassemblable snap fits
Reason			It is not possible to disassemble the joint since it is permanent. Hence, unless reuse or energy recovery of the part is possible, the part has to be land filled thus contributing negatively to the environment		
Disassembly for Recycling- (Manual and Destructive)	?	?	?	Using the rivet head a guide the joint can be drilled through. The scrap produced should mainly consist of the rivets material and parts will be easily separated	Unless a possible solution in found it is recommended to select a disassemblable joint
Reason			Joint can be disassembled However the technique used for disassembly, the number of rivets on the part and the amount of parts for disassembly are detrimental to the performance measurements		
Disassembly for Recycling- (Automated and Non Destructive)			High	None	Joining with screws or disassemblable snap fits
Reason			It is not possible to disassemble the joint since it is permanent. Hence, unless reuse or energy recovery of the part is possible, the part has to be land filled thus contributing negatively to the environment		

Table 2.1 Comparison of Fastening Techniques

Phases directly effected	Cost	Time	Environmental Impact	Possible solution	Possible alternative /Recommendation
Disassembly for Recycling- (Automated and Destructive)	high	low	High	If the rivets are destroyed by drilling, they should be located on easily accessible areas	Unless a possible solution is found it is recommended to select a disassemblable joint
Reason	If the rivets are located 'randomly' on the part and if the parts are not the same, the costs will substantially due to jig constructions , in order to obtain flexibility	Once automated the disassembly is generally faster than that carried out manually	Environmental impact is low if disassembly is automated but unless the amount of parts is large, such, such implementation would not be economically feasible		
Mechanical Recycling	?	?	high	Not applicable	If possible design the part for a long serving lifetime since it is not recyclable, otherwise avoid using such a joint
Reason			Joint can be disassembled However the technique used for disassembly, the number of rivets on the part and the amount of parts for disassembly are detrimental to the performance measurements		

CHAPTER 3

DISASSEMBLY EFFORT INDEX METRICS OF INDUSTRIAL FASTENERS

3.1 Introduction

Demanufacturing involves separating and disassembling a 'product' into its smaller 'subassemblies' and 'components'. There are two types of disassembly methods, they are destructive disassembly and non-destructive. Demanufacturing or disassembly involves two specific mechanical processes. One is Unfastening, unfastening carries out the physical separation itself and other is the physical separation techniques which are also used to separate the unfastened part, which is called as 'Disassembly Processes'. Unfastening is an important demanufacturing process, it involves the removal of the fasteners, unlocking them, unscrewing them etc or basically making the fastening effect or fastening force redundant, to assist separation of components. Unfastening is generally a non-destructive disassembly operation, but there are instances when the fasteners need to be broken to disassemble a component.

Fasteners come in different sizes, different shapes, different materials, and have different functional requirements and specifications. The problems that are faced with regard to Fasteners while Demanufacturing a component are because of the above mentioned factors.

The fasteners were analyzed to assist Demanufacturing and the Disassembly Effort Index Metrics (DEIM) of the fasteners was developed. The fasteners were grouped into four major categories since most of the different kinds of fasteners fall into these four major categories, They are:

One Piece Fasteners: One Piece Fasteners are those which achieve their fastening effect without the female part and also because of their shape. They are fasteners like nails, screws, rivets, retaining rings, staplers and panel fasteners.

Two Piece Fasteners: Two Piece Fasteners are those which achieve their fastening effect with the male and the female parts like the Nuts and Bolts, Push on Fasteners, Quick Release Fasteners and Spring Toggle Bolts.

Integral Fasteners: The Integral Fasteners are those that are a part of the component itself like snap fits, crimping and seaming.

Miscellaneous Fasteners: The Miscellaneous Fasteners include welding, tape, releasable clips, Zippers and Velcro©.

3.2 Fastener Resolution Variables

The **Disassembly Effort Index Metrics (DEIM)** focuses on eight different parameters, which are important while analyzing the Demanufacturing effort. They are:

1) Mechanism
2) Handling
3) Disassembly Technique
4) Accessibility
5) Tools
6) Part-Hold
7) Force
8) Instructions

The first three DEIM parameters i.e. Mechanism, Handling and Disassembly Technique are descriptive and only used to guide the dissemblers.

Mechanism: Mechanism describes the way the fasteners achieve their fastening effect. Different kinds of fasteners achieve their fastening differently.

Handling: describes the way the fastener relates to the part or the component and the way the fasteners can be used to assemble or disassemble a component.

Disassembly Technique: This describes the way fasteners can be disassembled easily and assists the dissemblers.

Time: Time plays an important role while considering disassembling or unfastening, since it has to take into account a lot of dependent variables like set up time, disassembly time, instruction time etc. Time when extrapolated, reflects on the disassembly cost. Time is resolved in to six different ranges from 5, 30, 75, 120, 180, 240 seconds. The unfastening time corresponds to the actual time that is needed to unfasten a fastener, let's say a screw wouldn't take long, as opposed to a rivet to unfasten. This explains our non-linear range of Time. Apart from the actual unfastening time we need to take into account other dependent variables which relate to time, it could be the set up time of the part that needs to be unfastened even locating or accessing a fasteners adds to the disassembly time.

The nonlinear time is converted to a linear scale that ranges from 0-5 which corresponds to the nonlinear actual time scale 240 –180 seconds, similarly 180-120 seconds corresponds to linear range 5-10, 120 –75 seconds corresponds to the linear scale 10 –15, 75-30 seconds corresponds to the linear range 15 –20, 30- ≤ 5 seconds corresponds to the linear range 20 -25. As seen in the scoring pattern the longer it takes to unfasten the fastener the lower the score it gets. In the charts the rivet gets a score of 15 and a nail gets a scoring of 25.

Tools: The Tools that assist unfastening are broadly classified in to six different categories they are No Tools, Simple, Mechanic, OEM tools, Special and Unavailable. No Tools essentially means that the unfastening can be done with hands. Simple Tools are a simple pair of screw drivers, pliers, Spanners etc, Mechanic Tools are sophisticated tools like power drivers ,power wrenches, etc .OEM (Original Equipment Manufacturers) these are tools that are supplied by the manufacturers itself so as to assist maintenance and serviceability of the component. Special Tools are the heavy-duty tools like heavy-duty pneumatic hammer. Power Cutters etc. Unavailable tools are the ones that are not available in the market and need to be specially manufactured to disassemble the specific fastener. The linear ranges of the Tools are from 0-4 for Unavailable to Special, 4 –8 from Special to OEM, 8 –12 for OEM to Mechanic, 12- 16 from Mechanic to Simple, Simple to No Tools gets a range of 16 –20. In our scoring pattern we have seen that for Nail, tools gets a scoring of 16 where as a zipper gets a score of 20 since no tools are necessary to disassemble.

Accessibility: Accessibility explains or focuses on the way a fastener can be located and unfastened, since lot of time and effort is lost since most fasteners these days are snap fits and it's difficult to approach and access them to unfasten. The ranges of Accessibility are Z-axis, X-Y Axis, ≥ 4 inch deep head, Dual Axis Complex Motion, Not Visible.

Z-Axis accessibility refers to the easiest accessibility since any fastener that has a Z axis accessibility can be removed very easily requiring less effort and time. X –Y Accessibility refers to a slight variation in the Accessibility this resolution includes both X and Y accessibility so in our evaluation Z is the easiest accessibility. $\geq$ 4 inch Deep Head, this resolution refers to the fasteners that are imbedded inside in grooves and sockets. Generally it easy to access if the depth of head is not more than 4 inches. Dual Axis motion is different from X-Y axis accessibility where the just refer to each of the axis but dual motion refers to a motion where both of them are happening at the same time. The Complex Motion refers to situation, when we face while disengaging a cantilevered Snap fit .As seen in most cases to disengage a cantilevered snap fit or a Compression Snap fit to access the cantilever which locks into the socket is very difficult because its covered and partially hidden so this resolution takes care of these problems we face while disassembling an integral fasteners. Not Visible refers to fasteners that are completely hidden. These days with Design for No Assembly and Design for Disassembly concepts gaining popularity we see that there are a lot of integral fasteners which are being developed are not at all visible to the surface these fasteners are like compression Snap fits, Panel Fasteners fall in to this category. Not visible –Complex Motion gets a score of 0-4,for Complex Motion– Dual Axis the range is 4 –8,

Dual Axis – $\geq$ 4 inches the score is between 8 –12 .the other ranges are from 12 –16 and 16 –20.

Force: The forces that are needed to disassemble a fastener are Cutting, High Impact, Low Impact, Leverage, Torsional and Axial Forces. Cutting Forces are generally more and requires a lot of effort so it gets a score of 0,High Impact refers to forces where lot of hammering and breaking takes place example when we break a rivet so this gets a score of 3. Low Impact forces get a score of 6, Leveraging gets a score of 9, Torsional gets a score of 12 and Axial gets a score of 15. Force is an important resolution because it's a dependent variable and actually adds on to the disassembly cost and effort .As seen in the resolution Rivets get a lower score of 2, where as a Screw get a score of 12 since it falls into the Torsional force category and Rivets fall in to a Cutting and high Impact category.

Part Hold: This is again a dependent variable of time because it adds on to the set up time and effort which then translated adds on to the disassembly cost. The faster the set up is the easier it is to remove, if there is no set up time then it gets a higher score in our resolution we have a range from Automated, Complex Fixturing, Fixture Necessary, Two Hand, No Hold. When we are trying to remove a fastener from a television monitor back cover we don't need any fixturing or support since the monitor itself is stable, so the Ranges refer to a wide varieties of fixturing. Automated refers to Robotic Grippers which are necessary when the component is big or hazardous. The Complex Fixtures Refer to Magnetic Chucks that are necessary to hold the component in place. The scoring ranges are from 0 –2 for Automated since there a whole range of end effectors that are available, from Automated to complex fixture gets a Score between 2-4, Complex Fixture – Fixturing Necessary gets a score of 4 – 6, Fixture-Necessary to Two Hand gets a score range of 6 – 8, Two Hand to No-Hold gets a score of 8-10. In our evaluation of fasteners Velcro gets a score of 8 since it requires two hands where as a screw gets a high score of 10 since it generally doesn't need part fixturing to remove a screw in most of the cases.

Instruction: Instruction as a parameter cannot be ignored because, these days a lot of different types of components need to be disassembled from aircraft's to Coffee Makers so the dissemblers need to be trained accordingly. These Instructions involve training the dissemblers in terms of the feasibility of the disassembly of a part and where and when to stop disassembling. There are instances where the dissemblers could be in danger because of Toxic substances and the unfastening process could be dangerous. The Ranges of our non linear parameter are Special classes, Whole Day, Half Day 60-30 min, 5 –30 min, None, each nonlinear ranges get a linear range of 0-2, 2-4, 4-6, 6-8, 8-10 respectively.

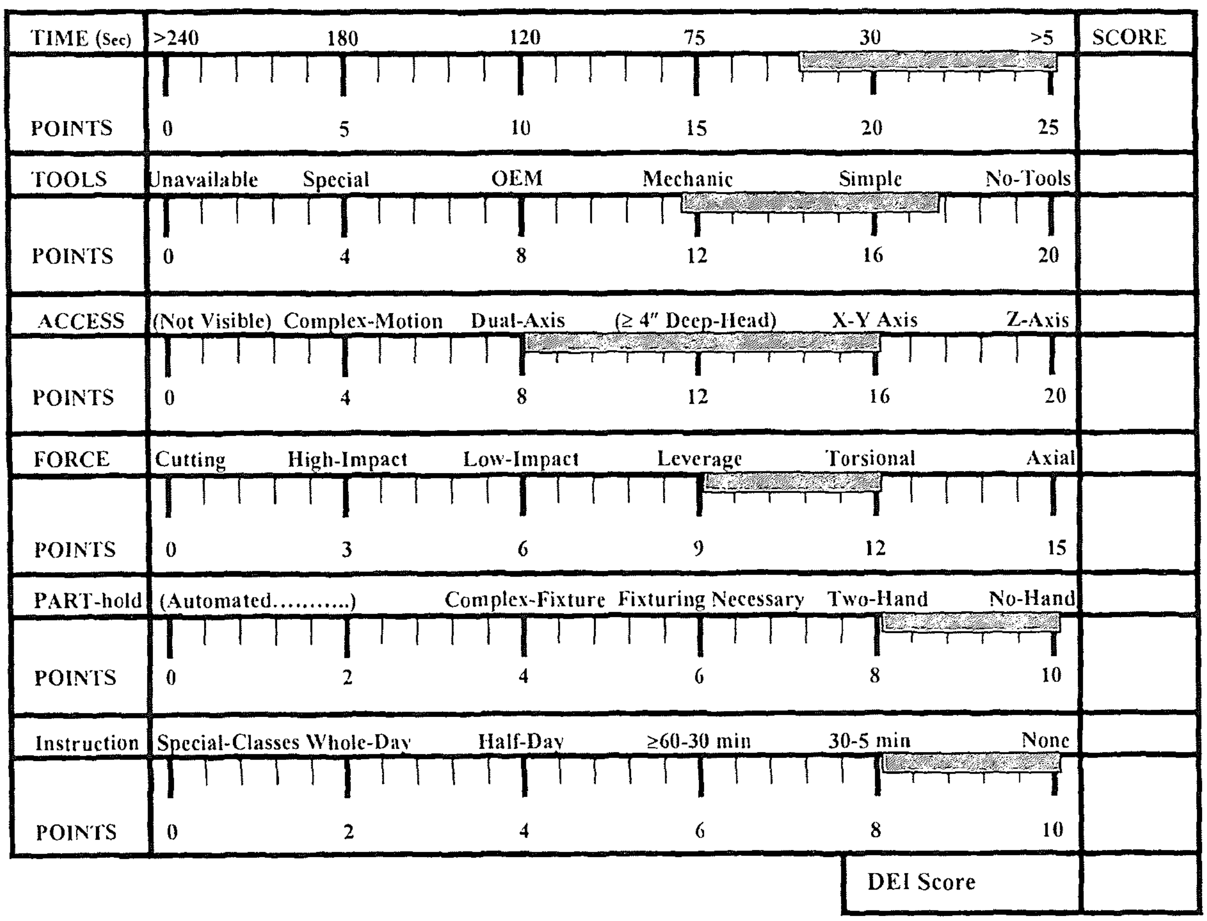


Figure 3.1 Disassembly Effort Index Metrics (DEIM) of Fasteners

The figure 3.1 shows the Disassembly Effort Index Metrics score board for each fasteners, the shaded boxes in the horizontal scrolling bar shows the actual range of the fastener as researched and evaluated. The scoring pattern of each fastener will be described in the next few pages.

3.3 One Piece Fasteners

3.3.1 Nail

One Piece Fasteners	Nail
	

Figure 3.2 Nail

Mechanism: Nails are used for putting together all kinds of wood plastic structure. Nails are the most practical means of fastening pieces quickly and inexpensively. Nails achieve their fastening when they displace wood fibers from their original position. The pressure exerted against the nail by these fibers as they try to spring back to their original position provides holding power.

Handling: Nails are the simplest of fasteners they are very easy to use and handle .

Disassembly: The Disassembly can be done very easily unless the nails are corroded using the pliers, lever end of the hammer.

Tools: Pliers, Hammers, and Hacksaw.

Score Description: The projected score for nail is 88 since it's an easy disassembly since it depends on the types of nails. Time it takes to disassemble a nail is usually less than 5 seconds since it's either pulled out or leveraged out .Time function gets a score of 25.Tools that are required to disassemble a nail is either a pliers or the lever end of a hammer and the tools are in the range of Simple and it gets a score of 16.The accessibility is always z axis with respect to nails thus it gets a score of 20.The forces that are used to remove a nail are usually between axial and Leverage forces thus it gets a score of 9. At times part needs to be held to remove the nail , usually the part is held by hand thus giving it a score of 8. The dissemblers don't need to be trained to disassemble a nail giving it a score of 10 .

disassemble a fastener are Simple a screw driver or a power driver thus it gets a score of 16. The Accessibility issues with a screw depend on the type of component and its complexities. The score it gets is between 12-20 ($\geq$4 Deep-Head –Z axis) usually it is 16. The force that is needed to unfasten a screw is torsional, the score it gets is 12. The part is not necessary to be held unless the part is very small or very big the score it gets is 9. The Instruction is not necessary to unfasten a screw the score it gets is 10. The total score is 85.

3.3.3 Rivets

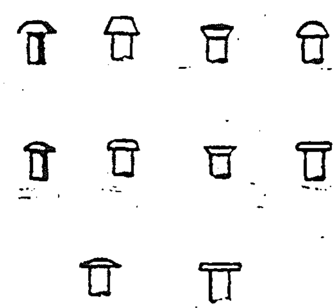
One Piece Fasteners	Rivets
	

Figure 3.4 Rivet

Mechanism: Riveting is exclusively for joining and fastening metal sheets and beams when welding, brazing or locking techniques do not provide a satisfactory joint.

disassemble a fastener are Simple a screw driver or a power driver thus it gets a score of 16. The Accessibility issues with a screw depend on the type of component and its complexities. The score it gets is between 12-20 (≥4 Deep-Head –Z axis) usually it is 16. The force that is needed to unfasten a screw is torsional, the score it gets is 12. The part is not necessary to be held unless the part is very small or very big the score it gets is 9. The Instruction is not necessary to unfasten a screw the score it gets is 10. The total score is 85.

3.3.3 Rivets

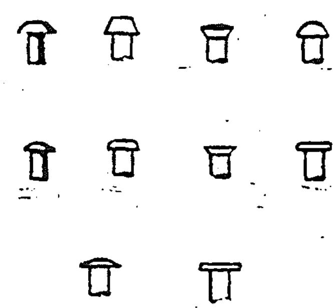
One Piece Fasteners	Rivets
	

Figure 3.4 Rivet

Mechanism: Riveting is exclusively for joining and fastening metal sheets and beams when welding, brazing or locking techniques do not provide a satisfactory joint.

Handling: Riveting involves three operations drawing, upsetting and heading. The sheets are drawn together by placing the deep hole of the rivet set over the protruding river shank and then the head of the set is upsetted.

Disassembly: It's a difficult to disassemble a rivet, because it's a permanent fastening. Non Destructive disassembly is the only suitable solution i.e. the rivet heads are broken or cut to separate the joint.

Tools: Chisel, Hammer, Grinders, Punches and Blow Torches.

Score Description: The Disassembly of a rivet is a tedious and time consuming operation, the score it gets for time is 15 since breaking a small rivet takes a lot of time around a minute and half. The tools that are needed to disassemble a rivet are between OEM-Mechanic thus giving it a score of 10. Rivets are easily accessible the accessibility is usually either X-Y Axis giving it a score of 16. The force that is needed to break a rivet is cutting or high impact forces thus giving it a score of 0. The part needs to be held while breaking the rivet. The part hold range is between (Complex fixture and Fixturing Necessary) the score it gets is 5. Sometimes the dissemblers need to be instructed while they break the rivet since it is a destructive disassembly . The score it gets is 8. The total score is 56.

3.3.4 Retaining Rings

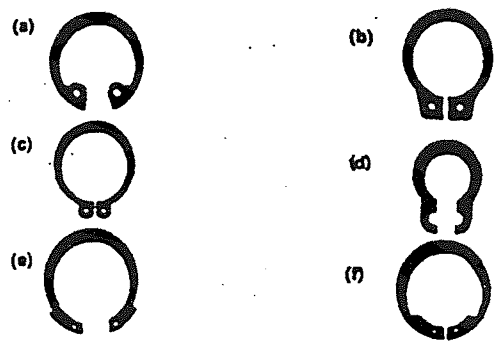
One Piece Fasteners	Retaining Rings
	

Figure 3.5 Retaining Rings

Mechanism: There are two types of rings they are internal retaining rings and external retaining rings .The internal type is compressed to fit into the bore or the socket and the external type is expanded to slip it over the shaft

Handling: The rings are designed to resist high rotational speeds and to provide a shoulder capable of withstanding heavy thrust loads when installed in their grooves.

Disassembly: Disassembly is performed by inserting ring pliers in to the two holes of the ring and pressing them together and pulling them out of their grooves.

Tools: Ring Pliers.

Score Description: The projected score is 61 for the retaining the time it takes to remove the retaining rings depend on the complexity of the groove the score it gets for Time is usually between 30- 5 seconds the corresponding score is 22. The tools that are needed to remove retaining rings are a pair of special pliers and are between OEM to simple the corresponding score it gets is 9. Accessing these fasteners are very difficult the score it gets is 5 since complex motions are needed to access them. The Force needed to separate the fasteners are between Low Impact –Leverage giving it a score of 8. The part holding is not necessary in most situations the corresponding score is 9. The total score it gets is 61.

3.3.5 Stapler

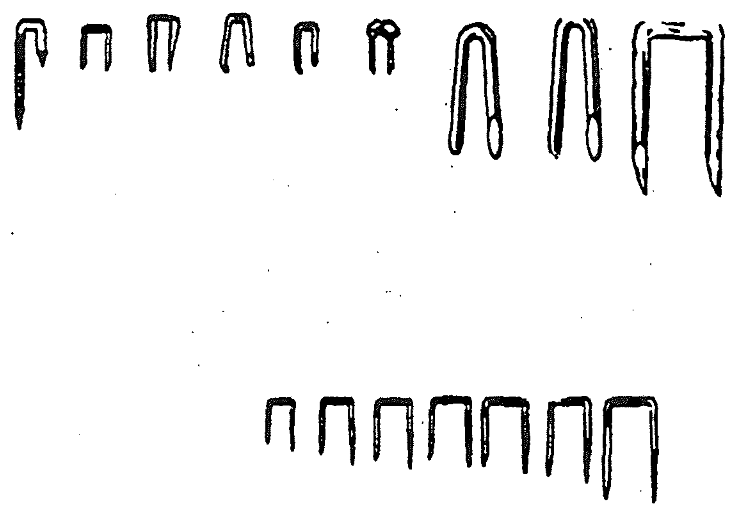
One Piece Fasteners	Stapler
	

Figure 3.6 Stapler

Mechanism: Staples are two pointed fasteners made of wire they can be driven by hand or by mechanical or electric staples. They hold the part or the component by clasping the part together.

Handling: Staples are driven by mechanical stapler or Electric or sometimes a simple hammer is used to staple them as nails. It's useful for both hard and soft surfaces and is very versatile.

Disassembly: The disassembly can be accomplished by pulling the stapler using the "stapler pliers" or by flat tipped screw drivers.

Tools: Pliers, Screw Drivers.

Score Description: Though stapler is easy to remove we are talking of Industrial Staplers which are big and strong the time it takes to remove the stapler is usually between 30-5 seconds giving it a corresponding score of 23. The tools that are necessary to remove the stapler are Simple tools like Pliers and snips etc. The score it gets is a 16.Stapled joints are very accessible and the score it gets is 18 because it is between X-Y Axis to Z axis. The force that is needed to remove a stapled pin is less usually leveraging forces or axial forces giving it a score of 13. Part hold is not very necessary since the part it self is stable and the score it gets on the scale is between Two –Hand to No-Hand giving it a score of 9. Instructions are not needed to remove a stapler unless it is very difficult .It gets a perfect score the total score it gets is 89.

3.3.6 Panel Fasteners

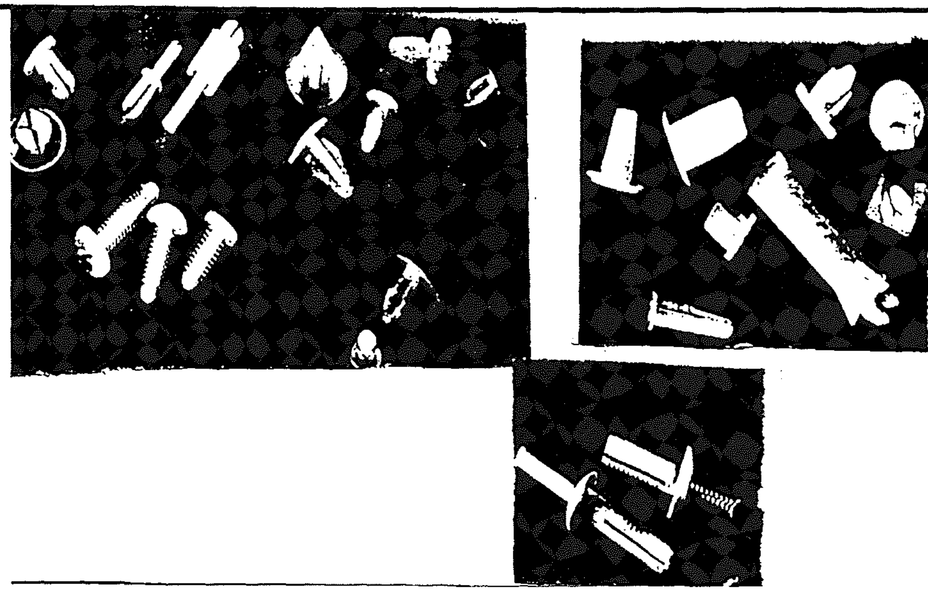
One Piece Fasteners	Panel Fasteners
	

Figure 3.7 Panel Fasteners

Mechanism: These Fasteners combine the advantages of a push in type fastener and a screw .For quick assembly, The part can be pushed into a threaded hole and then screwed in for a tighter fit or screwed out for disassembly.

Handling: The fastener functions both as compression fits and a threaded screw. Thus increasing their flexibility.

Disassembly: The screws could be screwed out or pulled out for disassembly.

Tools: Screw Driver , Pliers.

Score Description: The Panels Fasteners are easy to remove since they are Quick release fasteners. The time it takes to remove each of the fasteners is usually a little more than 5 seconds so it gets a corresponding score of 23. The tools that are required to disassemble the fastener are usually between Simple to No Tools the score it gets is 18. The Accessibility of these fasteners is usually Z-Axis the score it gets is 20. The Force that is needed to remove the fastener is usually axial getting a score of 14. The Part hold is not needed the scores are 10. The Instruction is not needed to disassemble the Panel Fasteners thus giving it a score of 10 . The total score is 89.

3.4 Two Piece Fasteners

3.4.1 Nuts and Bolts

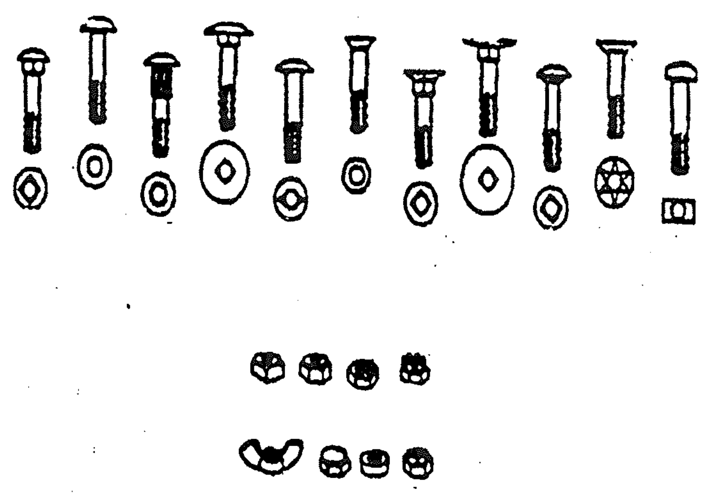
Two Piece Fasteners	Nuts & Bolts
	

Figure 3.8 Nuts and Bolts

Mechanism: Bolts and nuts are handy especially handy for putting together parts that have to be taken apart frequently and when lot of tensile forces act on the parts that are fastened.

Handling: Bolts have to be installed in parts so that their heads up so that this way the bolt will continue retaining it holding capacity even if the nut falls off.

Disassembly: Bolts and Nuts are easy to disassemble since applying a torque against the fastening force carries out unfastening operation.

Tools: Screw Drivers, Ratchets, Spanners, Wrenches Allen Keys.

Score Description: The time it takes to remove a nut and a bolt is (between 75-30 sec) the score it gets is 15. The tools are between (OEM-Simple) the score it gets is 12. The Accessibility gets a good score since the nuts and bolts are highly accessible getting a score of 18. The force that is needed to remove a nut and a bolt is torsional the score it gets is 12. The score it gets for part hold is eight .Instructions are not needed to disassemble a nut and a bolt thus it gets a score of 10 .The total score it gets is 75.

3.4.2 Push on Fastener

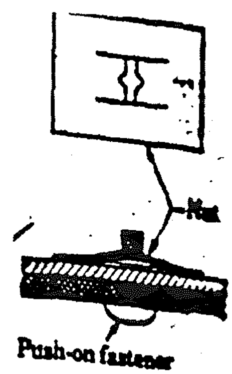
Two Piece Fasteners	Push on Fastener
	

Figure 3.9 Push on Fastener

Mechanism: Push on fasteners have two spring flaps as a nut and they fit into the groove of the fasteners when they are aligned and pressed together.

Handling: They are essentially used when thin sheets need to be fastened together.

Disassembly: These types of fasteners assist quick disassembly because the nut doesn't need to be unscrewed but just yanked out.

Tools: Pliers, Punches.

Score Description: Push on fasteners is quick disassembly fasteners and is very easy to disassemble, the time it takes it to disassemble the fastener is less than 5 sec the score it gets is 25. The tools that are needed to disassemble the fastener are usually simple thus the corresponding score is 16. The accessibility score is 18 since its usually between X-Y Axis to Z Axis. Force that is needed to dissemble the push on fastener is Torsional so it gets a score of 12. The Part hold score is nine since the part needs to be held at times to disassemble the fastener. The total score is 88.

3.4.3 Quick Release Fasteners

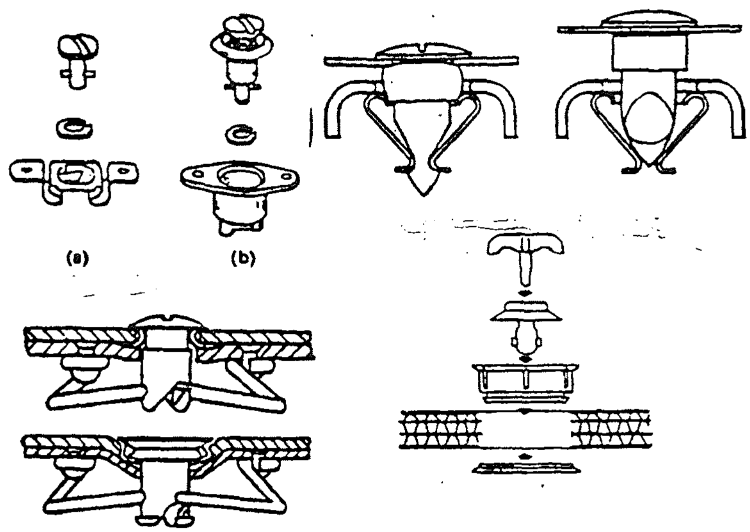
Two Piece Fasteners	Quick Release Fastener
	

Figure 3.10 Quick Release Fasteners

Mechanism: The Rotary Stud Fasteners comprise of a solid stud pin with a slotted head at one end and a bayonet type rescesses at one end. The stud passes through a hole in the de-mountable panel and is held captive.

Handling: Fastening is accomplished when the panel is offered up to the fixed structure , the fastener stud engages with a receptacle , which is secured to the inner face of fixed structure.

Disassembly: The disassembly can be done very easily by a quarter turn of the stud by means of a screw driver completes the disengagement.

Tools: Screw Driver.

Score Description: The DEI Score for Quick Release Fastener is 95. The score for time is 25 since it takes less than 5 seconds to disassemble. The tools that are needed to disassemble a fasteners are between Simple to No tools the corresponding score is 18. The accessibility is no problem with these fasteners. The score it gets is 20.The Force needed to unfasten is usually between torsional and Axial thus getting a score of 14. The part hold score is 9.The Instruction is necessary when the fastener is unusual giving it a score of 9.

3.4.4 Spring Toggle Bolt

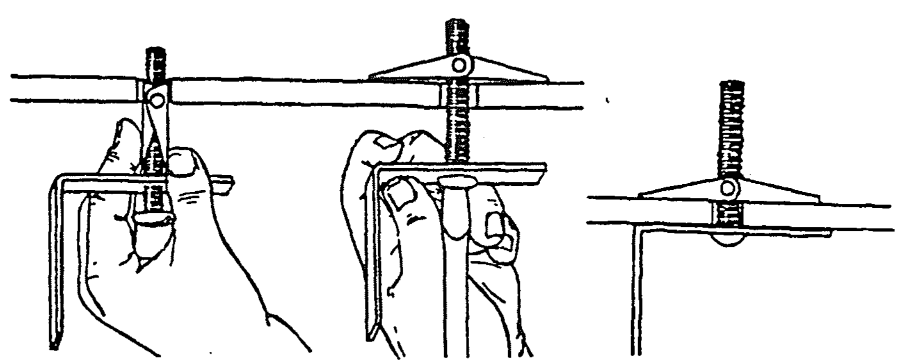
Two Piece Fasteners	Spring Toggle bolt
	

Figure 3.11 Spring Toggle Bolt

Mechanism: The Spring Toggle Bolt consists of a spring loaded wing which performs the function of a nut and thus spread the fastening force uniformly over a large surface area.

Handling: To fasten parts using the toggle bolt an oversized hole is drilled to admit the wings when folded , then the bolt is inserted through the parts , until the wings spring open to form a 90° angle with the mating part (as shown above) and then they are screwed.

Disassembly: During disassembly the wings are held tightly by a pair of pliers the screw is unscrewed and then the wings are folded and pushed.

Tools: Screw Drivers ,Pliers .

Score Description: The score for Spring Toggle bolt for time is 85. The score for time is 25 since it takes less than 5 seconds to disassemble. The tools that are needed to disassemble a fasteners are Simple tools the corresponding score is 16. The accessibility is usually X-Y axis the score it gets is 16. The Force needed to unfasten is usually between torsional thus getting a score 14. The part hold score is 8 since both hands usually hold it. The Instruction is necessary when the fastener is unusual giving it a score of 8.

3.5 Integral Fasteners

3.5.1 Cantilevered Snap Fits

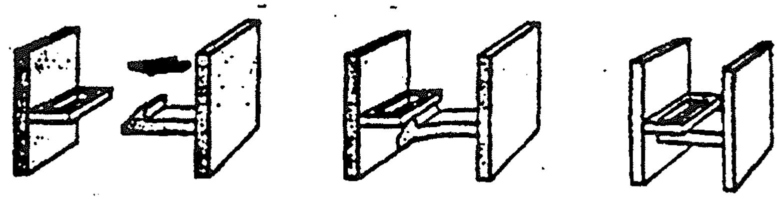
Integral Fasteners	Cantilevered Snap Fits
	

Figure 3.12 Cantilevered Snap Fit

Mechanism: In a typical cantilevered latch the ramped end of the finger is deflected down as it advances past the lip of the mating part , snap into position.

Handling: Cantilevered-latching mechanism is simple or a lip or a ball at the end of a springy lever engages a lip or a socket. The design requires a balance of stiffness and flexibility.

Disassembly: The Disassembly of a cantilever is difficult because of accessibility and because of multiple latches joining, the part can't be separated till all the multiple latches are released. This requires a lot of co-ordination than force.

Tools: Screw Drivers, Punches Pliers.

Score Description: The Cantilevered Snap fits are usually take less than 5 seconds to disassemble the score it gets for time is 25.The tools that are needed to disassemble are Simple like Screw Drivers etc thus giving it a score of 16. The Cantilevered Snap fits usually have a X-Y Axis accessibility giving it a score of 16. The force that is needed to remove a snapfit is between axial and torsional at times complex motions need to be done to access the fastener thus giving it a score of 12,The part hold score is 8 since its held by hand the Instruction score is 8 since at times the snap fits are complex and the dissemblers need to be trained.

3.5.2 Crimping

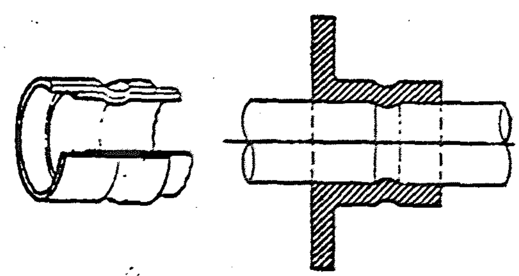
Integral Fasteners	Crimping
	

Figure 3.13 Crimping

Mechanism: Crimping is a method of joining without fasteners. The two parts that need to be joined have dimples all along the mating region. These dimples assist fastening (forced Fits) and are usually used for tubular and flat parts.

Handling: Crimping can be used on both tubular and flat parts provided that the materials are thin and ductile enough to with stand the large localized deformations.

Disassembly: The Disassembly is not easy it is performed by gripping or fixing one of the part on a vice or a gripper and then applying a linear force on the other part and pulling it out. Or by performing a destructive disassembly by cutting the joint.

Tools: Special Pliers, Vices, Punches ,Fixtures ,Hammers and Hacksaw.

Score Description: The DEI score it gets is 38,the score it gets for time is 10 since the time it takes to break the joint is usually 120-seconds.The score for tools is 4 because lot of special tools need to be used depending on the fastener. The accessibility is Dual Axis giving it a score of 8. The forces that need to break the joint is cutting impact etc thus getting a score of 4.Fixturing is necessary thus getting a score of 5.The instruction is also neded thus getting a score of 7.

3.5.3 Seaming

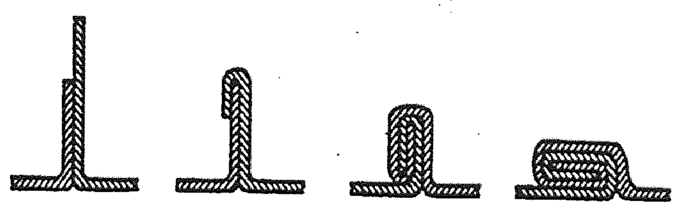
Integral Fasteners	Seaming
	

Figure 3.14 Seaming

Mechanism: Seaming is based on the simple principle of folding two thin pieces of material together. Seaming is much like joining two pieces of paper, in the absence of a paper clip.

Handling: In Seaming the materials should be capable of undergoing bending and folding at a very small radii, otherwise they will crack and the seams will not be airtight or watertight.

Disassembly: Seaming joint doesn't assist disassembly, because it cannot be unfastened. The only thing that can be done is to cut the seam using cutters or shears.

Tools: Cutters, Shears, and Hack Saws.

Score Description: The DEI score is 26 and is very less because it is a very time consuming operation. The score it gets for time is 6 because it takes around 180-120 sec to dissemble the fastener. The tools that are needed are Special giving it a score of 5. The Accessibility score is 3 because the joint is visible but not accessible. The Forces needed to break the joint are cutting so the score is 0.The part hold is necessary because it is being cut the score is 5.The instructions needed depend on the complexity of the joint the score in our evaluation is 7.The total score is 26.

3.6 Miscellaneous Fasteners

3.6.1 Welding

Miscellaneous Fasteners	Welding
	

Figure 3.15 Welding

Mechanism: Welding is a process used to join metals by the heating them ,in which both the work and the filler are melted so that they flow together and are integrally joined when cooled.

Handling: Weld Joints are permanent joints. The prevalent joints are T (tee) joint, Lap Joint, Butt joint etc.

Disassembly: Welding is a permanent joint so disassembly is a tedious process, which involves a lot of time and effort (cutting, sawing, shredding, grinding, heating). The component or the part is also damaged.

Tools: Chisels, Hammer, Blow Torches and Grinders.

Score Description: The disassembly time is usually 75 second because the weld is cut the score it gets is 15.The tools that are needed depend on the type of weld and the metal that needs to be cut. The score for tools is between Special To mechanic tools giving it a score of 8.The accessibility is not a big issue for a weld joint the score it gets is 18.The forces are between cutting and impact the score it gets is 2. The score it gets for fixturing is 5. The Instruction is needed because it is a destructive disasembly the score is 8. The total score is 58.

3.6.2 Tape

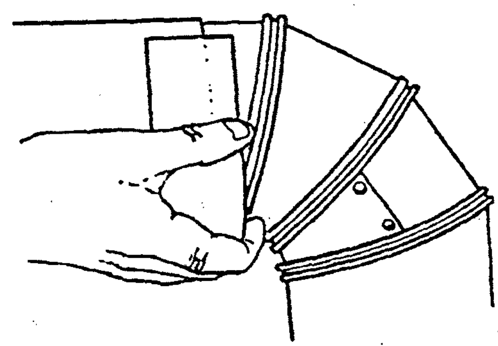
Miscellaneous Fasteners	Tape
	

Figure 3.16 Tape

Mechanism: There are many types of tape that help putting things together a great deal easier. Tape is used for binding , masking and decorating.

Handling: Two parts that need to be covered or fastened are brought together and the tape is stuck to both of the parts thus joining or masking them.

Disassembly: The tape can be pulled out.

Tools: Hands, Knives.

Score Description : Removing a tape is the easiest of all disassembly and this gets a score of 100.

3.6.3 Releasable Clips

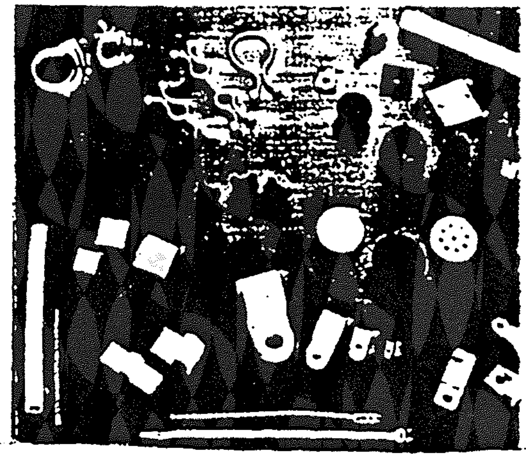
Miscellaneous Fasteners	Releasable Clips
	

Figure 3.17 Releasable Clips

Mechanism : These fasteners have a loop in which the wires or the tubing pass through and on the outer periphery of the loop they have a cantilever type or a protrusions which can be closed so as to complete the loop thus holding the wire , some fasteners also have compression fits which assist them to be fastened to a wall or a plate or a board.

Handling: The wire or tubing passes through the hole or the loop many of these releasable clips are used together to align and orient the pipe or wires.

Disassembly: The outer snap fits can be pulled out to release the wire or the pipe.

Tools: Hand ,Pliers etc.

Score Description: The score it gets is 100 because the clips are usually quick disassembly fasteners and are very easy to dissemble refer [Table 3.1].

3.6.4 Zippers

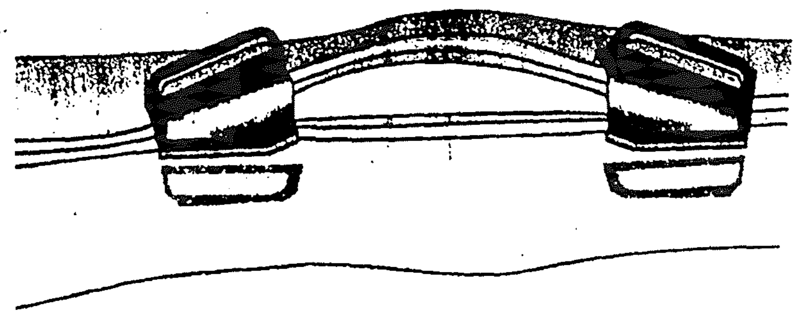
Miscellaneous Fastener	Zipper
	

Figure 3.18 Zippers

Mechanism: There are two parts one is the mortise and the other is the tennon there is a slider which slides along the two of them and the slider is the one that fastens the two together by compressing the two together so as to form a perfect joint.

Handling: The Zippers are welded, stitched or bonded to the parts that need to be fastened.

Disassembly: The slider need's to be pulled in the opposite direction of fastening.

Tools: Hand or Plier.

Score Description: Unzipping is the easiest of operation it gets a score of 100.

3.6.5 Velcro

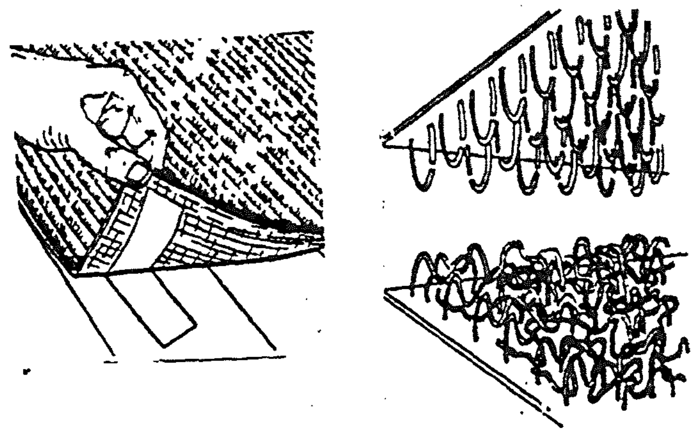
Miscellaneous Fasteners	Velcro
	

Figure 3.19 Velcro

Mechanism: The Velcro hook-and-loop tape is used in hundreds of thousands of household and industrial jobs. To use them you simply press to close and pull apart to open the hooked portion of the tape has a great number of precisely shaped snags (Top). When the hooked portion is pressed against the looped piece (bottom), fastening doesn't occur when two loop or two hook pieces together.

Handling: The loop strips are attached to one of the part and the hook is attached to the other.

Disassembly: The two pieces are pulled apart thus detaching the hook and the loop.

Tools: Hands or pliers.

Score Description : Removing the velcro is the easies operation the score it gets is 98,it loses score while Part needs to be held either by one hand or both.

Table 3.1 DEIM of Fasteners

Fastener	Time	Tools	Access	Force	Part-Hold	Instruction	Score
Nail	25	16	20	9	8	10	88
Rivets	15	08	16	2	5	8	54
Screw	25	16	20	12	10	10	93
Retaining Ring	22	9	5	8	9	8	61
Stapler	23	16	18	13	9	9	88
Panel Fasteners	23	18	20	14	9	10	94
Nuts & Bolts	15	08	18	02	05	08	58
Push on Fastener	25	16	18	12	9	8	88
Quick Release Fastener	25	18	20	14	9	9	95
Spring Toggle Bolt	25	16	16	12	8	8	85
Cantilevered Snapfit	10	12	2	8	7	8	85
Crimping	10	4	8	4	5	7	38
Seaming	6	5	3	0	5	7	26
Welding	15	8	18	2	5	8	58
Tape	25	20	20	15	10	10	100
Releaseable Clips	25	20	20	15	10	10	100
Zippers	25	20	20	15	10	10	100
Velcro	25	20	20	15	8	10	98

The table 3.1 shows the projected scores of each fastener have been shown in each of the fasteners have been evaluated accordingly to the DEIM parameters i.e. Time , Tools , Access , Force , Part-Hold , Instruction .The scores that have been calculate are not definitive which means that the scores can change depending on the fasteners and the parts that are fastened using these fasteners. As noticeable some fasteners have very low scores and some have perfect scores. This means to say that fasteners that have low scores are difficult to disassemble and fasteners like zippers and Velcro® that have high scores assist disassembly.

CHAPTER 4

DISASSEMBLY METRICS OF DISASSEMBLY PROCESSES

4.1 Disassembly Process and Variables Description

Disassembly Process involves separation of parts after or, before they have been unfastened. Disassembly processes have been classified as Non-Destructive Disassembly and Destructive Disassembly. Non Destructive Disassembly has been further resolved into five categories, which are:

1) Magnetic Separation.
2) Suction and Drainage.
3) Separation of an Unfastened Part.
4) Separation of a Fastened Part.
5) Self-Removal.

The Destructive Disassembly has been further resolved into eight categories, which are:

1) Weld Breakage
2) Impact Breakage
3) Shearing
4) Cutting
5) Shredding
6) Chemical Dissolution
7) Adhesive Separation
8) Smelting

In this thesis all the Non-Disassembly Processes listed will be discussed ,only two of the Destructive processes namely Weld Breakage and Impact Breakage will be discussed. The Disassembly processes have been analyzed in a mechanical perspective and the description includes the definition, process variables that describe how disassembly can be performed, the figure of the disassembly operation, Disassembly Effort Index Metrics (DEIM) of the Disassembly processes and the Resolution Description of the Metrics.

The Parameters of the metrics are Time in seconds, Equipment and tools, Force Applied both human and Machine (in lbs.), Part-Hold, Process Instruction and Hazard Tools.

Time: Time is an important parameter in the disassembly evaluation, since it reflects on the total disassembly time which includes setup time, material handling time and the actual hands on disassembly time. Setup time encompasses process instruction time, tool & equipment setup time.Disassembly time is a dependent variable of the disassembly cost, the dissemblers are actually interested in the viability of every disassembly operation with respect to the disassembly cost and the recovery cost.

The disassembly time has to be extrapolated to a linear scale for the matrix. The least time that synchronizes with the disassembly time is given the maximum score i.e., 25 the other non linear scales are 60 seconds, 150 seconds, 180 seconds, 240 seconds, and greater than or equal to 300 seconds they get scores of 20,15, 10, 5, 0 respectively. Other times in between them get linear scale as shown on the chart.

Tool: Tool setup finds an important place in the resolution since it's a multi dependent variable, which reflects on the disassembly time and the material handling effort. When we disassemble a component, we need specific tools that assist disassembling a part, which include unscrewing a fastener or cutting a rivet head or snapping an integral fastener etc.

The resolution for Equipment/Tools are: None (when the disassembly is performed by hands or at times the part itself falls out when the part has a secondary fastening). Mechanic tools (they are the simplest of tools, like a set of screwdrivers, wrenches, spanners, ratchet spanners, hack saws, pliers). Then OEM (Original Equipment Manufacturers Tools with the issue of serviceability and maintenance, most manufacturers provide special tools to assist maintenance and serviceability, that are not available as simple/ mechanic tools. Due to new technological developments new fasteners are being developed, tools really don't exist in the general market). Special Tools (are those, besides the one's mentioned above. They encompass tools that specifically need to be manufactured to assist disassembly). Heavy Duty Tools (are used for destructive disassembly and to generate forces greater than 250 pound, like a heavy sledgehammer, pneumatic hammer). Unavailable (There are new kinds of Integral Fasteners and Miscellaneous Fasteners, These days we encounter products that bear the label of DFA i.e., design for Assembly and DFNA i.e., design for no Assembly. These products assist assembly but are difficult to disassemble. Some components also have complex geometry's, which really don't assist disassembly.

Equipment/Tools is a dependent variable and adds to the disassembly effort as a function of Time so it gets a maximum score of 20. None gets a score of 20. Others get linear scores of 16, 12, 8, 4, 0 respectively.

Force: Force is a direct reaction of the disassembly effort per component, per part, per fastener. The force that needs to be applied on a part to effectively disassemble is either linear,(Push/Pull), leveraging forces, moment, torsional, impact, and a whole range of forces that include peeling, cutting, shearing, fracture etc. Force is classified into two categories Human and Machine. At any point of disassembly evaluation either one category of force can be used but not both. The human force generation range is given from 2 pounds to 50 pounds so that there is a safe threshold to reduce the hazard factor due to overstressing etc. The force that can be generated by a machine is from 100 pounds to greater than 300 pounds which is reliable.

In the resolution for the human force the range is from 2lbs to 50 lbs. where the less effort gets the score of 20 and the maximum effort gets a lower score i.e., 50 lbs. gets 0. 40, 30, 25, 10 get a score 2, 8, 12, 16 respectively. The scale resolution for machine applied force is 100 gets 20 and >300 gets a score 0 where as 250, 200, 175, and 125 get a score of 4, 8, 12, 16 respectively.

Force and Equipment/Tools get the same priority since they are direct dependent variables.

Part Hold: Part hold is an evaluation parameter that implies fixturing and indirectly setup time. This parameter is accounted for, because it adds up to the disassembly cost. Since, some components need to be fixed, some don't. The evaluation of part hold is classified into four parameters. They are Material Handling equipment ... Robots, Simple fixture, Hand Held, None. Material Handling Equipment... Robots classify most of the complex fixtures, heavy-duty fixtures, jigs & robotic grippers, Simple Fixtures are bench vices, hand held vices etc. Pliers and grippers fall into hand held. This gets parameter a score of 15 points on the evaluation scale. It is not a direct reference to equipment /tools, its only a reference to the time i.e., setup time etc, etc. The highest score of 15 is given to None, 12 to hand held, simple fixture gets 9, material handling equipment ... robots gets a score of 0-6.

Process Instruction: Process instruction help, train, assist the dissemblers to optimize disassembly process thus reducing time and disassembly cost etc. This parameter is used because these days dissemblers face a lot of problems, while disassembling complex components, which have lot of parts. A balance is necessary to stop disassembly at a specific level so as to focuses on components/parts that are valuable and important rather than wasting time on fluff & useless materials.

The range is from Obvious (where looking at the part/component the dissembler decides about the methodology). Others are from (30-5min), (60-30min), Half a day, whole day and OEM (where Original Manufacturer comes and gives training etc).

This parameter gets a score 15 points in our evaluation chart. This is dependent on the component location whichever is being disassembled. The one which is Obvious gets the highest score of 15 and the others like (30-5min), (60-30min), half a day, whole day, OEM gets 12, 9, 6, 3, 0 respectively.

Hazard: Hazard instructs and trains the operator about the dangers that occur, and trains to protect himself/herself from them The various options in this parameter are Fully Covered(where the operator must be fully covered to escape from the danger), Fire Proof(the operator must use protective fire resistant clothing in case a fire breaks out), Face Mask(this tells the operator to use a face mask to avoid flying splinters, chips or sparks to protect the face and eyes), Gloves and None. None indicates there is no need of using any item and indirectly it states that there is no danger present in that operation. This parameter gets a maximum score of 5 points Gloves, Facemask, FireProof, Fully Covered gets a score of 4, 3, 2 and 0-1 respectively.

Ranges give the scoring, then the average of each parameter range is put in to the adjoining score box. Then the average of each box is taken, which then gives the Disassembly Effort Index of the Disassembly Process score.

There are other parameters like Accessibility have not been included in the disassembly process resolution because disassembly is the next step after unfastening, Accessibility has been addressed in the Disassembly Effort Index of Fasteners ,which includes these specific parameters (Not-Visible ,Complex-Motion, Dual-Axis ,$\geq$ 4" Deep-Head ,X-Y Axis ,Z- Axis). After the fasteners have been unfastened Accessibility issue of the part itself becomes redundant, in the Disassembly Effort Index Metrics of Disassembly Processes.

TIME (Sec)	>300	225	150	100	60	5	SCORE
POINTS	0	5	10	15	20	25	
TOOLS	Unavailable	Heavyduty	Special	OEM	Mechanic	No-Tools	
POINTS	0	4	8	12	16	20	
FORCE Human (Lbs.)	50	40	30	25	10	2	
POINTS	0	4	8	12	16	20	
FORCE Machine	>300	250	200	175	125	100	
POINTS	0	4	8	12	16	20	
PART-hold	(Material Handling Eqpt-Robots ....)			Simple-Fixture	Hand-held	None	
POINTS	0	3	6	9	12	15	
PROCESS Instructions	OEM	Whole-Day	Half-Day	(60-30 min)	(30-5 min)	Obvious	
POINTS	0	3	6	9	12	15	
Hazard Tools	Fully-Covered.......)		Fire Proof	Face Mask	Gloves	None	
POINTS	0	1	2	3	4	5	
					DEI Score		

Figure 4.1 Disassembly Effort Index Metrics of Processes

4.2 Non-Destructive Disassembly

4.2.1 Magnetic Separation.

Definition: Magnetic separation is a disassembly process, which involves the use of permanent magnets or electromagnets to separate and disassemble components that are magnetically sensitive.

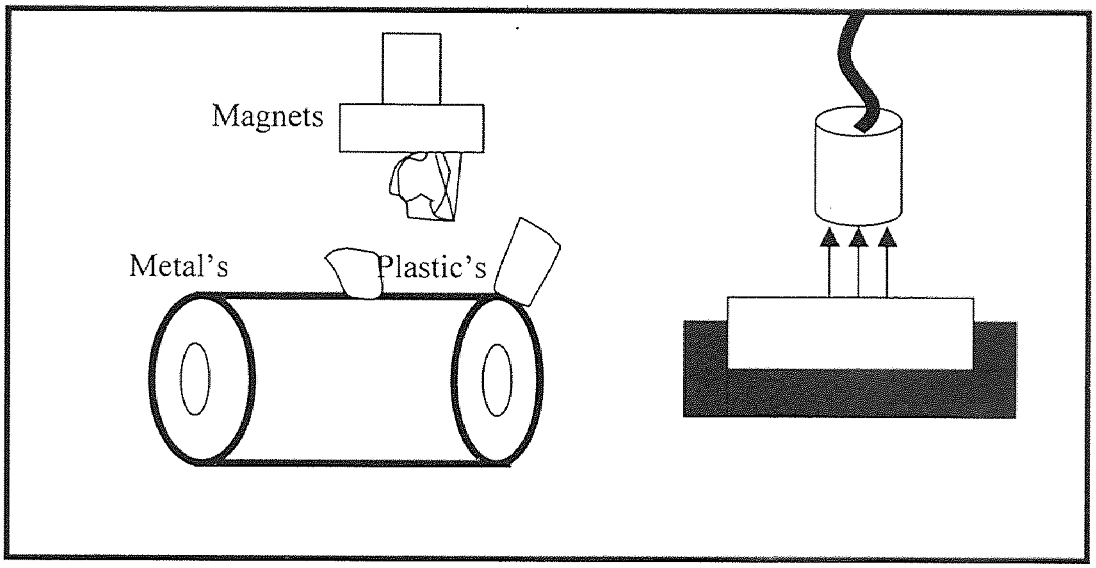


Figure 4.2 Magnetic Separation

Process Variables: The process variables are the weight of the material that needs to be separated, the permeability of the material, the separation distance (i.e. the distance between the magnet and the component that needs to be separated) and the force necessary to lift the weight of the component. Magnetic field intensity H, magnetic flux ϕ, and magnetic flux density B.

a) **Magnetic Flux ϕ:** is defined as the integral of the flux density over some surface area. For simplified case of magnetic flux lines perpendicular to a cross sectional area A, The units of flux is Weber, and is given by,

$$\phi = \int_{0}^{A} B\, dA$$

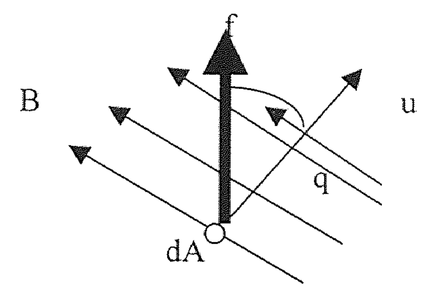


Figure 4.3 Flux Density

where B is the magnetic flux density in units of Weber per meter square(Wb/m^2) and (da) is the small perpendicular cross-sectional area also the vector component force is given by:

$$f = B\, q \frac{du}{dt} \sin \upsilon$$

Where (q) is a charge moving at a velocity (du/dt) in the presence of a magnetic

field with flux density (B), where (θ) is the angle between the vector force

component (f) and the velocity (du/dt).

b) **Permeability** μ: To define the behavior of magnetic materials or to differentiate materials that are magnetic or non magnetic or para-magnetic, a scalar constant called Permeability μ is used, this is generally constant for a material.

$$\mu = \mu_r \mu_o$$

Where μ_o is the permeability of free space and the μ_r is the relative permeability which represents a measure of the magnetic property of the material.

The relative permeability μ_r for common materials are:

Table 4.1 Relative Permeability of materials

Material	μ_r
Air	1
Permalloy	100,000
Cast Steel	1000
Sheet Steel	4000
Iron	5,195

c) Magnetic Field Intensity H :This is defined as the ration of the magnetic flux intensity to permeability which is given by Amps/meter A/m :

$$H = \frac{B}{\mu}$$

Tools: The tools are permanent magnets, electromagnets, conveyor belts and material handling devices.

Score Description: The DEIM of Magnetic Separation is 79, the time it takes to separate a component depends on the rate at which the conveyor moves or the time it takes the magnet to position itself to attract the metal piece. In the analysis the time is given a range between 60-5 seconds thus giving it a score of 23. Not many tools required to separate the parts because the magnet does the work, occasionally some intervention is needed thus the range is between Mechanic to No –Tools,giving it a score 18. The Force (Human) is zero as not much of human effort is needed. The Force that is generated by the magnet is generally strong enough to separate the part , the force is generally between 125 –100 lbs. It gets a linear score of 3. Magnetic Separation is an obvious separation not much of instruction is necessary unless there are some difficult situations are encountered, it gets a score of 14. Hazard tools are generally gloves or hard helmets thus it gets a score of 3.5.

4.2.2 Suction and Drainage

Definition: Suction and drainage is one method of disassembly process,Wherein fluids and liquids are drained from their containers to assist further disassembly.

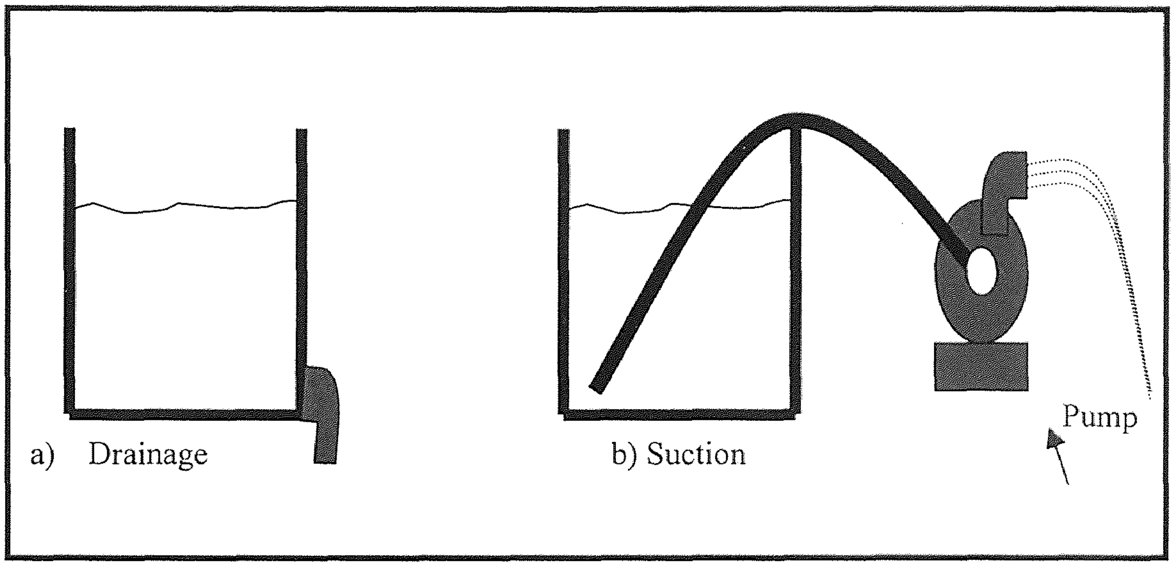


Figure 4.4 Suction and Drainage

Process Variables: This form of disassembly process involves removal of oils, acids, water, coolants, mercury and other liquids like solder etc, so as to assist disassembly. The process variables of this form of disassembly process are

a) pH .

b) Kinematic Viscosity of the fluid.

c) Specific Gravity.

d) Speed Discharge HorsePower of the pump.

a)**pH:** The pH of a liquid is important since it helps us deciding the type of pump, the piping, the container into which the liquid needs to be drained. The pH is defined as the negative logarithm of the hydrogen ion concentration of liquids, the lower the pH the higher is the acidity of the liquid. The pH of water is 7.

b)**Kinematic Coefficient of Viscosity of the fluid**: The viscosity of a fluid is that property which determines the amount of its resistance to a shearing force. Viscosity is due primarily interaction between fluid molecules. The Kinematic coefficient of viscosity is defined as:

$$\text{Kinematic Coefficient } (\upsilon) = \frac{\text{absolute viscosity } (\mu)}{\text{mass density } (\rho)}$$

The units of viscosity are ft^2 /sec.

c)**Specific Gravity:** The specific gravity of a body is that pure number which denotes the ratio of the weight of a body to the weight of an equal volume of water which is taken as standard.The specific gravity of water is 1.00 and of mercury is 13.57.

d)**Speed, Discharge, Horse power of the pump:** The unit speed is defined as the speed of a geometrically similar (homologous) rotating element having a diameter of 1 in., operating under a head (H of 1 ft). This unit speed (N_u in rpm) is usually expressed in terms of (D_1 in inches)and (N in rpm). Thus:

$$N_\mu = \frac{D_1 N}{\sqrt{H}}$$

also the discharge relationship is expressed as :

$$\frac{\text{discharge } Q \text{ (cfs)}}{(\text{diameter } D \text{ (ft)})^2 \sqrt{\text{head } H \text{ (ft)}}} = C_a$$

also,

$$Q = C_a D^2 \sqrt{H}$$

The coefficient (C_a) is expressed in terms of (gpm) flow units.

The speed of the impeller, which is necessary to determine the horsepower of the motor

$$\frac{\text{diameter } D\ (\text{ft}) \times \text{speed } N\ (\text{rpm})}{\sqrt{g \times \text{head } H\ (\text{ft})}} = C'_N$$

is.

In which the g gravity component is incorporated in the C'_N

The power relation , obtained by using values of (Q) and (H) above

We get

$$\text{Horsepower } P = \frac{wQH}{550\,e}$$

Tools: The tools that are needed for this disassembly process is Pumps, Piping, Wrenches, Pressure Gages, and Containers to handle the waste.

Score Description: The analysis of Suction and Drainage depends on the liquid that is being drained or sucked out it could be mercury or oils or melted solder. The weighted average of Suction and Drainage , when melted solder taken into case is 81.5, the time it takes to drain melted solder is generally between 60-5 seconds the score then is 24, the tools that are necessary are special or original equipment since it's an unusual operation. It gets a score of 10 since it's between special and OEM. The human force is not taken into consideration as the suction (force) is generated by the pump thus the score is 20 since the score is less than 100 lbs. Because of the resolution on the scale it is approximated. The suction hose is usually held by hand thus it gets a score 0f 11 generally between 9-12.Process instructions are obvious unless some thing is complicated thus giving it a score of 13. The protection that is needed is facemask and gloves thus giving it a score of 3.5.

4.2.3 Separation of a Fastened Part

Definition: This involves the removal of parts or separation of two mating surfaces (parts) from one another, before the fastener has been removed or disengaged .

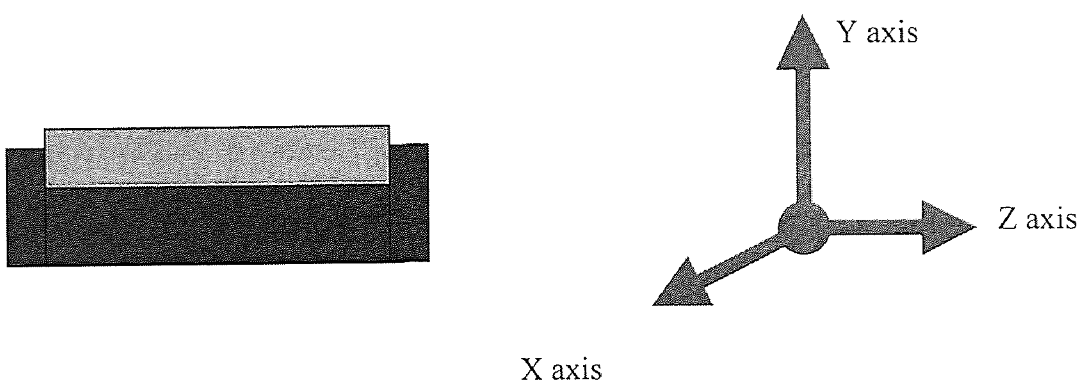
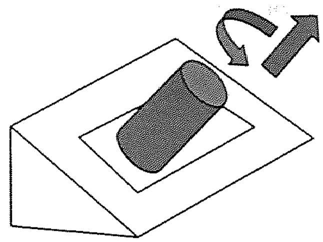


Figure 4.5 Single Motion Separation

Single Motion Separation :This type of separation involves the removal of the part in either of x , y or z direction . This is the simplest form of separation.



4.6 Multi Motion Separation

Multi Motion Separation: Multi motion Separation involves dual motion separation which involves both twisting (torque) and pulling (linear force) and angular separation.

Process Variables : The Process Variables that need to be considered are

a) Forces.

b) Fixturing.

c) Effort.

a) **Forces:** There are four kinds of forces that need to be considered while separation that involves the above three kinds of separation as illustrated above are

a) **Linear:** Linear forces include push and pull kinds of forces at times we can also include light impact forces which are also linear.

b) **Torsional Forces:** Twisting involves parts that need to be rotated to unseat them the torque required to unseat the part depend on the size of the part and the frictional forces that need to be overcome.

c) **Leveraging:** When parts are sitting in another part then we need to leverage them out even after the fastener has been removed ,as shown in the complex motion separation.

d) **Vibrations:** Vibration again comes under complex motion separation it actually involves a continuous force that is sinusoidal which could involve linear or torsional forces.

b)Fixturing: The parts or the components that need to be separated from one another at times need to be fixed or gripped .The parameters are

a) **No Fixturing:** When we use hands to separate them.

b) **Normal Fixturing:** Using hand held vices or bench vice etc.

c) **Complex Fixturing:** This includes Special types of vices and robotic grippers.

c)Tools: Screw Drivers , Vices ,Grippers ,Mechanized Tools(Power Screw Drivers)

Score Description: The Time that takes to break a fastened part is between 100 seconds to >300 seconds for normal component. This gets a low score not because of the actual separation time but because of the setup time that is necessary. The score is 7.50. The resolution Equipment –Tools, for the separation of a fastened part lies between Mechanic to Unavailable. The actual tools that are needed for the separation are situational so its difficult for us to define them specifically so it gets a score of 10.00.

To break the fastened part the necessary force would be between 125 lbs. - >250 lbs. These forces are the cutting forces needed and generated by the Shears, Cutters, Impact Hammers to break the part and the fastener ,the score is 11.50.Part Hold is a dependent variable since it contributes to the effort evaluation both in Time and Equipment-Tools .This is classified as None ,Hand Held ,Simple Fixture (like bench vice ,hand held vice or chains etc) and Material Handling Equipment's and

Robots (These include robots and mechanical hands and Heavy duty and Special fixtures to hold the component when it's being disassembled) .

In the evaluation for separation of an fastened part breakage, the resolution is between Robot's- None. The score is 10.50. These days dissemblers face a lot of problems because of the varieties and complexities of products that are disassembled ,apart from this there are Environmental Laws that need to be followed .So, the work force needs to be trained accordingly this again is a dependent variable with respect to time. The classification is between Obvious (where the workers can himself figure out the disassembling approach without any other's involvement) – OEM (Where the Original Equipment Manufacturers themselves give the disassembly methodology).The resolution for weld breakage is between Obvious to Whole Day . Score 12.00. The workers need to be protected when they are handling complex components , or hazardous materials or tools . So we give a higher score when None (when its easy to disassemble without any covering or protection) otherwise the resolutions are Fully Covered ,Fire Proof Clothing ,Face Mask Gloves . For separation of an unfastened part the resolution is from None to Gloves since the breaking is not hazardous in our analysis. The score 4.50 . Thus the weighted score is 56.00

4.2.4 Separation of an Unfastened Part

Definition: This involves the removal of parts or separation of two mating surfaces (parts) from one another, before the fastener has been removed or disengaged (integral fasteners).

Single Axis Separation: This type of separation involves the removal of the part in either of x , y or z direction . This is the simplest form of separation.

Multi-Motion Separation:

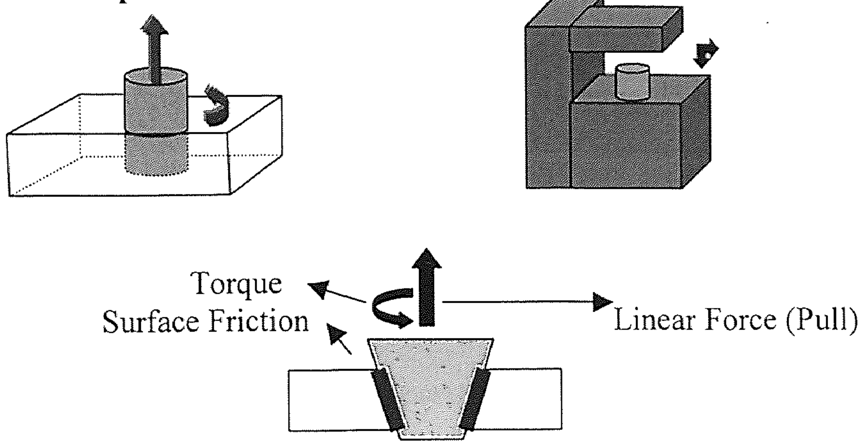
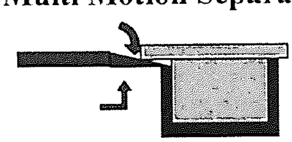


Figure 4.7 Complex Multi Motion separation.

Multi motion Separation: This involves dual motion separation, which involves both twisting (torque) and pulling (linear force).

Assisted Multi Motion Separation:



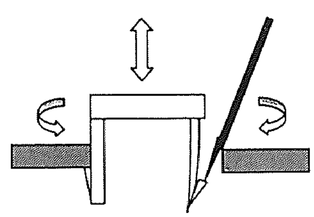


Figure 4.8 Assisted Multi Motion Separation

Assisted Multi Motion Separation: When more then two types of forces are used to separate after the fastener has been removed e.g. Separation of snap fits or integral fasteners.

Process Variables: The Process Variables that need to be considered are

a) Forces

b) Fixturing

c) Effort

Forces: There are four kinds of forces that need to be considered while separation that involves the above three kinds of separation as illustrated above are.

Linear Forces: Linear forces include push and pull kinds of forces at times we can also include light impact forces which are also linear.

Torsional Forces: Twisting involves parts that need to be rotated to unseat them the torque required to unseat the part depend on the size of the part and the frictional forces that need to be overcome.

Leveraging: When parts are sitting in another part then we need to leverage them out even after the fastener has been removed ,as shown in the complex assisted motion separation.

Vibrations: Vibration again comes under complex motion separation it actually involves a continuous force that is sinusoidal which could involve linear or torsional forces.

b) **Fixturing:**The parts or the components that need to be separated from one another at times need to be fixed or gripped .The parameters are

No Fixturing: When we use hands to separate them.

Normal Fixturing : Using hand held vices or bench vice etc.

Complex Fixturing: This includes Special types of vices and robotic grippers.

a) **Tools:** Screw Drivers , Vices ,Grippers ,Mechanized Tools(Power Screw Drivers).

Score Description: The time it takes to separate an unfastened part is between 150-60 seconds depending on the way it is anchored. The score it gets is 15. The tool's that are needed to separate an unfastened part are usually between OEM to Mechanic tools because the part needs to be pulled or yanked out, the score is 14.The force that is needed to separate the part is between 50-40 so it gets a score of 2. The part hold depends on the size of the part that needs to be removed or separated thus it gets a score of 9 since simple fixtures are necessary to hold the part. Process instructions are needed when the part becomes complicated and the time for process instruction is between 30-5 but usually less than that thus it gets a score of 12. The hazard tools are gloves thus getting a score of 4.00. The weighted score is 56.

4.2.5 Self-Removal

Definition: This kind of separation essentially involves secondary separation i.e. when a part just falls off when the covering / adjacent part is removed ,this kind of separation is seen when gaskets fall off when the abutting part is removed or floating balls of the bearings fall off when the cones or supporting members are removed. This is seen when Y axis separation is performed the parts fall off due to gravity.

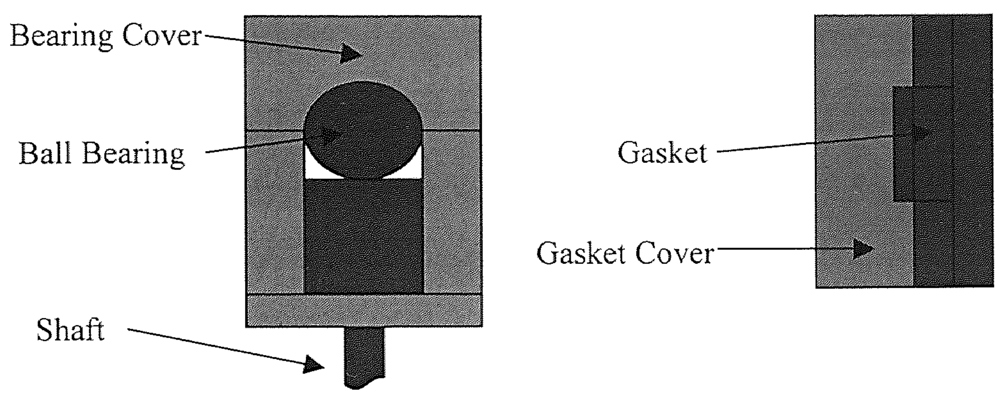


Figure 4.9 Self Removal (Bearings and Gasket)

Process Variables: The Process Variables that need to be considered are

d) Forces

e) Fixturing

f) Effort

b) **Forces:**There are four kinds of forces that need to be considered while separation that involves the above three kinds of separation as illustrated above are.

Linear Forces: Linear forces include push and pull kinds of forces at times we can also include light impact forces which are also linear.

Torsional Forces: Twisting involves parts that need to be rotated to unseat them the torque required to unseat the part depend on the size of the part and the frictional forces that need to be overcome.

Leveraging: When parts are sitting in another part then we need to leverage them out even after the fastener has been removed ,as shown in the complex assisted motion separation.

Vibrations: Vibration again comes under complex motion separation it actually involves a continuous force that is sinusoidal which could involve linear or torsional forces.

b) Fixturing: The parts or the components that need to be separated from one another at times need to be fixed or gripped .The parameters are

No Fixturing: When we use hands to separate them.

Normal Fixturing : Using hand held vices or bench vice etc.

Complex Fixturing: This includes Special types of vices and robotic grippers.

c) Tools: Screw Drivers , Vices ,Grippers ,Mechanized Tools(Power Screw Drivers).

Score Description: Time that takes to evaluate Self Removal is easy since it's a secondary or probably tertiary separation since the part just falls off when a covering or abutting part is removed so specifically evaluating the resolution would be between 10 – 60 seconds. So this gets a very high score of 22.50 since the part just falls off. The Equipment and tools are classified as Unavailable, Heavy Duty, Special, OEM, Mechanic, None is when human hands are used to separate the component. The resolution for Self Removal lies between None – Mechanic. In most cases the part just falls of due to gravity or minimal usage of Equipment. Again it gets a high score of 18.00

The Forces that are needed for separation are generally between the range of 2 – 10 lbs. Since it's a secondary or tertiary separation it gets a score of 18.00. Part Hold is a dependent variable since it contributes to the effort evaluation both in Time and Equipment-Tools. This is classified as None, Hand Held, Simple Fixture (like bench vice, hand held vice or chains etc) and Material Handling Equipment's and Robots (These include robots and mechanical hands and Heavy duty and Special fixtures to hold the component when it's being disassembled) .In our evaluation the range would be between Hand-held- None. Since we just need little effort to disengage the part which is possible by hand. The score would be 18.00.

Process Instructions, these days dissemblers face a lot of problems because of the varieties and complexities of products that are disassembled ,apart from this there are Environmental Laws that need to be followed .So, the work force needs to be trained accordingly this again is a dependent variable with respect to time. The classification is between Obvious (where the workers can himself figure out the disassembling approach without any other's involvement) – OEM (Where the Original Equipment Manufacturers themselves give the disassembly methodology). The resolution for Self Removal is between Obvious to 30 –5 min . Thus we get a score of 13.50

Hazard, the workers need to be protected when they are handling complex components, or hazardous materials or tools. So we give a higher score when None (when its easy to disassemble without any covering or protection) otherwise the resolutions are Fully Covered, Fire Proof Clothing, Face Mask Gloves. For Self Removal the resolution is from None to Gloves . The score is 4.50

The Weighted Disassembly Effort Index Score Average is 90.00

4.3 Destructive Disassembly

4.3.1 Weld Breakage

Definition: Welding is a materials joining process that produces the coalescence of Materials by heating them to welding temperature ,with or without the application of pressure or by the application of pressure alone ,and with or without the use of filler metal.

Process Variables: When we talk of Weld Disassembly we have to concentrate on weld breakage per se ,using the impact forces and linear forces so as to break the weld (assisted by the mechanical failure properties of a weld)

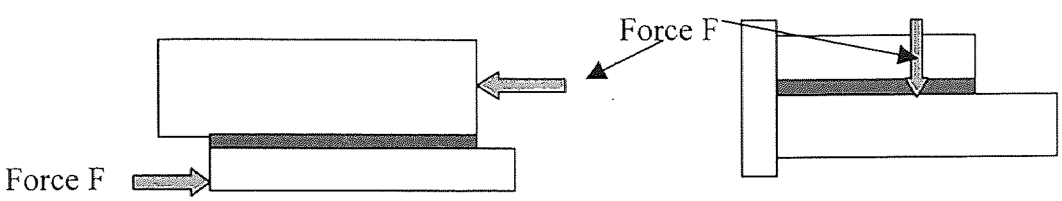


Figure 4.10 Weld Breakage

Figure 4.15 shows how, a weld can be demanufactured/disassembled/broken using the basic mechanical properties of the weld. In our study we noticed that welds can be broken easily when the weld is subjected to an **impact force** or subjected to an **continuous force** so as to cause a shear stress to accelerate the failure of the weld per se. To cause a shear stress break the weld, the forces must be applied to the weld as shown in the figure. We have discussed 2 approaches to break the same weld (fillet weld) either applying a force parallel to the weld in most cases or to apply a force that is perpendicular to the weld.

Typical weld joints are Butt Joint, Edge Joint, Lap Joint, Corner Joint. A Butt weld is used in connecting two members to transmit the full capacity of the smaller one. This is a full strength weld, since a butt weld has equal or greater strength than the mild steel plates being joined .The Corner, Edge, Lap and Tee joint can be broadly classified as a Fillet weld. The strength of a fillet weld is based on the effective throat thickness defined as the shortest distance from the root to the face of the diagrammatic weld. Therefore, for an equal leg (45 degrees) fillet weld the throat is 0.707 times the normal leg size of the weld

For us to break a weld or to disassemble a weld using the least effort, We have to understand the mechanics of the weld .The Strength of a weld depends upon the direction of the applied load, which may be parallel or transverse to the weld. Usually a weld fails in shear, but the plane of rupture is not the same. The weld will fail on the throat plane, which has the maximum shear stress.

The Welds can be classified according to the magnitude of the forces and also by the type of forces transmitted. They are Primary, Secondary, Transverse, Parallel.

As shown in this figure the weld can be broken per se when the joint or the weld is subjected to a parallel or transverse load. The strength (load) of a weld is determined as follows

Fillet Weld

Double Fillet Weld

Figure 4.11 Types of Weld

$$P1 = \tau\, lw(0.707) \quad [24]$$

P1= The Maximum Allowable load on the weld /linear inch

τ = Shear Stress in psi

l= length of the weld inches (We have considered it to be 1 inch for simplicity)

w= Thickness of the weld (leg) in inches

0.707 = cosine 45° (Shearing Angle)

(Ref :*Design of Welded Structural Connections** *by Omer W. Blodgett & Jhon B. Scalzi)*

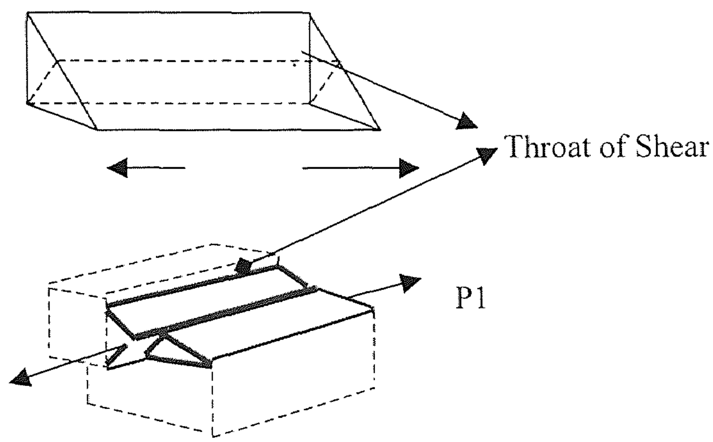


Figure 4.12 Weld Breakage Parameters

Tests also show that a fillet weld is 33% stronger when loaded Transversely as opposed to Parallel Loading . Welds loaded as shown indicated failure on a plane at 67.5 degrees to the horizontal .

The allowable load per inch based on the allowable unit shear stress is calculated as follows

$$P2 = \tau\, l w 1.08$$

P2= The Maximum allowable load in lbs./linear inch .

τ= Shear on throat lbs. /l inch.

l= Length of the weld in inches(We have considered it to be 1 inch for simplicity).

w = Leg width of the weld in inches.

1.08 = 1/ sin 67.5° (Shearing Angle).*

(Ref :*Design of Welded Structural Connections** *by Omer W. Blodgett & Jhon B. Scalzi)*

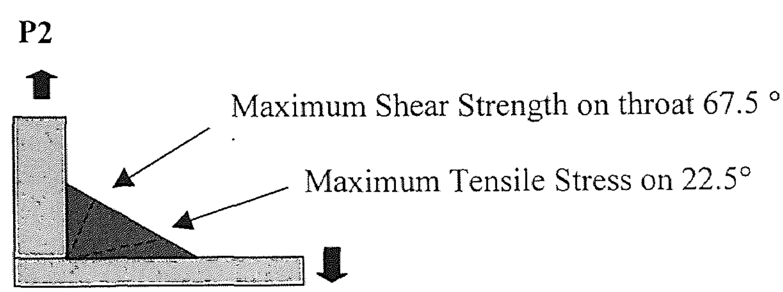


Figure 4.13 Weld Parameters

The Breaking Loads of metals that can be welded are

Table 4.2 Breaking Loads of Welds

Materials	P1 Pounds W=1"	P1 Pounds W= ½"	P1 Pounds W= ¼"	P2 Pounds W =1"	P2 Pounds W = ½"	P2 Pounds W = ¼"
Lead	352.46	176.23	88.115	535.73	268.92	134.28
Tin	456.12	228.06	114.03	693.30	348.01	173.78
Aluminum	1886.71	943.35	471.67	2867.79	1439.56	718.83
Gold	2467.23	1233.61	616.80	3750.19	1882.49	940.01
Silver	3358.76	1679.38	839.69	5105.31	2562.73	1279.68
Cast Iron	3628.29	1814.14	907.07	5515.00	2768.38	1382.37
Magnesium	3628.29	1814.14	907.07	5515.00	2768.38	1382.37
Zinc	3628.29	1814.14	907.07	5515.00	2768.38	1382.37
Copper	4810.07	2405.03	1202.51	7311.30	3670.08	1832.63
Bronze-Silicon	5826.00	2913.00	1456.50	8855.52	4445.23	2219.70
Iron-Wrought	5826.00	2913.00	1456.50	8855.52	4445.23	2219.70
Nickel	6696.00	3348.00	1674.00	10177.92	5109.04	2551.17
Tantalum	7277.30	3638.65	1819.32	11061.50	5552.58	2772.65
Copper-N	8002.97	4001.48	2000.74	12164.51	6106.26	3049.13
Everdur	8002.97	4001.48	2000.74	12164.51	6106.26	3049.13
Nickel Silver	8438.37	4219.18	2109.59	12826.32	6438.47	3215.01
Steel Low Carbon	8749.36	4374.68	2187.34	13299.03	6675.76	3333.50
Titanium	8749.36	4374.68	2187.34	13299.03	6675.76	3333.50
Brass	9039.63	4519.81	2259.90	13740.24	6897.23	3444.09
Bronze-Phosphor	9630.15	4815.07	2407.53	14637.83	7347.80	3669.08
Monel	10926.3	5463.17	2731.58	16608.04	8336.79	4162.93
Steel Low Alloy	10926.3	5463.17	2731.58	16608.04	8336.79	4162.93
Stainless Steel (Ferritic)	10926.3	5463.17	2731.58	16608.04	8336.79	4162.93
Bronze (Alum)	11071.4	5535.73	2767.86	16828.63	8447.53	4218.23
Inconel	12377.6	6188.82	3094.41	18814.03	9444.14	4715.88
Steel(MedCarbon	12688.6	6344.32	3172.16	19286.75	9681.44	4834.37
Stainless Steel (Austentic)	13103.3	6551.65	3275.82	19917.03	9997.82	4992.36
Stainless Steel (Matensitic)	14575.3	7287.68	3643.84	22154.55	11121.0	5553.21
Steel-Manganese	17187.7	8593.86	4296.93	26125.35	13114.2	6548.52
Steel(HiCarbon)	20401.3	10200.6	5100.34	31010.07	15566.2	7772.91
Tungsten	72793.9	36396.9	18198.48	110646.7	55541.7	27734.4

Thus we can disassemble a weld joint without using cutting tools by applying a force to the weld .This study has been done for one fillet weld for a T joint or a double Lap joint we have to multiply the force factor by 2.

Tools : The Tools that can be used to break a weld are

1) Hammer (5 l bs, 10 lbs ,20 lbs).

2) Chisels.

3) Compressed Air Hammers.

Score Description: Weld Breakage is a time consuming activity , the weld joint could be separated by cutting , grinding or heating using oxy-acetylene flame. In the analysis the weld breakage is analyzed using the fracture failure of the weld using the weld shear properties the time it takes to break the weld is generally between 225-100 seconds thus it gets a score of 10 . The tools that are necessary to separate the weld are Heavy duty because of the forces that are involved in breaking the weld thus it gets a score of 4. The force that is needed to break a weld as calculated in the table depends on the type of material needs to be broken thus it gets a score of 4 since the range is generally between 250 ->300 lbs. The Welded Part needs to be fixed well since lot of forces are applied to the weld thus material handling equipment's and robotic arm are necessary to break the weld getting a score of 6. The weld breakage is done differently with different types of weld since the weld is broken using the shear properties of the weld the dissemblers need to be instructed so as to reduce the effort and effectively break the weld. The score is 12. The hazard tools are usually face masks and gloves thus getting a score of 3. The total weighted score is 39.

4.3.2 Impact Breakage

Definition : Impact Breakage defines destructive disassembly when the part that needs to be disassembled is broken down . Impact refers to those kinds of forces where the time intervals during which are quite small and usually indeterminate.

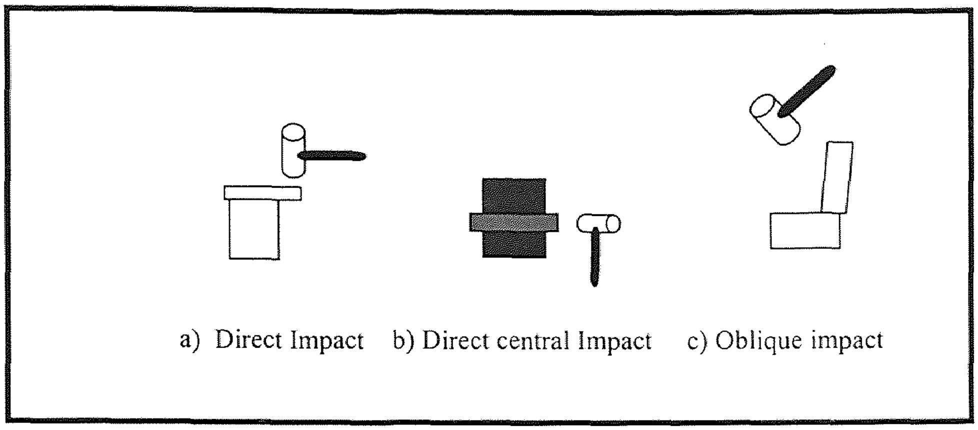


Figure 4.14 Impact Breakage

Process Variables: The Process variable are the types of impact , velocity of the tool, the mass of the tool.

The types of impact are:

Direct impact: Direct Impact Occurs when the tool and the part are perfectly along the line of impact.

Direct central impact: Direct central impact occurs when the mass centers of the part and the tool are along the line of impact.

Direct eccentric: This type of impact occurs when the initial velocity of the tool is normal to the striking surface of the part but not collinear.

Oblique Impact: This occurs when the initial velocity of the tool is not along the line of impact.

$$\sum F = \frac{dG}{dt} = m\frac{d(v-u)}{dt}$$

The Velocity of the breaking tool: The velocity of the tool is u before impact , the velocity after impact is v.The force generated by the tool equal to the rate of change of momentum.

F = The total Force generated by the tool is lb-ft/sec^{2}.

G= The momentum of the tool is lb-ft/sec.

m =mass of the tool .

v= final velocity of tool at the time of impact, ft/sec.

u= the initial velocity of the tool , ft/sec.

t= time in seconds.

The above formula is shown for straight line motion but of more general nature, when the impact is oblique , the normal components of the velocities are used in the above formula.

Tools: The tools are generally sledge hammers, pneumatic impact hammers.

Score Description: Impact Breakage depends on the type of material and the tool that is being used to break the part, the time it takes to break a component is generally between 150-100 seconds averaging a linear score of 17. Tools are again depend on the type of part that is being broken or separated it could be between Special to Mechanic giving it a score of 12. The force that is needed to break a part is usually 125 pounds /impact the linear score would be 16. Simple fixtures are needed to hold the part, to assist the dissemblers, linear score is 09. The Instruction that is needed to break the part again depends on the complexity of the part that needs to be disassembled ,the non-linear range would be (30-5 min) .The linear range would be 12. Face masks and Gloves are always used during destructive disassembly .The score is 03 .The total DEI score is 69.

Table 4.3 Disassembly Score of Disassembly Processes

Process	Time	Tools	Force Human	Force Machine	Part-Hold	Process Instruction	Hazard Tools	Final Score
Magnetic Separation	23	18	00	18	03	14	3.5	**79.5**
Suction & Drainage	24	10	00	20	11	13	3.5	**82.5**
Separation Fastened Part	15	10	00	11.50	10.5	12.0	4.0	**63**
Separation of Unfastened Part	15	14	02	00	09	12	4	**56**
Self Removal	22.5	18	18	00	18	13.5	4.5	**90**
Weld Breakage	10	04	00	04	06	12	03	**39**
Impact Breakage	17	12	00	16	09	12	03	**69**

The disassembly score defines the scoring pattern used to define each of the disassembly process and acts as a ready reckoner to evaluate each of the processes with respect to time ,tools force, parthold, process instruction and hazard tools.

CHAPTER 5

CONCLUSION

This chapter summarizes the results and conclusions of the entire research conducted in this thesis, the DEIM of a TV Monitor has been analyzed as an example and has a reference to the software that is being developed at the Design for Manufacturability Lab.

5.1 Development

The Disassembly Effort Index Calculator (DEI) is still in the development stage. The DEI Calculator is being programmed using Visual Basic 5.0 as a front-end tool and MS Access is used as a back end database. The software is used to calculate the Disassembly Effort Required to Demanufacture a component, and gives out quantitative scores which assist Demanufacturing. The Research that has been done in this thesis forms the base of the quantitative scoring pattern. The software also assists waste stream characterization and generates a tree which shows the Bill of Material and the mating relationships of each component with the fastener.

The DEI [figure 5.1] uses the Graphic User Interface (GUI) developed using Visual Basic 5.0 to input and retrieve data from the database. The data that is input from the first few screens are the Design Name , Design Number , Bill of Materials ,Mating Table and the Process plan. The DEI calculator generates the Mating Relationship, the Disassembly Tree and the Waste Stream Characterization of the Component. The Final out come of the DEI Calculator is the total Disassembly Effort Index Metrics of the Component ,which quantitatively decides the viability of Demanufacturing a component.

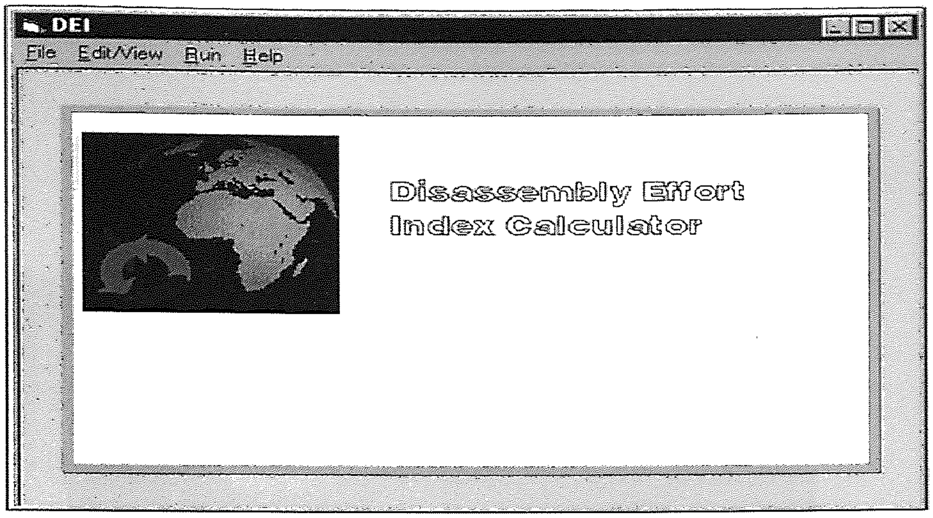


Figure 5.1 Disassembly Effort Index Calculator

The Bill of Material [figure 5.2] first asks /or shows the number of parts in the design and takes in the name of the part, the part description, material of the part or the fastener ,if the part is a fastener the number of fastener and the Bill of material ID. The BOM tab also shows the Data grid as the part is input or updated, edited or deleted.

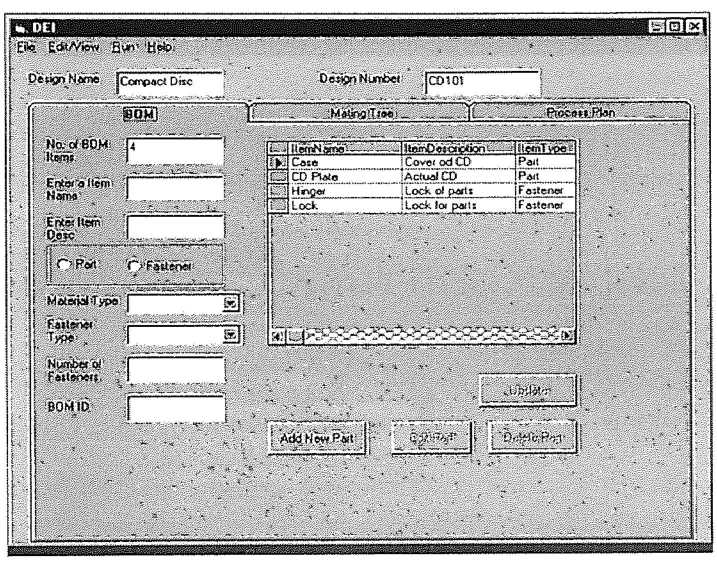


Figure 5.2 BOM tab

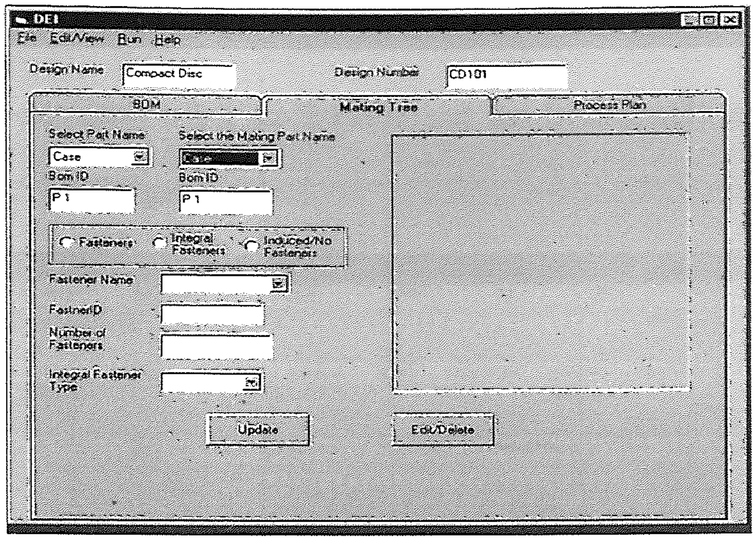


Figure 5.3 Mating Table tab

The Mating Table is used to generate the mating relationships of the components and the fasteners which join the components the Tree is also generated in the blank square as shown.

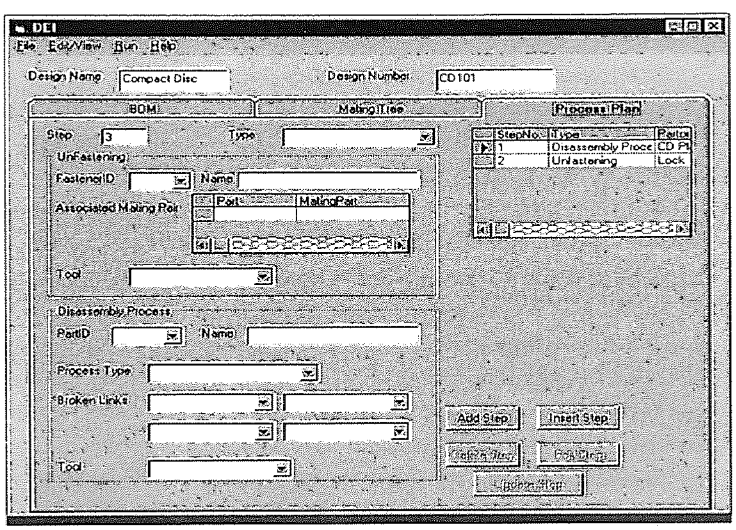


Figure 5.4 Process Plan tab

This screen describes the Process Plan required to demanufacture a component and then decide whether each of the steps is unfastening or disassembly.

The metrics is calculated using the fastener and the Disassembly process screen as shown in [figure 5.5 and figure 5.6.]

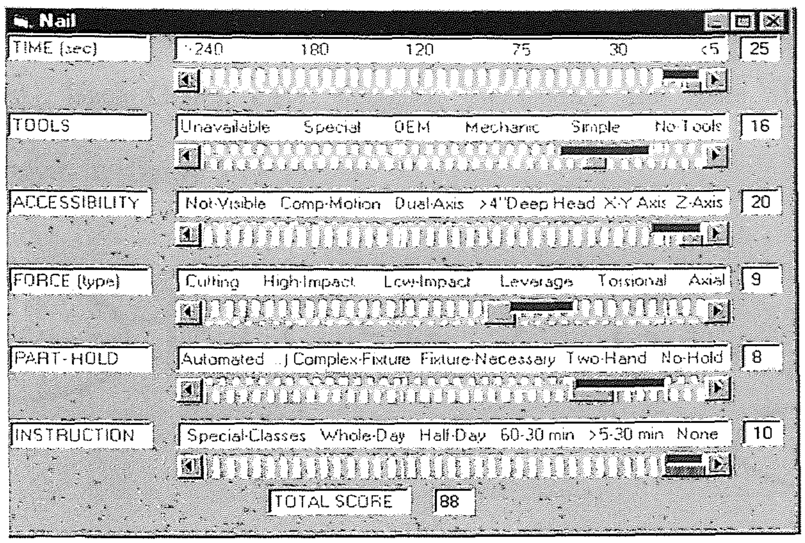


Figure 5.5 DEIM of Fastener

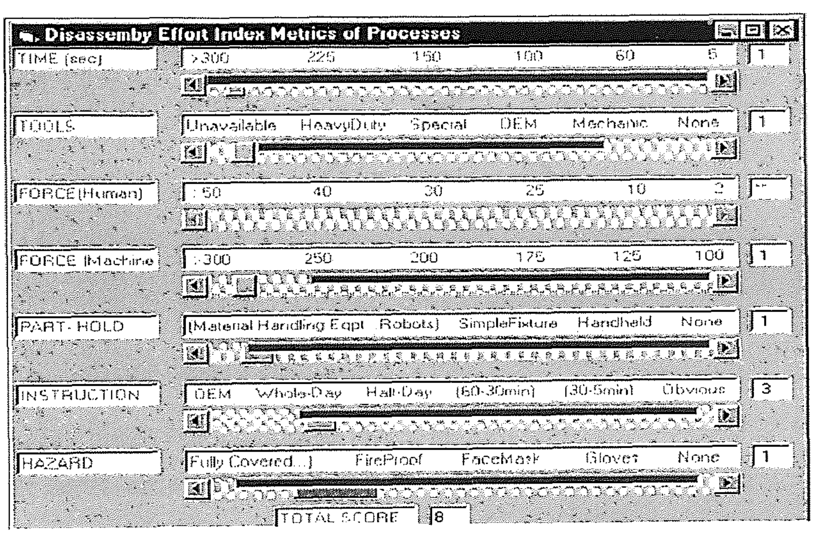


Figure 5.6 DEIM of Disassembly Processes

The scroll bar is used to select the required parameter of the unfastening or the disassembly process.

5.2 Example

The TV Monitor of a Sun Sparc 10 was disassembled and the Disassembly Effort Index of the Television was calculated the TV monitor consists of six main components they are Front cover , Back Cover, CRT, Chassis, Electronics and Base Slider. They are connected as shown in [figure 5.7]

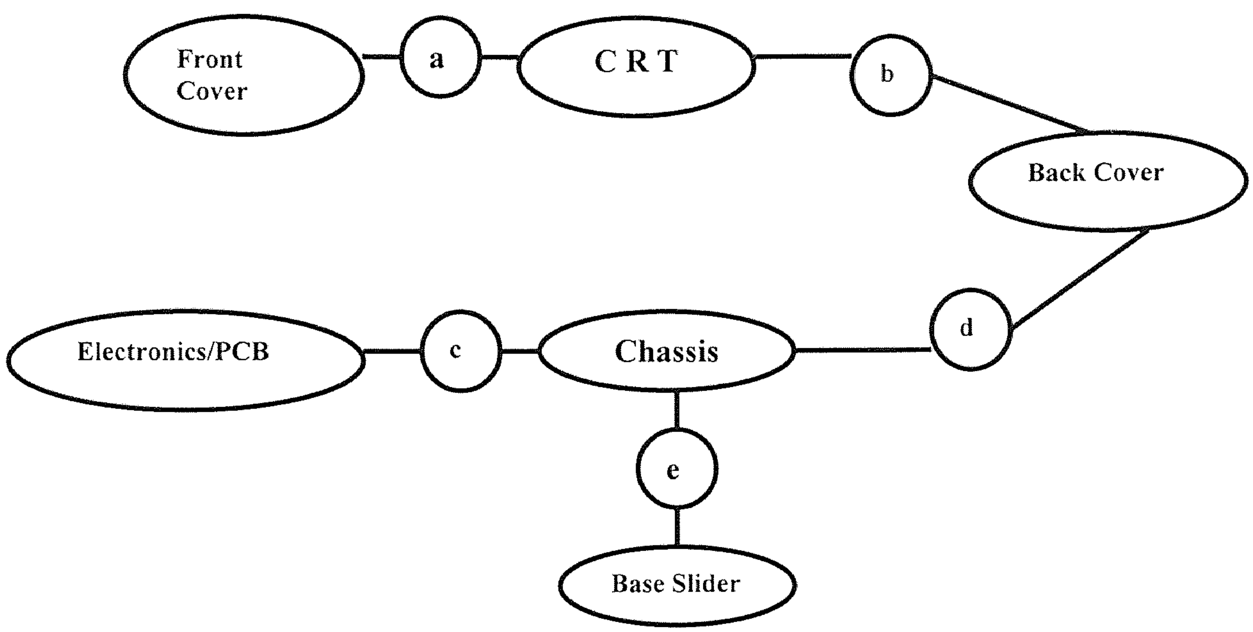


Figure 5.7 T V Monitor diagram

The fasteners are represented by the alphabets a, b, c, d and e.

a) 4, Philips Head ½" screw.

b) 4, Philips Head ¾ " Screw.

c) 6,Philips Head ¾" Screw.

d) 4, Philips Head ¾" Screw.

e) 2,Nuts & Bolts ½" Nut.

The chassis is a box structure and consists of 5 plates , left, right, top, bottom and back plate.

The DEIM Score of Fastener is as shown

Table 5.1 DEIM Score Card

Mating Part Relationship	Fastener ID	Fastener Type	Number Of Fastener	DEIM Score	Max Score
Front Cover & CRT	a	Philips Head ½"	4	372	400
Back Cover & CRT	b	Philips Head ¾"	4	372	400
Electronics/PCB & Chassis	c	Philips Head ¾"	6	558	600
Back Cover & Chassis	d	Philips Head ¾"	4	372	400
Chassis & Base Slider	e	Nuts & Bolt ½" (Hex)	2	116	200
				1790	2000

The DEIM score is 1790/2000 and the percentage effort evaluation is 89.5 % thus concluding the Disassembly is effortless and the disassembly is a viable one. This is evaluated with respect to the only Unfastening Effort .

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