PRODUCT DESIGN IMPROVEMENT THROUGH DESIGN FOR ASSEMBLY (DFA) AND THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ) METHODOLOGY

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ABSTRACT

The goal of this project is to improve product design of consumer product by integrating Boothroyd-Dewhurst Design for Assembly (DfA) methodology with a Russian Theory of Inventive Problem Solving (TRIZ). The outcome of previous research has shown integrating several design tools has improved the reliability and reduce cost of the product.

A consumer product was selected as a case study to evaluate the integration of both design tools. The Boothroyd-Dewhurst Design for Assembly Methodology (DfA) is used as a quantitative improvement tools. The powerful tool can reduce parts number of a product and is expressed in percentage. While, the Russian Theory of Inventive Problem Solving (TRIZ) is used to improve the design qualitatively.

The results show that the integration of these tools can be a very powerful design tool for product design engineers in reducing cost by eliminating unnecessary parts while improving the ease of user handling and reliability of the consumer product.

ABSTRAK

Matlamat projek ini adalah untuk meningkatkan reka bentuk produk pengguna dengan mengintegrasikan metodologi *Boothroyd-Dewhurst Design for Assembly* (DfA) dengan *Theory of Inventive Problem Solving* (TRIZ). Hasil penyelidikan sebelumnya telah menunjukkan integrasi beberapa alat reka bentuk telah meningkatkan kebolehpercayaan dan mengurangkan kos produk.

Satu produk pengguna telah dipilih sebagai kajian kes untuk menilai integrasi kedua-dua alat reka bentuk. Metodologi *Boothroyd-Dewhurst Design for Assembly* (DfA) digunakan sebagai alat penambahbaikan kuantitatif. Ia boleh mengurangkan bilangan bahagian produk dan dinyatakan dalam bentuk peratusan. Sementara itu, metodologi *Theory of Inventive Problem Solving* (TRIZ) digunakan untuk meningkatkan reka bentuk kualitatif.

Keputusan menunjukkan bahawa integrasi metodologi ini boleh menjadi satu alat reka bentuk yang sangat berguna untuk jurutera reka bentuk produk dalam mengurangkan kos dengan menghapuskan bahagian-bahagian yang tidak perlu serta meningkatkan dan memudahkan pengendalian pengguna dan kebolehpercayaan produk pengguna.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to the problem

The significant demands made on engineers to reduce assembly time, improve performance and reliability at a reduced cost requires the ability to improve the design of the existing product. It necessitates the improvement of the existing design to reduce the number of parts and ease of user handling. In addition, the improved design needs to be performing the same function or more with ease of assembly, reduce in cost and ease of handling. Some of the method that can be used to get this opportunity is by using DFMA and TRIZ.

DFMA and TRIZ share similar 'best practice' that allows systematic transfer to other generically similar situations. In DFMA, this knowledge of process has focused on manufacturing industry and the 'best practices' identified after intensive periods of assessing and analyzing what defines an efficient manufacture or assembly operation over one that is less efficient. The method presents this knowledge in terms of quantified metrics that enable a user to assess how long will series of given tasks will take, rules that enable the user to improve the system, and then quantify the level of that improvement.

In TRIZ, the knowledge base from which best practice has been extracted and comprises a substantial proportion of the world's most successful patents, taken from all fields of engineering endeavour. The main focus of TRIZ has been the creation of a systematic innovation capability.

1.2 Objective of the project

The objective of this project is to improve product design through Design for Manufacture and Assembly (DFMA) methodology and Theory of Inventive Problem Solving (TRIZ) approach.

1.3 Scope of the project

Scopes of this project are limited to:

i. Conduct patent search of related invention.
ii. Integration for improvement on mechanical part of a selected consumer product (fruit juicer extractor).
iii. Application of Boothroyd-Dewhurst Design for Assembly (DfA) methodology.
iv. Integrate the quantitative improvement by Boothroyd-Dewhurst DfA to qualitative improvement by Theory of Inventive Problem Solving (TRIZ).

1.4 Methodology of study

The methodology of study begins with literature review on both design tools DFMA and TRIZ. The scrutinized on the combination of these two tools on previous researches are also conducted to see the effectiveness of design improvement.

1.5 Significant of study

The research will be carried out within two semesters. Semester 1 (Master Project I – MP I) will focus on defining a problem statement, collecting and reading literature review on DfA and TRIZ, identify the product to study, and apply DfA method such as evaluate both original and improvement design part of the product.

Semester II (Master Project II – MP II) will focus on design evaluation, and design improvement using TRIZ method and also integration of DfA and TRIZ. The flow of this master project activity is shown in Figure 1.1.

The research finding shall be indispensable of improving the existing product design in terms of cost, minimize parts numbers and ease of handling. The capability of Boothroyd-Dewhurst DFMA methodology should help product design engineer to increase product design efficiency. Additional Theory Inventive Problem Solving (TRIZ) strategies should usefully deploy to qualitatively enhance Boothroyd Dewhurst DFMA capability.

With the application of DFMA and TRIZ methodology this research will benefits design engineering as a guide on how to apply this two powerful design tools for a more reliable and better functional products at a lower cost. This will indirectly benefit the consumer and the environments.

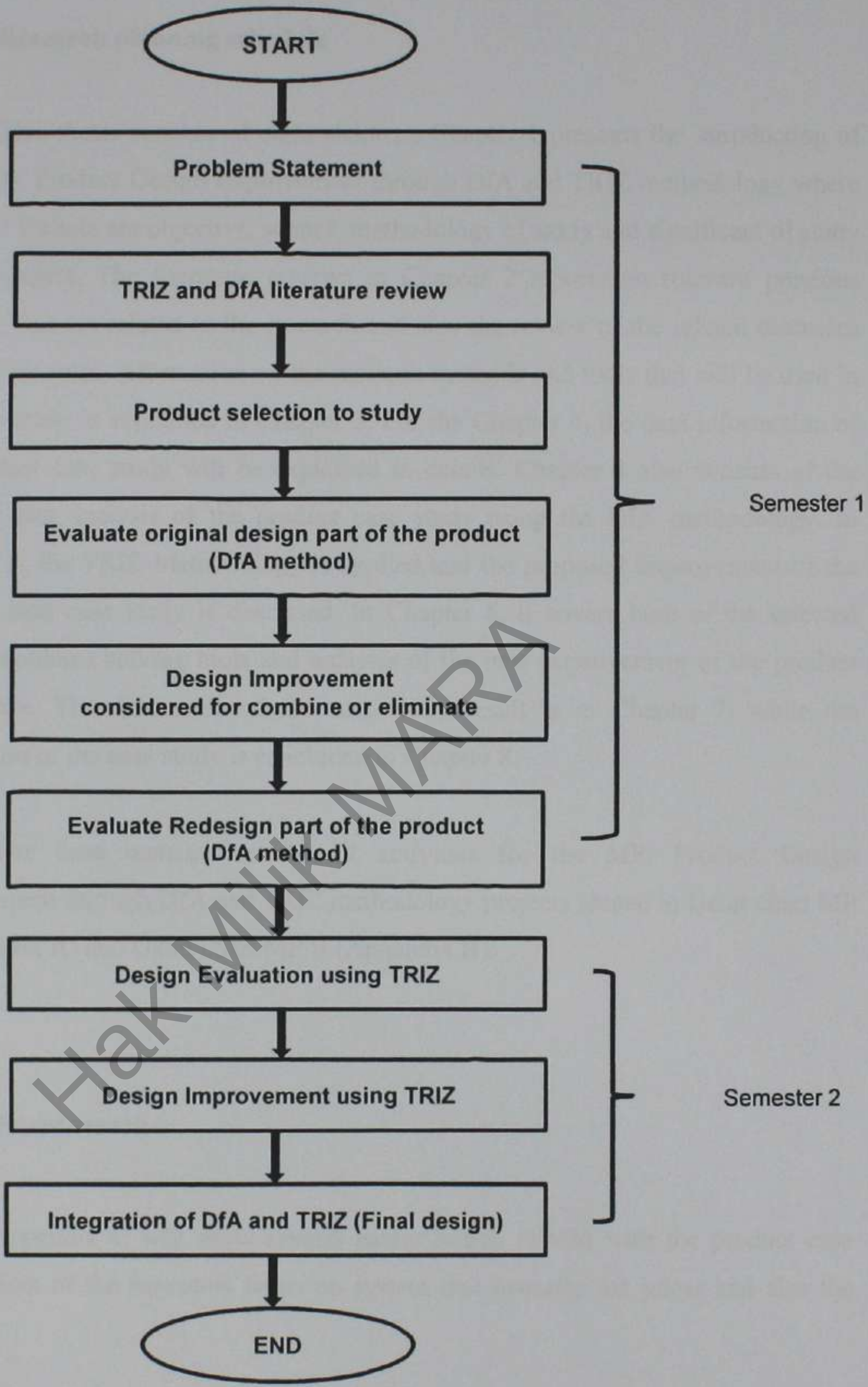

Figure 1.1: Flow chart of the project activities for MP 1 and MP 2.

1.6 Research planning schedule

This thesis consists of eight chapters. Chapter 1 presents the introduction of the thesis, Product Design Improvement through DfA and TRIZ methodology where the topic include are objective, scopes, methodology of study and significant of study of the project. The literature reviews in Chapter 2 reports on relevant previous findings that are related to the research and also the review of the related discusses topics. The detail information on the research methods and tools that will be used in the case study is explained in Chapter 3. For the Chapter 4, the data information of the product case study will be explained in details. Chapter 4 also consists of the original data analysis of the product case study using the DfA methodology. In Chapter 5, the TRIZ Methodology is applied and the proposed improvement of the original data case study is discussed. In Chapter 6, it covers both of the selected design problems solving tools and analysis of the new improvement of the product case study. The discussion of the case study result is in Chapter 7, while the conclusion of the case study is concluded in Chapter 8.

The time management of all activities for the MP, Product Design Improvement through DfA and TRIZ methodology projects shown in Gantt chart MP I (Appendix A) and Gantt chart MP II (Appendix B).

1.7 Patent search

Appendix C will show several patent search related with the product case study. Most of the inventors focus on system that operates the juicer and also the feature.

1.8 Summary

Through this thesis, the objective of the project is hopefully achieved as expected which is contained the important result such as success to improve design of the product case study by applying the selected methods and also develop a product that have maximize value, convenience, suitable and easy to use by the consumer. On the other hand, this chapter is providing information about the aim for the rest of the chapter

CHAPTER 2

LITERATURE REVIEW ON DESIGN FOR ASSEMBLY (DfA) AND THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

2.1 Introduction

This chapter discusses on basic principle of TRIZ and DfMA methodologies, and also example the application of the both tool in simplify and improving product design.

The integration of TRIZ and DfMA is studied and applied in order to show how product can be improved into a maximize value.

2.2 Design for manufacturing and assembly (DFMA)

DFMA stands for Design for Manufacture and Assembly. DFMA is the combination of two methodologies; Design for Manufacture, which means the design for ease of manufacture of the parts that will form a product, and Design for Assembly, which means the design of the product for ease of assembly.

DFMA is used as the basis for concurrent engineering studies to provide guidance to the design team in simplifying the product structure, to reduce manufacturing and assembly costs, and to quantify improvements. The practice of applying DFMA is to identify, quantify and eliminate waste or inefficiency in a product design.

2.2.1 Introduction to DFMA

DFMA is a proactive and concurrent design process that allows for early consideration of manufacturing aspects. The purpose is to generate an environment where a cross-functional team works together to optimize the design for cost effective manufacturing.

2.2.2 Basic Principle of DFMA

DFMA principles, when used properly, will allow parts to be machined easily and assemblies assembled efficiently. For the most part when these principles are adhered to, the resulting design will be more efficient in regards to materials and labour. Every principle may not be desirable in every application so care must be taken when deciding when to apply these principles.

i) Near net parts

This principle has to do with raw parts that will be processed. The basic premise behind this principle is to have the raw parts profile be as close to the finished parts profile as possible. The benefits are less processing, reduced tool wear, less scrap by product and less material in raw part.

This principle can be achieved in many ways. A part that is currently machined from a solid chunk of raw material can be either cast, forged, extruded, or moulded into a shape as close to the finished profile as the design will allow. Keep in mind that even in each of these categories some processes may be better than others.

For example an investment casting is able to be held to closer tolerances than a typical sand casting. Some machining processes may be able to be done away with because of this.

The benefits are great with this principle. Less processing of material is directly related to reduce labour. The reduced labour will decrease the cost of the finished part. Reduced labour will either allow you more through put in your current system of manufacturing or allow you to reduce your required resources. The reduced weight of the part has many benefits in that the freight to have part shipped will be reduced because of the lower weight. The operators will be handling lighter parts which will increase efficiency and reduce risk of injury. Since there will be less material to be removed tooling should therefore last longer and less scrap by product will be produced.

The ideal application of this DFMA principle would be to receive the raw material in a profile that would not require any secondary machining. Keep in mind that there may be up front cost that may need to be accounted for and that this principle will not make sense in all applications. For example low volume products may not be able to overcome the initial financial investment required.

ii) Standard parts

This principle is self-explanatory so I will not go to deep into it. Generally speaking it is advisable when purchasing to try to use standard products verses non-standard or special made to order ones when the design will allow. Typically they will cost less, and be more readily available than special parts. Also if your design changes and that part is no longer required, you will not be stuck with the non-standard or special made to order inventory.

iii) Liberal tolerances

There are two main factors for determining how stringent tolerances should be. The first is what the design requires to function properly. The second is what the manufacturing process will allow. Generally speaking the more liberal the tolerances on a part the easier it will be to hold the tolerances. So one should generally assign as liberal tolerances as the design and process allows. This will for the most part reduce the time that it takes to manufacture and check the part and may also reduce the amount of non-conforming parts.

iv) Reduce parts count

The premise behind this principle is that the fewer parts are in an assembly, the easier it should be to assemble. An assembly that is easier to assemble will also tend to have lower labour costs. Other advantages include fewer parts in inventory and fewer chances to make mistakes.

Reduction of parts can be achieved by either eliminating unneeded parts or combining multiple parts. An example of eliminating unneeded parts could be reducing the number of fasteners in a flange assembly by improving the grade of the fasteners.

v) Combination of parts

The advantage of this principle is the reduction of the number of parts through combining some of the assemblies' parts. An example of combining multiple parts could be to incorporate threaded holes into a casting to eliminate the need for a nut. Another example could be to replace a flat washer, split lock washer, and a nut with a serrated flanged lock nut. In this case the flange of the serrated flanged nut acts like the washer. The serrations perform the job of the split lock washer by deforming the base material and preventing the nut from loosening.

vi) Standardization of parts

Standardization of parts refers to using common parts on multiple designs. The benefit of this design principle includes possible reduction of the number of parts to inventory and increased volume for the resulting part. For example if design

"A" used a 1-1/4" long bolt, design "B" used a 1-1/2" long bolt and design "C" used a 1-3/4" bolt, standardize on the 1-1/2" long bolt for all three designs as long as the designs will allow it.

vii) Symmetrical parts

The concept of using symmetrical parts can eliminate the need for right and left hand versions of a part. The advantage to this principle is that it reduces the opportunity for mistakes and requires less attention to position parts at assembly. Both of which will reduce the amount of time at assembly.

viii) Self-featuring

The principle of self-featuring is based on the idea that parts would have tabs and pins that would align parts during assembly. These parts could be assembled with less effort and labour and reduced potential for errors.

ix) Easy handling

This one is fairly simple. Design your parts to be handled efficiently and safely. Avoid sharp edges that may cause injury to the people handling part. Design parts that can be easily stored. Avoid parts that can become wedged or entangled.

x) Mistake proof or Poka Yoke

By applying Poka Yoke principles, potential errors can be reduced to the point of being eliminated. There are two types of Poka Yoke. Informative poka yokes notify you when a condition exists that could lead to non-conforming parts. Preventative poka yokes eliminate the possibility of a defective part being passed down stream.

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2.3 Boothroyd-Dewhurst Methodology

Design for assembly (DFA) is a process by which products are designed with ease of assembly in mind. If a product contains fewer parts it will take less time to assemble, thereby reducing assembly costs. In addition, if the parts are provided with features which make it easier to grasp, move, orient and insert them, this will also reduce assembly time and assembly costs. The reduction of the number of parts in an assembly has the added benefit of generally reducing the total cost of parts in the assembly. This is usually where the major cost benefits of the application of design for assembly occur.

2.3.1 Design for Assembly (DfA) Evaluation

The Boothroyd Dewhurst method provides a quantitative measure called the ***design efficiency*** based on analysis of a product. The efficiency compares the total assembly time for a product with the total assembly time for an ***ideal product*** (determined by a method suggested by the authors). The efficiency can be used to compare various designs in terms of their relative efficiencies (for manual assembly).

The design improvement is brought about by two considerations (Boothroyd, G. 2002):

1. A decision is made as to whether the part can be considered a candidate for elimination, or combination with other parts of the assembly.
2. An estimation of the time taken to grasp, manipulate, and insert the part.

The procedure:

STEP 1. Obtain design details

Engineering drawings, or Exploded 3-D views, or Existing product, or Prototype

STEP 2. Take assembly apart (or imagine doing so) -- assigning identification to each part as it is removed.

Consider sub-assemblies as parts, and analyse them separately (recursively).

STEP 3. Begin re-assembly of the product. Start with the part with the highest identification number, going all the way up to the part 1.

STEP 4. Compute the design efficiency, given as:

$$EM = 3 \times NM / TM$$

(Boothroyd, 2002)

One of the key features of the Boothroyd-Dewhurst method is estimation of the ideal product -- which translates to the method of filling up column 9 in the chart as shown in Table 2.1. They give the following guidelines:

Rule 1. During operation of the product, does the part move relative to all other parts already assembled?

Rule 2. Must the part be of a different material than the parts already assembled? [Only fundamental reasons associated with material properties are acceptable.]

Rule 3. Must the part be separate from all parts already assembled (because otherwise necessary assembly/disassembly of other parts would be impossible)?

If the answer to any of these questions is YES, a 1 is entered in column 9 (except if there are multiple parts in column 2, in which case the minimum number of separate parts required is entered in column 9.)

Table 2.1: Table for computation of Design efficiency

c1	c2	c3	c4	c5	c6	c7	c8	c9	Name of Assembly
Part ID	No of times the operation is carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	manual insertion time per part	Operation time c2(c4 + c6)	Operation cost 0.4 c7	Estimation for theoretical minimum parts	
Total:									**Design efficiency =**
						TM	**CM**	NM	*3 NM/TM =*

(Boothroyd, 2002)

2.4 TRIZ

Theory of Inventive Problem-Solving (TRIZ) is a unique knowledge-based methodology, for accelerated development of design concepts. TRIZ is a creative problem-solving methodology especially tailored for scientific and engineering problems.

2.4.1 Introduction to TRIZ

"TRIZ" is acronym for "Teoriya **R**esheniya **I**zobretatelskikh **Z**adatch" in Russian or also best known as "Theory of Inventive Problem Solving" or TIPS". TRIZ was developed by Genrich Altshuller and his colleagues in the former USSR starting in 1946.

TRIZ aims to create an algorithmic approach to the invention and enhancement of systems.

TRIZ is a problem solving method based on logic and data, but not intuition. It has the ability to solve the problems creatively. TRIZ also provides repeatability, predictability, and reliability due to its structure and algorithmic approach.
The three primary findings are as follows:

1. Problems and solutions are repeated across industries and sciences. By classifying the "contradictions" in each problem, you can predict good creative solutions to that problem.
2. Patterns of technical evolution tend to be repeated across industries and sciences.
3. Creative innovations often use scientific effects outside the field where they were developed.

TRIZ offers users access to the knowledge and experiences of the world's finest inventive minds. It is intended to complement and add structure to our natural creativity rather than replace it.

TRIZ can be used in a number of different ways. An overall process enables users to systematically define and then solve any given problem or opportunity situation. Some users will rigorously apply this process. Others are happier extracting individual elements from the overall structure and using those. Although TRIZ are easily the most exhaustive creativity aid ever assembled, it inevitably contains gaps and holes. In keeping with TRIZ philosophy, TRIZ researchers are actively looking outside TRIZ at the best of creativity practice from all disciplines and integrating them together into a seamless whole. The overall aim of TRIZ has been to construct a problem definition and solving process that works for any situation users may care to throw at it – whether that be technical, simple or complex, highly constrained or clean-sheet, step change innovation or incremental improvement, or focused on products, processes or service. TRIZ effectively strips away all boundaries between different scientific, engineering and creative disciplines and its effectiveness has been proved across a broad spectrum of fields and problem types.

2.4.2 Basic Principle of TRIZ

The "forty principles" of TRIZ are basic engineering parameters of common objects, such as weight, length, and manufacturing tolerances. TRIZ methodology claims that by studying an individual parameter which is causing a problem (e.g., the weight of an object needs to be reduced), and the other parameters which are in conflict with it (e.g., lower weight would require thinner material, which is more likely to undergo catastrophic failure if overstressed), engineering solutions can be created for invention. (Kai Yang, Design for Six Sigma - A Roadmap for Product Development, 2003).

Each of the 40 principles contains a few subprinciples, totaling up to 86 subprinciples. It should be noted that the 40 principles are formulated in a general way. If, for example, the contradiction table recommends principle 30, "flexible shell and thin films," the solution of the problem relates somehow to change the degree of flexibility or adaptability of a technical system being modified.

2.4.3 40 principles for Reference (Altshuller 2002)

***Principle 1**: Segmentation*

- Divide an object into independent parts.
- Make an object easy to disassemble.
- Increase the degree of fragmentation (or segmentation) of an object.

***Principle 2:** Taking out.* Separate an "interfering" part (or property) from an object, or single out the only necessary part (or property) of an object.

***Principle 3**: Local quality*

- Change an object's structure from uniform to nonuniform, or change an external environment (or external influence) from uniform to nonuniform.

- Make each part of an object function in conditions most suitable for its operation.
- Make each part of an object fulfill different and useful functions.

***Principle 4**: Asymmetry*

- Change the shape of an object from symmetric to asymmetric.
- If an object is asymmetric, increase its degree of asymmetry.

***Principle 5**: Merging*

- Bring closer together (or merge) identical or similar objects; assemble identical or similar parts to perform parallel operations.
- Make operations contiguous or parallel, and bring them together in time.

***Principle 6**: Universality.* Make a part or object perform multiple functions, to eliminate the need for other parts.

***Principle 7**: "Nested doll"*

- Place each object, in turn, inside another, larger object.
- Make one part pass through a cavity in the other part.

***Principle 8**: Antiweight*

- To compensate for the weight of an object, merge it with other objects that provide lift.
- To compensate for the weight of an object, make it interact with the environment (e.g., use aerodynamic, hydrodynamic, buoyancy, and other forces).

***Principle 9:** Preliminary antiaction*

- If it will be necessary to perform an action with both harmful and useful effects, this action should be replaced later with antiactions to control harmful effects.
- Create stresses in an object that will oppose known undesirable working stresses later on.

Principle 10: Preliminary action

- Perform, before it is needed, the required modification of an object (either fully or partially).
- Prearrange objects in such a way that they can perform their intended actions expeditiously from the most convenient position.

Principle 11: Beforehand cushioning. Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

Principle 12: Equipotentiality. In a potential field, limit position changes (e.g., change operating conditions to eliminate the need to raise or lower objects in a gravity field).

Principle 13: "The other way around"

- Invert the action(s) used to solve the problem (e.g., instead of cooling an object, heat it).
- Make movable parts (or the external environment) fixed, and fixed parts movable.
- Turn the object (or process) upside-down.

Principle 14: Spheroidality

- Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones, moving from flat surfaces to spherical ones, or from parts shaped as a cube (parallelepiped) to ball-shaped structures.
- Use rollers, balls, spirals, and/or domes.
- Go from linear to rotary motion, using centrifugal force.

Principle 15: Dynamics

- Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
- Divide an object into parts capable of movement relative to one another.
- If an object (or process) is rigid or inflexible, make it movable or adaptive.

***Principle 16:** Partial or excessive actions.* If 100 percent of an effect is hard to achieve using a given solution method, then, by using "slightly less" or "slightly more" of the same method, the problem may be considerably easier to solve.

***Principle 17:** Another dimension*

- Move an object in two- or three-dimensional space.
- Use a multistory arrangement of objects instead of a single-story arrangement.
- Tilt or reorient the object, laying it on its side.
- Use "another side" of a given area.

***Principle 18**: Mechanical vibration*

- Cause an object to oscillate or vibrate.
- Increase the object's frequency (even up to the ultrasonic level).
- Use an object's resonance frequency.
- Use piezoelectric vibrators instead of mechanical ones.
- Use combined ultrasonic and electromagnetic field oscillations.

***Principle 19:** Periodic action*

- Instead of continuous action, use periodic or pulsating actions.
- If an action is already periodic, change the periodic magnitude or frequency.
- Use pauses between impulses to perform a different action.

***Principle 20:** Continuity of useful action*

- Carry on work continuously; make all parts of an object work at full load, all the time.
- Eliminate all idle or intermittent actions or work.

***Principle 21:** Skipping.* Conduct a process, or certain stages (e.g., destructive, harmful, or hazardous operations), at high speed.

***Principle 22:** "Blessing in disguise"*

- Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.

- Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.
- Amplify a harmful factor to such a degree that it is no longer harmful.

Principle 23: *Feedback*

- Introduce feedback (referring back, cross-checking) to improve a process or action.
- If feedback is already used, change its magnitude or influence.

Principle 24: *"Intermediary"*

- Use an intermediate carrier article or intermediary process.
- Merge one object temporarily with another (which can be easily removed).

Principle 25: *Self-service*

- Make an object serve itself by performing auxiliary helpful functions.
- Use waste resources, energy, or substances.

Principle 26: *Copying*

- Instead of an unavailable, expensive, or fragile object, use simpler and inexpensive copies of it.
- Replace an object or process with its optical copies.
- If visible optical copies are already used, move to infrared or ultraviolet copies.

Principle 27: *Cheap short-living.* Replace an expensive object with a multitude of inexpensive objects, compromising certain qualities (e.g., service life).

Principle 28: *Mechanical substitution*

- Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.
- Use electric, magnetic, and electromagnetic fields to interact with the object.
- Change from static to movable fields, from unstructured fields to those having structure.
- Use fields in conjunction with field-activated (e.g., ferromagnetic) particles.

Principle 29: *Pneumatics and hydraulics.* Use gas and liquid parts of an object instead of solid parts (e.g., inflatable, liquid-filled, aircushioned, hydrostatic, hydroreactive parts).

Principle 30: *Flexible shells and thin films*

- Use flexible shells and thin films instead of three-dimensional structures.
- Isolate the object from the external environment using flexible shells and thin films.

Principle 31: *Porous materials*

- Make an object porous or add porous elements (inserts, coatings, etc.).
- If an object is already porous, use the pores to introduce a useful substance or function.

Principle 32: *Color changes*

- Change the color of an object or its external environment.
- Change the transparency of an object or its external environment.

Principle 33: *Homogeneity.* Make objects interacting with a given object of the same material (or a material with identical properties).

Principle 34: *Discarding and recovering*

- Dispose of portions of an object that have fulfilled their function (discard by dissolving, evaporating, etc.) or modify them directly during operation.
- Conversely, restore consumable parts of an object directly during operation.

Principle 35: *Parameter changes*

- Change an object's physical state (e.g., to a gas, liquid, or solid).
- Change the concentration or consistency.
- Change the degree of flexibility.
- Change the temperature.

Principle 36: *Phase transitions.* Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat).

Principle 37: *Thermal expansion*

- Use thermal expansion (or contraction) of materials.
- If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.

Principle 38: *Strong oxidants*

- Replace common air with oxygen-enriched air.
- Replace enriched air with pure oxygen.
- Expose air or oxygen to ionizing radiation.
- Use ozonized oxygen.
- Replace ozonized (or ionized) oxygen with ozone.

Principle 39: *Inert atmosphere*

- Replace a normal environment with an inert one.
- Add neutral parts, or inert additives to an object.

Principle 40: Composite materials. Change from uniform to composite (multiple) materials.

2.5 TRIZ Approaches

TRIZ is a combination of methods, tools, and a way of thinking (Mann, 2002). The ultimate goal of TRIZ is to achieve absolute excellence in design and innovation. In order to achieve absolute excellence, TRIZ has five key philosophical elements. They are:

2.5.1 Ideality

Ideality is defined in similar terms to 'value'. It is typically defined as benefits divided by cost and harm. In studying the patent database, TRIZ researchers uncovered the perhaps not unsurprising facts that as systems evolve, they move in the direction of increasing ideality – i.e. greater levels of benefit; less cost; less harm. The evolutionary end-point for a system – defined as 'Ideal Final Result' (IFR) – is thus the point where the benefit (function) is delivered without cost or harm. While this might appear to be somewhat abstract, examples of systems that have evolved to this point, especially at the sub-system level, are increasingly commonplace. (Mann, 2002). The formula for Ideality is;

$$Ideality = \frac{All\ useful\ effects\ or\ functions}{All\ harmful\ effects\ or\ functions}$$

(R. Strattona, 2002)

2.5.2 Functionality

Function and functionality are very important in the TRIZ context. Functions (benefits) are the things that customers want. TRIZ encourages users to focus on the functional relationships between the different components within and around a system. Typically this is done through an evolved version of the function analysis/value engineering methods originally developed by Miles. The innovation introduced by TRIZ has been the modelling of the negative as well as positive functional relationships in a system. This enables users to define both the problems present in a system and the most appropriate tools to help solve them. By forcing users to examine a system on a component by component basis, the tool enables systematic management of complexity. Latterly, the method has further advanced (Reference 6) to better take into account manufacture and assembly process systems. Another important aspect of TRIZ is that it uses function as the principle means of classifying knowledge (example in Reference 1). Knowledge classification by function enables users to access, for example, all known ways of 'moving liquids' or 'joining surfaces', etc very rapidly. (Mann, 2002)

2.5.3 Resource

TRIZ defines a resource as 'anything in or around a system which is not being used to its maximum potential', and encourages users to embark on a relentless search for things that can work harder in a system. In many senses, this philosophy is very similar to the underlying directions encouraged within DFMA. The major difference comes when the concept of resource maximization is combined with the trends of evolution uncovered by TRIZ researchers and the concept of 'evolutionary potential' is introduced. Figure 4 illustrates one of the TRIZ trends 'Surface Segmentation' and the evolutionary stages that it contains. Systems evolve from left to right along the trend as designers uncover the benefits of shifting from one evolution stage to another. The evolutionary potential concept relates to systems that have not evolved to the end of a given trend. Thus, in terms of the example surface segmentation trend and the importance of resources, a smooth surface – having three unused evolutionary stages – should be thought of as a resource. (Mann, 2002)

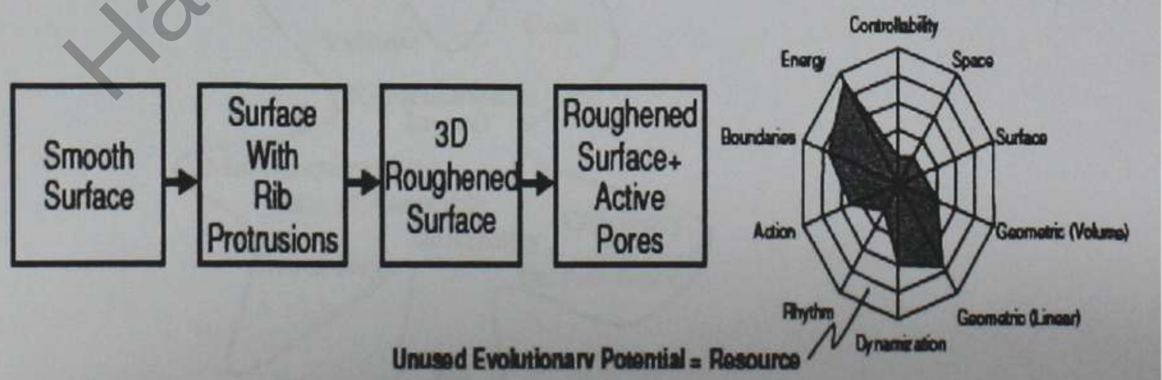


Figure 2.1: Surface Segmentation Trend and 'Evolutionary Potential' Concept in a Resources Context

2.5.4 Contradiction

TRIZ researchers also uncovered the fact that the principle driver through which ideality is increased is the resolution or elimination of contradictions. In terms of evolutionary s-curves, the mechanism causing the leveling off of the top of the s-curve is some form of limiting contradiction. Improving a system beyond the fundamental limits imposed by a given s-curve demands the realisation of a new s-curve. By codifying the successful contradiction-eliminating strategies of others, TRIZ offers user's systematic means of improving systems beyond the limits inherent to trade-off based approaches. Figure 1 illustrates a typical way of looking at the design process – a flexible bag filled with an incompressible fluid comprised of all the parameters it is necessary to take into consideration when designing a system. Conventional wisdom, and just about all engineering design methods tell designers that an attempt to improve one parameter (squeeze the bag in one place) will cause something else to get worse (bulge in another). This can often be seen to be the case in a DFMA (or indeed Design for X) context – where attempts to improve manufacturability or assembly time often result in adverse consequences elsewhere. (Mann, 2002)

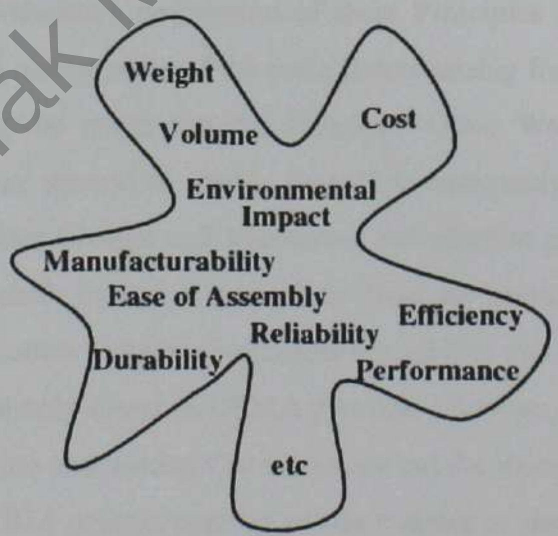


Figure 2.2: The Design Process as Fluid-Filled Bag

TRIZ researchers have configured a tool called a Contradiction Matrix which takes the list of parameters inside the fluid-filled bag and for each pair, identifies the strategies adopted by inventors who have refused to accept the conventional trade-off approach, and have instead achieved a design in which the trade-off has been successfully challenged. Included in the list of parameters considered by the TRIZ researchers have been 'manufacturability', 'device complexity' and 'level of automation' all of which have strong connections to the DFMA purpose. Analysing the strategies that inventors have used to improve these parameters without adverse effects on other design parameters (i.e. the contradiction-breaking strategies) results in the top-five list of Inventive Principles detailed in Table 2.1. (Mann, 2002)

Table 2.1: Inventive Strategies for DFMA-type Contradiction Elimination

Manufacturability	System Complexity	Level of Automation
1) Segmentation	1) Taking Out	1) Parameter Changes
2) Parameter Changes	2) Segmentation	2) Mechanics Substitution
3) Cheap Disposables	3) Copying	3) Other Way Around
4) Mechanics Substitution	4) Other Way Around	4) Taking Out
5) Other Way Around	5) Prior Action	5) Copying

A more comprehensive description of these Principles may be found. In the meantime it is worth noting some of the main points arising from the analysis. In the first instance, it may be noted that the Principle 'Other Way Around' ('turn the process the other way around or upside down') is commonly applied in a DFMA context. The Parameter Change and Mechanics Substitution principles on the other hand point to the shift from mechanical to fluid or (more usually) field-based solutions r when it comes to improving manufacturability and assembly issues. This is a feature not commonly found in DFMA practice. Likewise, the importance of the Segmentation, Copying and Taking Out ('separate out the harmful functions from the useful ones') in a TRIZ context appears to run counter to the conventional DFMA practice of reducing part count. The full implications of this contradictory advice require further analysis. (Mann, 2002)

2.5.5 Evaluation

TRIZ found that the trends of evolution of many technical systems are very similar and predictable. Many technical systems will go through five stages in their evolution processes which are pregnancy, infancy, growth, maturity, and decline. If we put time line in the horizontal axis, and plot;

a. Performance
b. Level of inventiveness
c. Number of inventions
d. Profitability

on the vertical axis, then we will get the four curves shows in Figure 2.3.

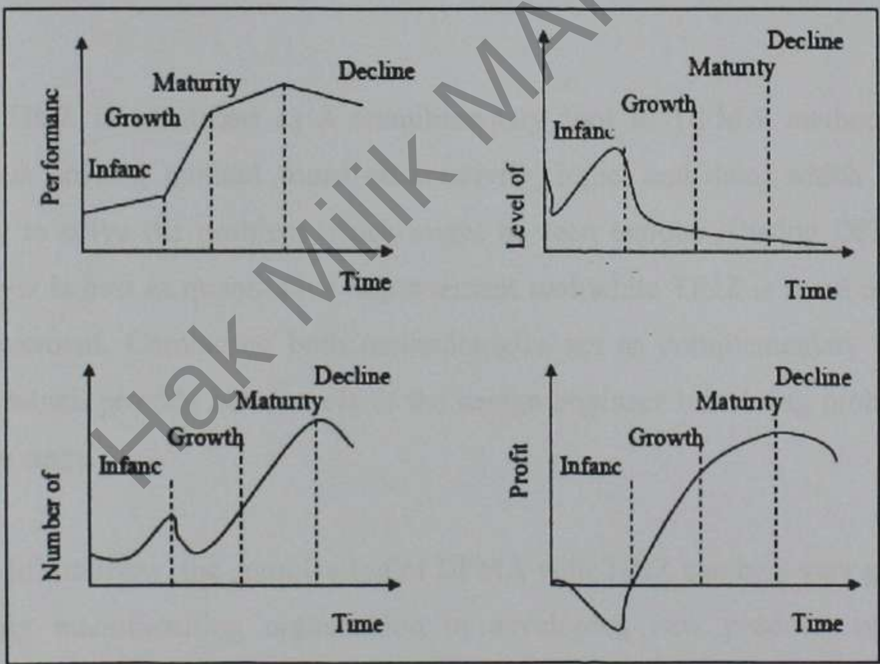


Figure 2.3: Curves of technical system evolution (Kai Yang, 2003)

2.6 Integration of DFMA and TRIZ

Newcomers most often view TRIZ as a somewhat complex looking entity. Certainly it contains a level of richness that is unique among creativity and innovation tools. The first misconception surrounding TRIZ is that it is necessary to master the whole before any benefits can be derived. The reality is that many of the tools within TRIZ can be used independently of the others. There are, however, a number of philosophical elements to TRIZ that it is helpful to be aware of. These pillars have been detailed elsewhere, but for the benefit of the discussion here, it is worth re-emphasising some of those pillars from the perspective of how they might benefit a DFMA practitioner. (Mann, 2002)

2.7 Summary

TRIZ is identified as a complimentary tool to DFMA methodology. This problem solving method based on creativity, logic, and data, which enhance the ability to solve the problem which might be seen tedious if using DFMA. DFMA however is best as quantitative improvement tool while TRIZ is more on qualitative improvement. Combining both methodologies act as complementary to 106 each other which provide better tools to the design engineer in solving problem at early design stage.

In summary, the combination of DFMA with TRIZ can be a very powerful tool for any manufacturing organization in developing new products or optimizing existing products. As stated earlier, it is best to utilize the DFMA tool as early as possible in the design development process for any given product such that the best designs may be developed with optimized materials and processes when considering manufacturability.

The TRIZ tool may be used on a variety of problems or when a new inventive solution is necessary and it has evolved into a system that can be the cornerstone of a company's innovation practice. It can be used effectively as an iterative tool with DFMA when the initial analysis does not meet the cost target for a given product as set either internally, by the customer, or by market conditions.

Manufacturing organizations today need to be able to apply new technology to their products and processes to be successful in the highly competitive global marketplace, and the usage of TRIZ in combination with DFMA can help them meet this objective.

CHAPTER 3

SELECTION OF PRODUCT CASE STUDY

3.1 Introduction

This chapter will discuss about the information of the product, product assembly sequences and function of each part that had been selected.

3.2 Product as a case study

Figure 3.1 show the fruit juicer extractor that had been chosen as a product case study. The power used is 300 W with capacity of 4450 ml juice reservoir jar. It has a removable juice container and lid. The grater and filter is made of stainless steel. Overall dimension is 28.0 cm (L) x 20.0 cm (W) x 32.0 cm (H).

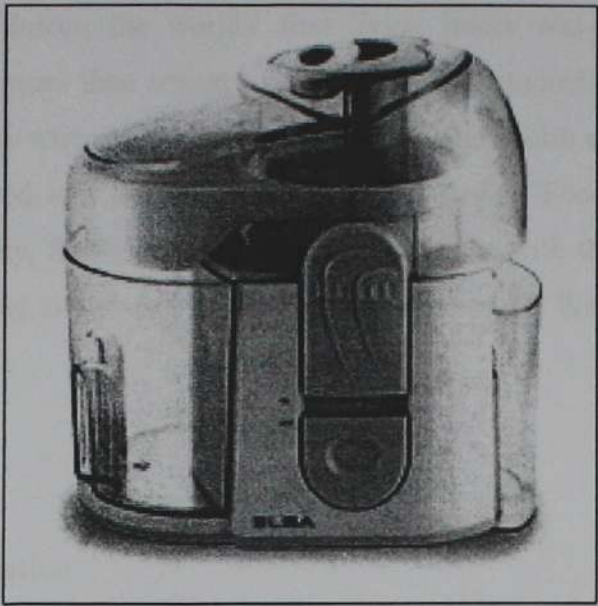


Figure 3.1: Fruit Juicer Extractor

3.2.1 Product Selection

One of the "Product Design Improvement DFMA Methodology" objectives is to select a consumer product as a case study. Therefore, "Fruit Juicer Extractor" had been chosen for this case study as illustrated in Figure 3.1. In this chapter, the product information, product assembly sequences, and function of each part of the selected product will be shown.

3.2.2 Product Case Study

Using something akin to an apothecary grinder and crude linen, the first juicer had been invented. Since then, herbal remedies have been ground up and applied both externally and internally for health benefits. The Koreans have also used green juice in ceremonial practice for more than two thousand years. However it was not until early this century that the importance of juicing and the technology to provide a way to readily extract a worthy juice become a reality.

The Norwalk Juicer, the worlds' first living juicer was invented by Dr Norman Walker. For more than seventy years Dr Walker studied living foods and developed a philosophy whereby the best way to nutritional health was with a diet of predominately raw food and juices which he termed Living Food. The Norwalk, which is still sold today, firstly grates and cuts the produce with the resulting mass then put into a linen bag and placed under a hydraulic press. Dr Walker lived to 118 years of age.

3.2.3 Parts Identification

Figure 3.2 show the exploded view of the fruit juice extractor with 12 main parts.

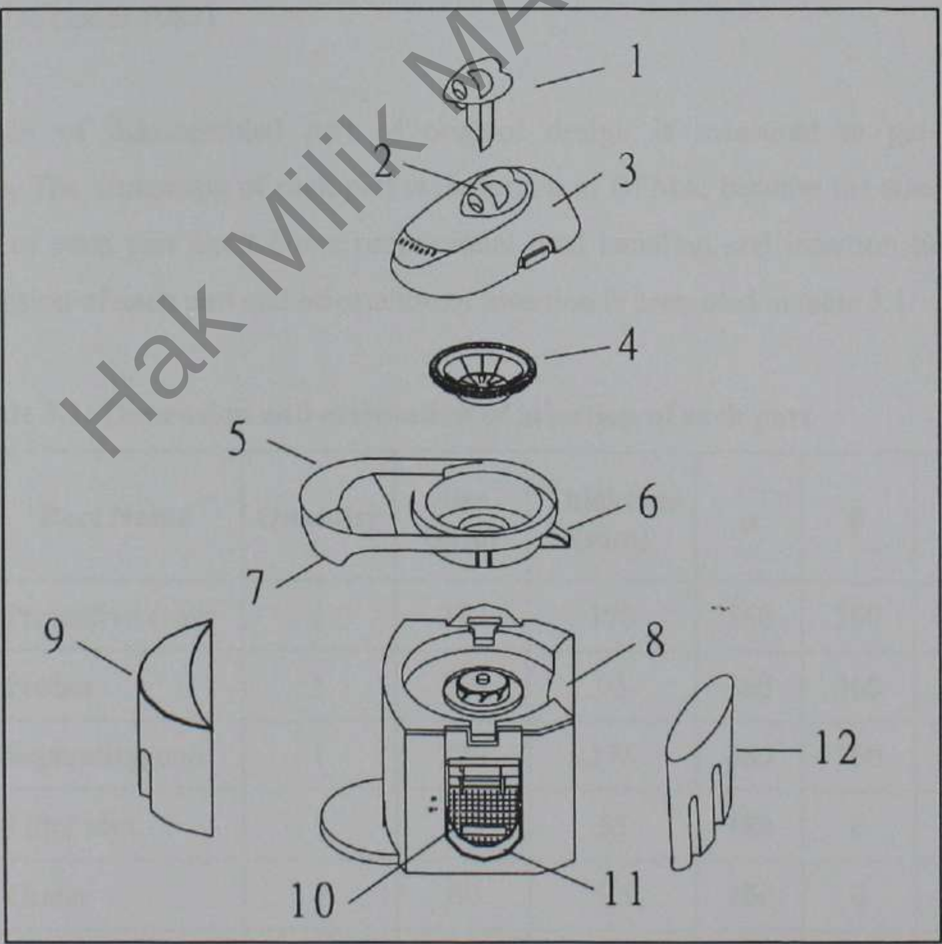


Figure 3.2: Exploded View of Fruit Juice Extractor

MAIN PARTS

1. Pusher
2. Feeder tube
3. Protective cover
4. Grater and filter unit
5. Separating unit
6. Juice spout
7. Residue spout
8. Motor unit
9. Residue container
10. Safety lock
11. On/Off switch
12. Juice cup

3.3 Parts Critiques

A classification and coding system for manual handling (Appendix D), insertion (Appendix E), and fastening processes, was presented in the form of a time standard system for designers to use in estimating manual assembly times (Dvorak 1982 and De Lisser 1982).

Each of disassembled part of original design is measured to get the dimension. The dimension of each part is important in DFMA, because the size and thickness of each part exert direct proportional total handling and insertion times. The dimension of each part and orientation of insertion is presented in table 3.1.

Table 3.1: Dimension and orientation of insertion of each part

Part No.	Part Name	Quantity	Size (mm)	Thickness (mm)	α	β	α+β
1	Protective cover	1	270	170	360	360	720
2	Pusher	1	150	95	360	360	720
3	Separating unit	1	225	175	360	360	720
4	Filter unit	1	125	55	180	0	180
5	Grater	1	60	1.5	180	0	180
6	Washer	4	5	1	0	0	0

Table 3.1: Dimension and orientation of insertion of each part (Continued)

Part No.	Part Name	Quantity	Size (mm)	Thickness (mm)	α	β	α+β
7	Juice spout	1	25	20	360	360	720
8	Motor unit	1	250	175	360	360	720
9	Safety lock	2	100	60	360	360	720
10	Pin	2	66	17	360	360	720
11	On/Off switch	1	60	56	360	360	720
12	Lower Base	1	280	175	180	180	360
13	Stopper Screw	1	52	30	180	0	180
14	Motor Casing	1	130	145	360	360	720
15	Screw	3	15	5	360	0	360
16	Motor	1	75	145	180	180	360
17	Vibration Damper	3	15	15	360	0	360
18	Screw	4	12	5	360	0	360
19	Product Label	1	1	0.2	180	0	180
20	Residue container	1	134	160	360	360	720
21	Juice cup	1	135	103	360	360	720

Each part in original design is critique to identify the important or function of each part. The written critique of each part is presented in table 3.2.

Table 3.2: Written Critique of Each Part in Old Design

Part No.	Part Name	Critiques
1	Protective cover	It more efficient to combine the top cover with the separating unit.
2	Pusher	To push fruits into the grater.
3	Separating unit	It more efficient to combine the separating unit with the top cover.
4	Filter unit	It more efficient to combine the filter unit with the grater
5	Grater	It more efficient to combine the grater with the filter unit
6	Washer	The used of screw can be replaced with snap fitting concept to allow easy insertion during assembly.
7	Juice spout	It more efficient to combine the juice spout with the separating unit
8	Motor unit	Easy handling and insertion
9	Safety lock	It more efficient to used snap fit.
10	Pin	Can be replaced with snap fit.
11	On/Off switch	Easy handling and insertion
12	Lower Base	It more efficient to used rubber as material.
13	Stopper Screw	Easy handling and insertion
14	Motor Casing	It more efficient to combine the juice spout with the separating unit
15	Screw	The used of screw can be replaced with snap fitting concept to allow easy insertion during assembly.
16	Motor	Easy handling and insertion
17	Vibration Damper	It more efficient to combine the vibration damper with the lower base.
18	Screw	Easy handling and insertion
19	Product Label	It more efficient to combine the product label with the lower base.
20	Residue container	It more efficient to used standard container for example jug.
21	Juice cup	It more efficient to used standard container for example mug.

3.4 Summary

Fruit Juice Extractor had been chosen because it is one of the consumer product that had been used frequently and its part can be easily disassembled and determined by using manual DFA analysis. The process of disassemble had been done to determine the sequence of product assembly process. Besides that, the function of each part also been determined by the disassemble process. The total number of parts of fruit juice extractor is 21 parts while the total number of different parts is 19 parts.

CHAPTER 4

DESIGN FOR ASSEMBLY (DfA) ANALYSIS FOR ORIGINAL DESIGN

4.1 Introduction

This chapter will discuss the Design for Assembly (DFA) analysis using Boothroyd-Dewhurst methodologies for the original design of the product case study. The discussion will cover on the estimation of time and cost for manual and insertion of the components in order to produce of the sandwich maker and also the design efficiency of the original design. This is usually where the major cost benefits of the application of design for assembly occur. (Boothroyd, 2002)

4.2 Product analysis

The classification system for assembly processes is a systematic arrangement of part features that affect acquisition, movement, orientation, insertion, and fastening of the part together with some operations that are not associated with specific parts such as turning the assembly over (G. Boothroyd 2002).

Selected portions of the complete classification system, its associated definitions, and the corresponding time standards are presented in Appendix D1.

4.2.1 Classification of Manual Handling

The classification system for manual handling processes is a systematic arrangement of part features in order of increasing handling difficulty levels. It can be seen that the classification numbers consist of two digits; each digit is assigned a value from 0 to 9. Table 4.1 shows the description of first digit in coding system.

Table 4.1: Description of First Digit in Handling Code

First digit of 0-3	Parts of nominal size and weight that is easy to grasp and manipulate with one hand (without the aid of tools).
First digit of 4-7	Parts that require grasping tools to handle due to their size.
First digit of 8	Parts which severely nest or tangle in bulk.
First digit of 9	Parts which require two hands, two persons, or mechanical assistance in handling.

The second digit of the handling code is based on flexibility, slipperiness, stickiness, and fragility and nesting characteristics of a part. The second digit also depends on the group divisions of the first digit in the following manner. Table 4.2 shows the description of first digit in coding system.

Table 4.2: Description of Second Digit in Handling Code

First digit of 0-3	The second digit classifies the size and thickness of a part.
First digit of 4-7	The second digit classifies the part thickness type of tool required for handling the part and the necessity for optical magnification during the handling process.
First digit of 8	The second digit classifies the size and symmetry of a part.
First digit of 9	The second digit classifies the symmetry, weight, and interlocking characteristics of parts in bulk.

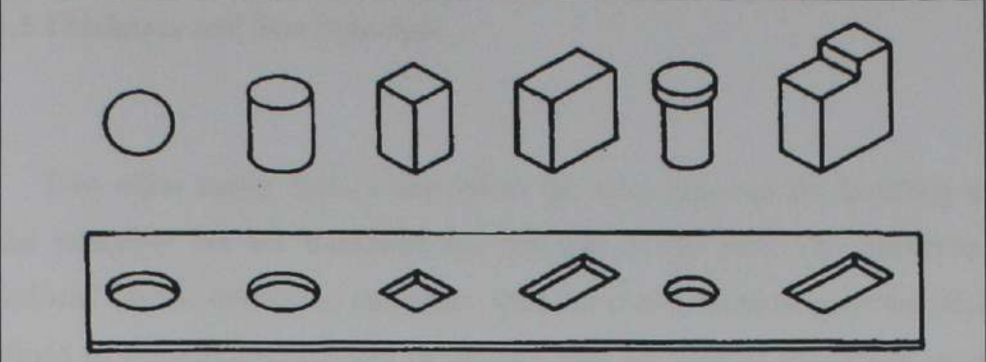
4.2.1.1 Symmetrical Principle

One of the principal geometrical design features that affects the times required to grasp and orient a part is its symmetry. Assembly operations always involve at least two component parts; the part to be inserted and the part or assembly (receptacle) into which the part is inserted. Orientation involves the proper alignment of the part to be inserted relative to the corresponding receptacle and can always be divided into two distinct operations: (i) alignment of the axis of the part that corresponds to the axis of insertion, and (ii) rotation of the part about this axis.

It is therefore convenient to define two kinds of symmetry for a part:

1. Alpha symmetry - which depends on the angle through which a part must be rotated about an axis perpendicular to the axis of insertion, to repeat its orientation.
2. Beta symmetry - which depends on the angle through which a part must be rotated about the axis of insertion, to repeat its orientation.

A variety of predetermined time standard systems is presently used to establish assembly times in industry. In the development of these systems, several different approaches have been employed to determine relationships between the amount of rotation required orienting a part and the time required to perform that rotation. The two most commonly used systems are the methods time measurement (MTM) and work factor (WF) systems. Figure 4.1 gives examples of the symmetry of simple-shaped parts.



α	0	180	180	90	360	360
β	0	0	90	180	0	360

Figure 4.1: Alpha and Beta Rotational Symmetries for Various Parts.

The relation between the symmetry of a part and the time required for orientation is determined by the summation of the alpha (α) and beta (β) symmetries, given by:

$$\text{Total angle of symmetry} = \alpha + \beta$$

The effect of the total angle of symmetry on the time required to handle (grasp, move, orient, and place) a part is shown in Figure 4.2.

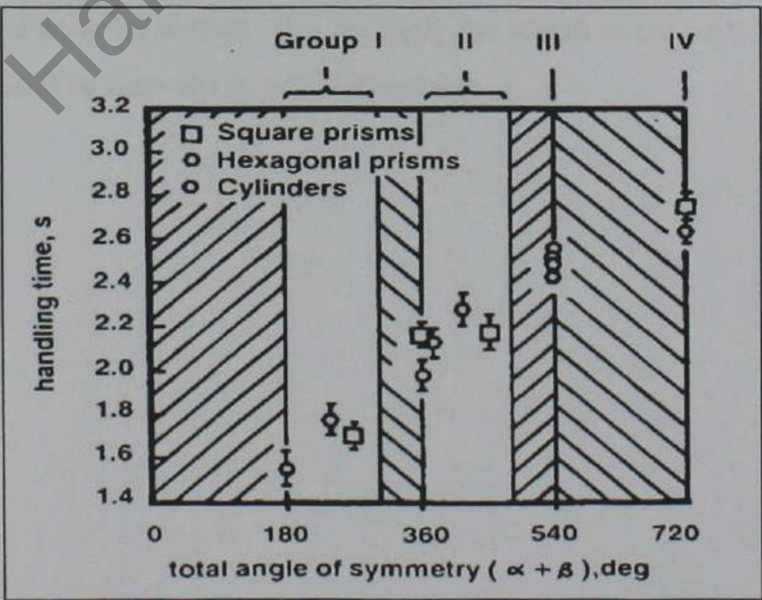


Figure 4.2: Effect of Symmetry on the Time Required Handling a Part

4.2.1.2 Thickness and Size Principle

Two other major factors that affect the time required for handling during manual assembly are the thickness and the size of the part. The thickness of a "cylindrical" part is defined as its radius while for non-cylindrical parts the thickness is defined as the maximum height of the part with its smallest dimension extending from a flat surface (Figure 4.3).

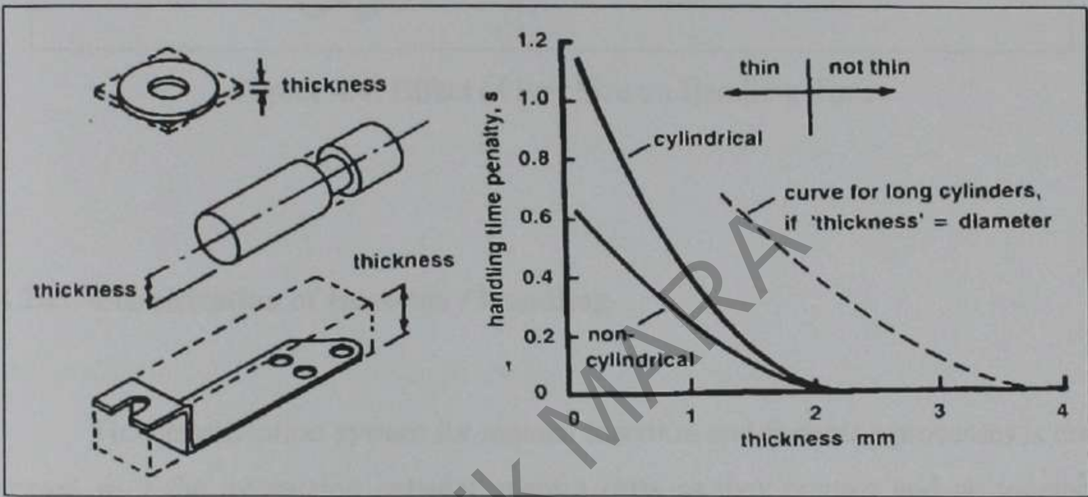


Figure 4.3: Effect of Part Thickness on Handling Time.

The size is defined as the largest non-diagonal dimension of the part's outline when projected on a flat surface. It is normally the length of the part. The effects of part size on handling time are shown in figure 4.4.

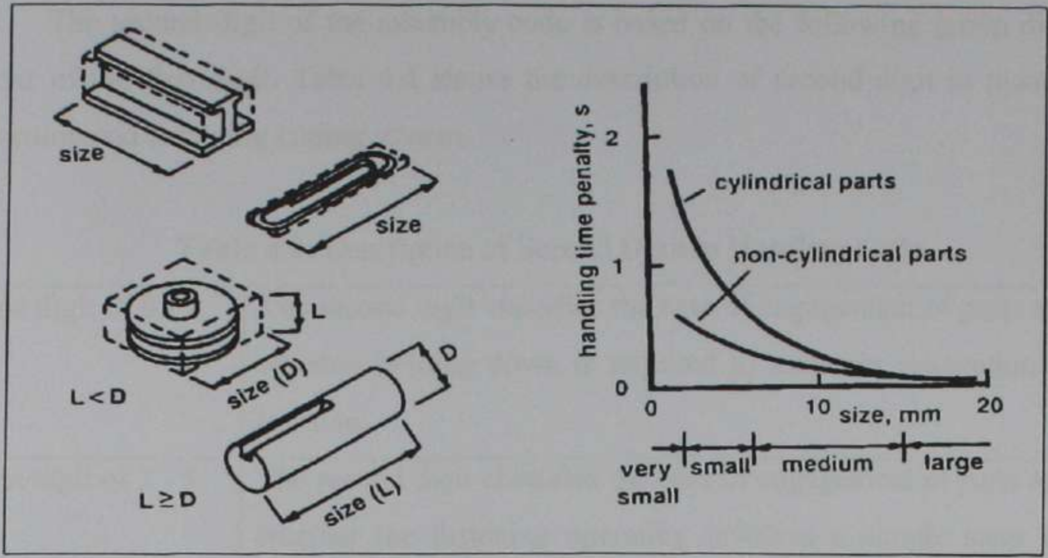


Figure 4.4: Effect of Part Size on Handling Time

4.2.2 Classification of Insertion / Handling

The classification system for manual insertion and fastening processes is concerned with the interaction between mating parts as they contact and go together. Manual insertion and fastening consists of a finite variety of basic assembly tasks (peg-in-hole, screw, weld, rivet, force fit, etc.) that are common to most manufactured products. The corresponding classification system and its associated definitions and time standards are presented in Appendix D2.

The two-digit code numbers range from 00 to 99. The first digit is divided into three main. Table 4.3 shows the description of first digit in manual insertion and fastening coding system.

Table 4.3: Description of Second Digit in Handling Code

First digit of 0 - 2	Part is not secured immediately after insertion.
First digit of 3 - 5	Part secures itself or another immediately after insertion.
First digit of 9	Process involving parts that are already in place.

The second digit of the assembly code is based on the following group divisions of the first digit. Table 4.4 shows the description of second digit in manual insertion and fastening coding system.

Table 4.4: Description of Second Digit in Handling Code

First digit of 0 - 2	The second digit classifies the ease of engagement of parts and whether holding down is required to maintain orientation or location.
First digit of 3 - 5	The second digit classifies the ease of engagement of parts and whether the fastening operating involves a simple snap fit, screwing operation or plastic deformation process.
First digit of 9	The second digit classifies mechanical, metallurgical and chemical processes.

Consideration Factor for Manual Insertion and Fastening

The design features that significantly affect manual insertion and fastening times are;

- Accessibility of assembly location
- Ease of operation of assembly tool
- Visibility of assembly location
- Ease of alignment and positioning during assembly
- Depth of insertion

4.2.3 Estimated Assembly Time

The value of total assembly cost (CM) is gained from the calculation below:

Value of labour cost per second (n) may vary due to different assumption and for this case study, below n assumption is used.

Monthly salary for one operator = RM 600

Number of working day = 20 days/month

Number of working hour/day = 8 hours/day

So, labor cost per second, n = RM 600 / (20 days x 8 hours x 3600secs)

= RM 0.001042/sec

= 0.1042 cents/sec

Thus,

CM = TM x n

= 168.64 secs x 0.1042 cents/sec

= 17.57

The design efficiency of the original design is gained by using below formula;

$$DE = \frac{3 \times NM}{TM} \times 100\%$$
$$= \frac{3 \times 13}{168.64} \times 100\%$$
$$= 23.1$$

4.2.4 Theoretical Minimum Number of Part

The establishment of a theoretical minimum number of part counts is the most powerful way to identify possible simplification in the product structure. In order to give guidance to the designer in reducing the number of part count, the DFA methodology provide three criteria against which each part must be examined as it added to the product during assembly:

1. During operation of the product, does the part move relative to all other parts already assembled?
2. Must the part be of a different material from all other parts already assembled? Or isolated from them?

3. Must the part be separated from all those already assembled?

If the answer to any of these three questions is 'yes' score '1' is given. However, if the answer for all the questions is 'no', score '0' is given. For the part which is got score 1, that part cannot be eliminated. Meanwhile for the part got score 0, so that the part can be eliminated or combined with the others part.

Table 4.5 present the classification of part for original design based on the classification system.

Table 4.5: Classification of Part for Original Design

Part No.	Part Name	Quantity	Size (mm)	Thickness (mm)	α	β	α+β
1	Protective cover	1	270	170	360	360	720
2	Pusher	1	150	95	360	360	720
3	Separating unit	1	225	175	360	360	720
4	Filter unit	1	125	55	180	0	180
5	Grater	1	60	1.5	180	0	180
6	Washer	4	5	1	0	0	0
7	Juice spout	1	25	20	360	360	720
8	Motor unit	1	250	175	360	360	720
9	Safety lock	2	100	60	360	360	720
10	Pin	2	66	17	360	360	720
11	On/Off switch	1	60	56	360	360	720
12	Lower Base	1	280	175	180	180	360
13	Stopper Screw	1	52	30	180	0	180
14	Motor Casing	1	130	145	360	360	720
15	Screw	3	15	5	360	0	360

Table 4.5: Classification of Part for Original Design

(Continued)

Part No.	Part Name	Quantity	Size (mm)	Thickness (mm)	α	β	α+β
16	Motor	1	75	145	180	180	360
17	Vibration Damper	3	15	15	360	0	360
18	Screw	4	12	5	360	0	360
19	Product Label	1	1	0.2	180	0	180
20	Residue container	1	134	160	360	360	720
21	Juice cup	1	135	103	360	360	720

Table 4.6 present the summary or step-by-step according the three criteria against which each part must be examined as it added to the product during assembly.

Table 4.6: Summary for three criteria for original design

0	Rule 1	Rule 2	Rule 3	9
Name of Part	During operation of the product, does the part move relative to all other parts already assembled?	Must the part be of a different material than the parts already assembled?	Must the part be separate from all parts already assembled	Estimation of theoretical minimum # of parts, 0 or 1
Juice cup	0	0	0	0
Residue container	0	0	0	0
Product Label	0	0	0	0
Screw	0	0	0	0
Vibration Damper	0	0	0	0
Screw	0	0	0	0
Motor	1	1	0	1
Screw	0	0	0	0
Motor Casing	1	1	1	1
Stopper Screw	1	0	0	1
Lower Base	1	0	0	1
On/Off switch	0	0	0	0
Pin	1	0	0	1
Safety lock	1	0	0	1
Upper Case	1	0	0	1
Motor unit	1	0	1	1
Juice spout	0	0	0	0
Washer	0	0	0	0
Grater	1	1	0	1
Filter unit	1	1	0	1
Separating unit	1	0	0	1
Pusher	0	0	0	0
Protective cover	1	0	0	1

4.2.5 DfA Worksheet

DFA worksheet will show the result of the analysis of the product, fruit juice extractor. In this section, the analysis is done for the original design of the fruit juice extractor.

From the DFA worksheet analysis shown in table 4.7, the results of the estimated time, cost and design efficiency of the assembly are obtained. Below are the summary of the result for the original design analysis.

Total assembly time, TM = 168.64 seconds.
Total assembly cost, CM = 17.57229 cents.
Theoretical minimum number of part, NM = 13

The design efficiency of the original design is gained by using below formula;

$$DE = \frac{3 \times NM}{TM} \times 100\%$$

$$DE = \frac{3 \times 13}{168.64} \times 100\%$$

$$DE = 0.23126 \times 100\%$$

$$DE = 23.126\%$$

Table 4.7: DFA worksheet analysis for original design

0	1	2	3	4	5	6	7	8	9
Name of Part	Part ID#	# of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two0digit manual insertion code	Manual insertion time per part	Operation time, sec, (2) x [(4) + (6)]	Operation cost, cents, 0.1042 (MYR) x (7)	Estimation of theoretical minimum # of parts, 0 or 1
Juice cup	21	1	32	2.70	30	2.00	4.70	0.48974	0
Residue container	20	1	32	2.70	30	2.00	4.70	0.48974	0
Product Label	19	1	30	1.95	30	2.00	3.95	0.41159	0
Screw	18	4	30	2.70	30	2.00	18.80	1.95896	0
Vibration Damper	17	3	30	2.70	30	2.00	14.10	1.46922	0
Motor	16	1	30	2.70	12	5.00	7.70	0.80234	1
Screw	15	3	30	2.70	00	1.50	12.60	1.31292	0
Motor Casing	14	1	30	2.70	00	1.50	4.20	0.43764	1
Stopper Screw	13	1	12	2.25	30	2.00	4.25	0.44285	1
Lower Base	12	1	12	2.25	01	2.50	4.75	0.49495	1
On/Off switch	11	1	12	2.25	30	2.00	4.25	0.44285	0
Pin	10	2	10	1.50	01	2.50	8.00	0.8336	2
Safety lock	9	2	10	1.50	30	2.00	7.00	0.7294	2
Motor unit	8	1	02	1.88	30	2.00	3.88	0.404296	1
Juice spout	7	1	02	1.88	38	6.00	7.88	0.821096	0
Washer	6	4	02	1.88	08	6.50	33.52	3.492784	0
Grater	5	1	00	1.13	30	2.00	3.13	0.326146	1

Table 4.7: DFA worksheet analysis for original design (Continued)

Filter unit	4	1	00	1.13	38	6.00	7.13	0.742946	1
Separating unit	3	1	30	2.70	30	2.00	4.70	0.48974	1
Pusher	2	1	30	2.70	30	2.00	4.70	0.48974	0
Protective cover	1	1	30	2.70	30	2.00	4.70	0.48974	1
TOTAL							**168.64**	**17.57229**	**13**
							TM	**CM**	**NM**

From the DFA worksheet analysis in table 4.8, the results of the estimated time, cost and design efficiency of the assembly are obtained. Below are the summary of the result for the new design analysis.

Total assembly time, TM = 77.56 seconds.

Total assembly cost, CM = 8.08175 cents.

Theoretical minimum number of part, NM = 16

The design efficiency of the new design is gained by using below formula;

$$DE = \frac{3 \times NM}{TM} \times 100\%$$

$$DE = \frac{3 \times 16}{77.56} \times 100\%$$

$$DE = 0.61887 \times 100\%$$

$$DE = 61.88\%$$

Table 4.8: DFA worksheet analysis for new design

0	1	2	3	4	5	6	7	8	9
Name of Part	Part ID#	# of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two0digit manual insertion code	Manual insertion time per part	Operation time, sec, (2) x [(4) + (6)]	Operation cost, cents, 0.1042 (MYR) x (7)	Estimation of theoretical minimum # of parts, 0 or 1
Juice cup	21	1	32	2.70	30	2.00	4.70	0.48974	1
Residue container	20	1	32	2.70	30	2.00	4.70	0.48974	1
Vibration Damper	17	4	30	2.70	30	2.00	14.10	1.46922	4
Motor	16	1	30	2.70	12	5.00	7.70	0.80234	1
Stopper Screw	13	1	12	2.25	30	2.00	4.25	0.44285	1
Lower Base	12	1	12	2.25	01	2.50	4.75	0.49495	1
On/Off switch	11	1	12	2.25	30	2.00	4.25	0.44285	1
Pin	10	1	10	1.50	01	2.50	8.00	0.8336	1
Motor unit	8	1	02	1.88	30	2.00	3.88	0.404296	1
Filter unit	4	1	00	1.13	38	6.00	7.13	0.742946	1
Separating unit	3	1	30	2.70	30	2.00	4.70	0.48974	1
Pusher	2	1	30	2.70	30	2.00	4.70	0.48974	1
Protective cover	1	1	30	2.70	30	2.00	4.70	0.48974	1
TOTAL							**77.56**	**8.08175**	**16**
							TM	**CM**	**NM**

4.3 Summary

The analysis result of the original Fruit Juice Extractor had been showed through the DFA worksheet analysis. From the design efficiency result, the product needs to be improved because the value was categorized in less efficient. The design improvements of the product Fruit Juice Extractor will be done based on analysis through minimize the theoretical minimum number of parts and total assembly time.

4.3 Summary

The analysis result of the original Fruit Juice Extractor had been showed through the DFA worksheet analysis. From the design efficiency result, the product needs to be improved because the value was categorized in less efficient. The design improvements of the product Fruit Juice Extractor will be done based on analysis through minimize the theoretical minimum number of parts and total assembly time.

4.3 Summary

The analysis result of the original Fruit Juice Extractor had been showed through the DFA worksheet analysis. From the design efficiency result, the product needs to be improved because the value was categorized in less efficient. The design improvements of the product Fruit Juice Extractor will be done based on analysis through minimize the theoretical minimum number of parts and total assembly time.

CHAPTER 5

TRIZ DESIGN ANALYSIS FOR NEW DESIGN

5.1 Introduction

This chapter discusses the application of TRIZ in design improvement of the selected product as case study in continuation with the improved design by DfA tool.

After applying DfA in the design improvement Fruit Juice Extractor, it is found that the previous design still can be improve. However to resolve the problem using DfA might be complicated. It is hard to determine where to start and how. Here, TRIZ with its general solution is very helpful to create the solution

5.2 Case study

The on-going application of TRIZ for the Fruit Juice Extractor improved design by DfA is detailed in the following subtopic.

5.2.1 TRIZ Way of Problem Solving

The strategy in which TRIZ resolves problems is a typical of a normal problem solving process. A typical problem solving is to move from a specific problem directly to find a specific solution. However, there are many instances where this approach may not work due to contradictions or conflicts which prevent good solutions from being generated. The TRIZ problem solving process which works towards resolving contradictions or conflicts while providing an inventive solution is shown in Figure 5.1 ((D. Mann, 2002)

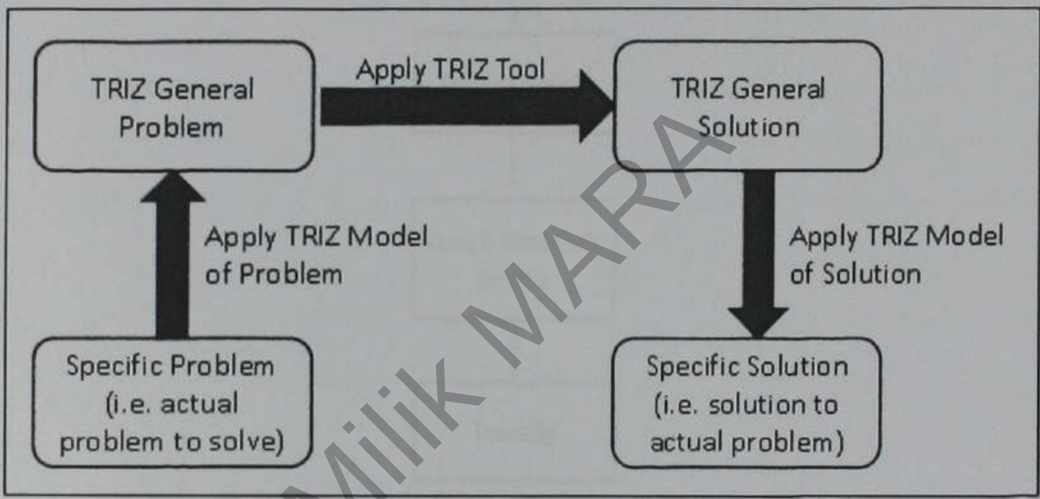


Figure 5.1: TRIZ way of problem solving

5.2.2 TRIZ Models and Tools

Start with the original problems to resolve. Examples include equipment low yield or low productivity, high failure rate for a certain failure mode, high equipment downtime. The original problem is normally at high level and does not really provide enough details to solve the problem.

The first step is to perform Function Analysis on the identified system. Hierarchically, we have the Supersystem, System and Subsystem. Function Analysis helps to clearly identify the Engineering System, along with detailing the components within the Engineering System, along with its interaction with the Supersystem.

The second step is to perform Cause & Effect Chain Analysis. The Cause & Effect Chain Analysis will help identify the fundamental root cause(s). These are then worked on by the process called Trimming. The TRIZ process flow for solving a particular problem is detailed in figure 5.2 (Yeoh Teong San, 2012).

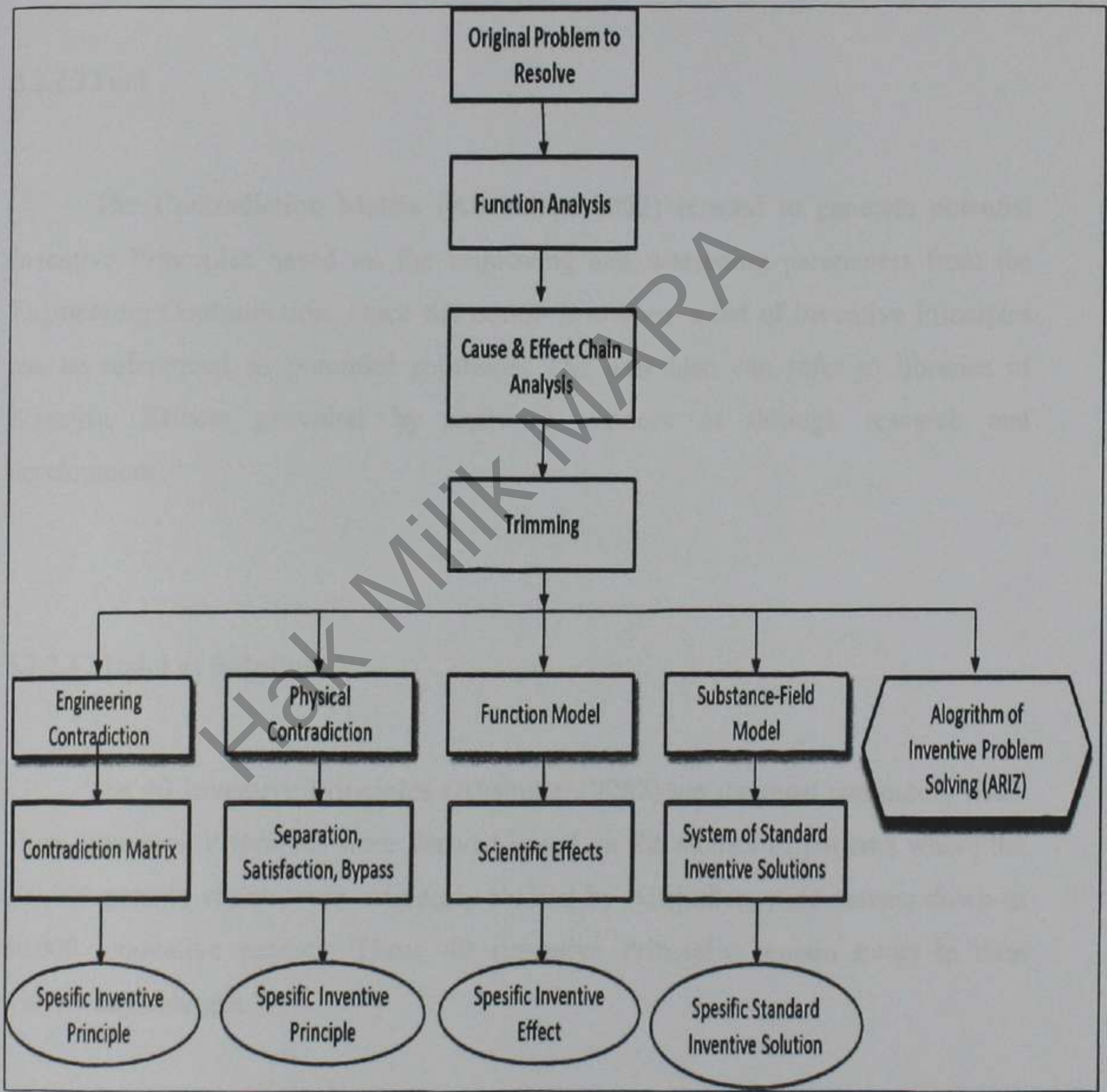


Figure 5.2: TRIZ problem solving map

5.2.2.1 Model of Problem

Developing the Model of Problem is one of the most important steps towards solving a problem which has a contradiction. The contradiction can be modelled in the form of a function whereby a useful function may give rise to ineffective, excessive or harmful functions.

5.2.2.2Tool

The Contradiction Matrix (Altshuller, 2002) is used to generate potential Inventive Principles based on the improving and worsening parameters from the Engineering Contradiction. Once the option is chosen, a list of Inventive Principles can be referenced as potential solutions. The user also can refer to libraries of Scientific Effects provided by software vendors ot through research and development.

5.2.2.3 Model of Solution

The 40 Inventive Principles (Altshuller, 2002) are the most commonly used. These Inventive Principles were derived based on the studies of patterns where the 200,000 patents which were originally studied by Altshuller, were narrow down to 40,000 innovative patents. These 40 Inventive Principles remain intact to date without any changes.

5.2.3 Function Analysis

Function Analysis is the analysis performed on two or more components in terms of their interactions between each other (GEN3, 2006; Ena et al., 2002). These interactions are called functions. Basically, functions are actions between two components. (Figure 5.3)

These functions can be either useful or harmful functions. Useful functions can be further categorized under normal, insufficient or excessive. In simple word, normal useful function does not cause any damage or undesired effect on the object, whereas insufficient and excessive useful functions may create some amount of damage or undesired effect on the object.

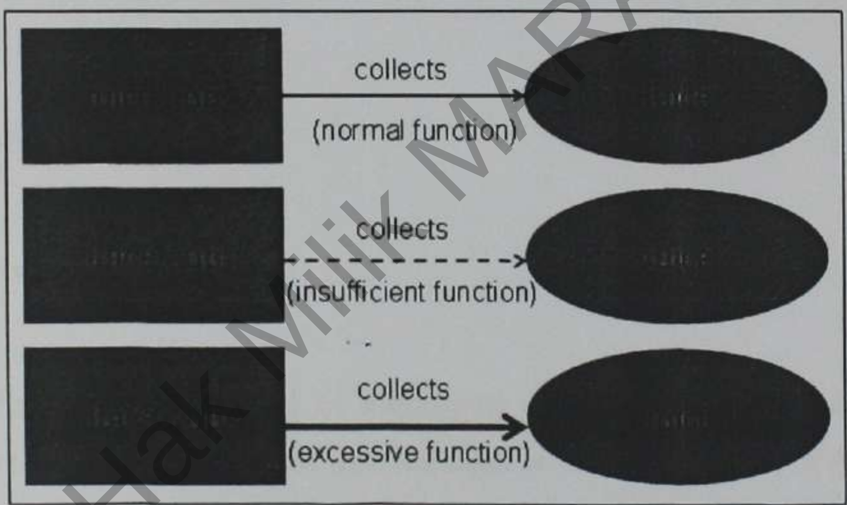


Figure 5.3: Different line styles for useful functions

5.2.4 Product Analysis

In Product Analysis, there are 4 steps to follow;

i. Component Analysis
The Engineering System is broken down into components and the interactions between these components are defined (GEN3, 2006).

ii. Structural Analysis

Used to analyze the Engineering System based on identifying the interactions between components in both the System and Supersystem.

iii. Function Analysis

The severity value needs to be included for any insufficient / excessive useful functions and harmful functions.

iv. Product Diagnostic Analysis

It compares the functional significance of each component relative to the number of useful functions provided by each component, level of severity of the insufficient / excessive useful and harmful function

5.3 Problem solving

5.3.1 Trimming

Trimming is a method of eliminating components from an Engineering System to reduce or eliminate the disadvantages or harmful functions of the trimmed components. Trimming increases the efficiency and reduces the cost of the Engineering System.

There are three rules for Trimming (GEN3, 2006). Figure 5.4 show the hierarchy of components of the fruit juice extractor. Based on this hierarchy, it will help to generate the function analysis model.

Figure 5.5 illustrate the trimming from the original state and figure 5.6 illustrate trimmed state based on the rules. **Rule A**: The function is not needed anymore because the object of the function no longer exists. **Rule B**: The object being worked by the function performs the function itself.

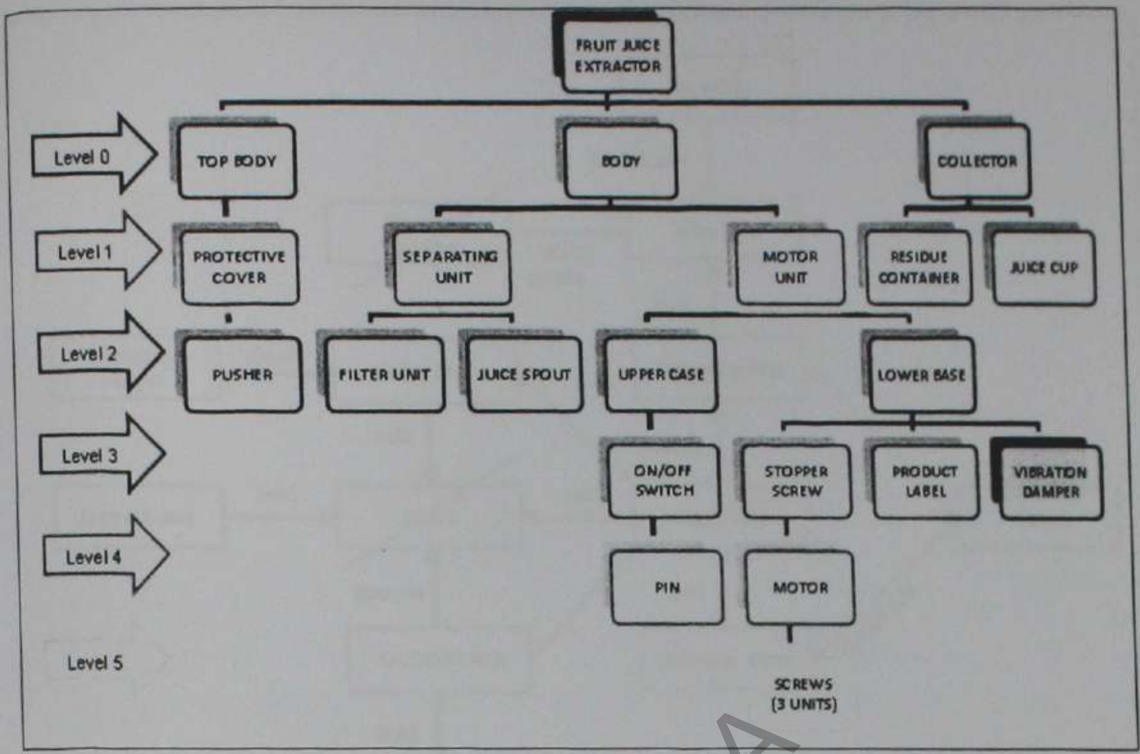


Figure 5.4: Hierarchy of Components

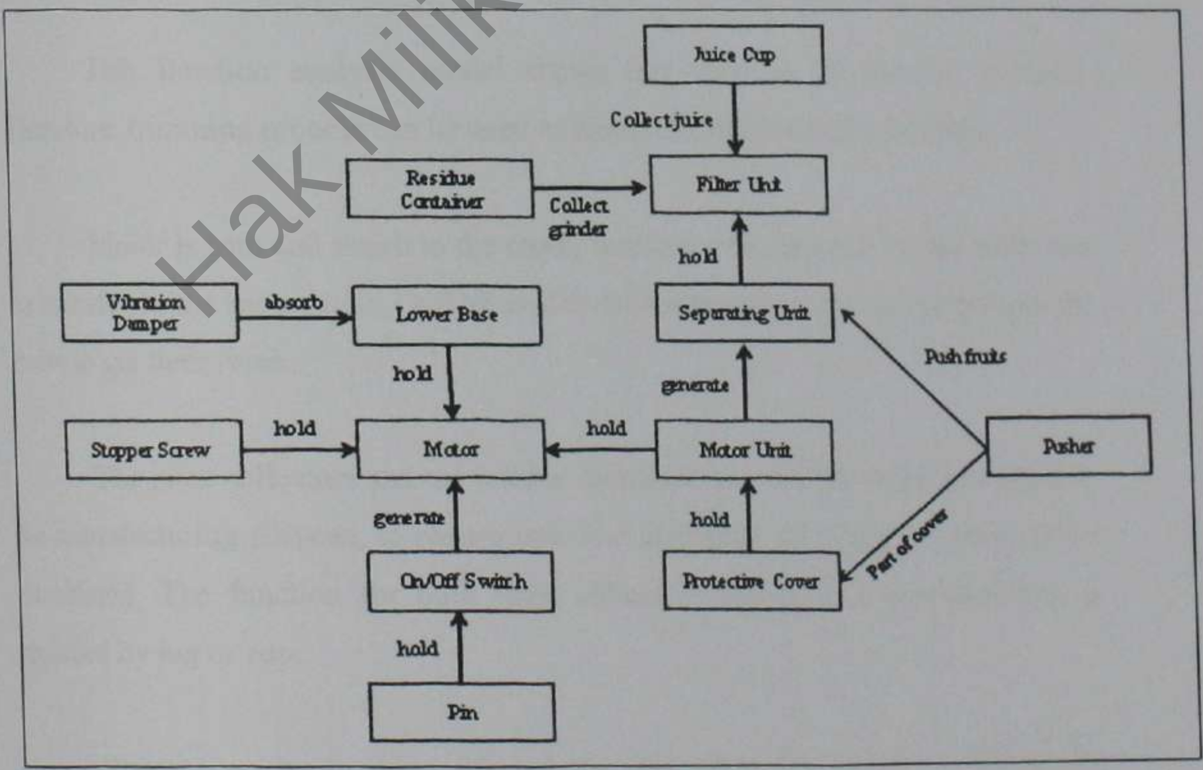


Figure 5.5: Function Analysis Model – New Design

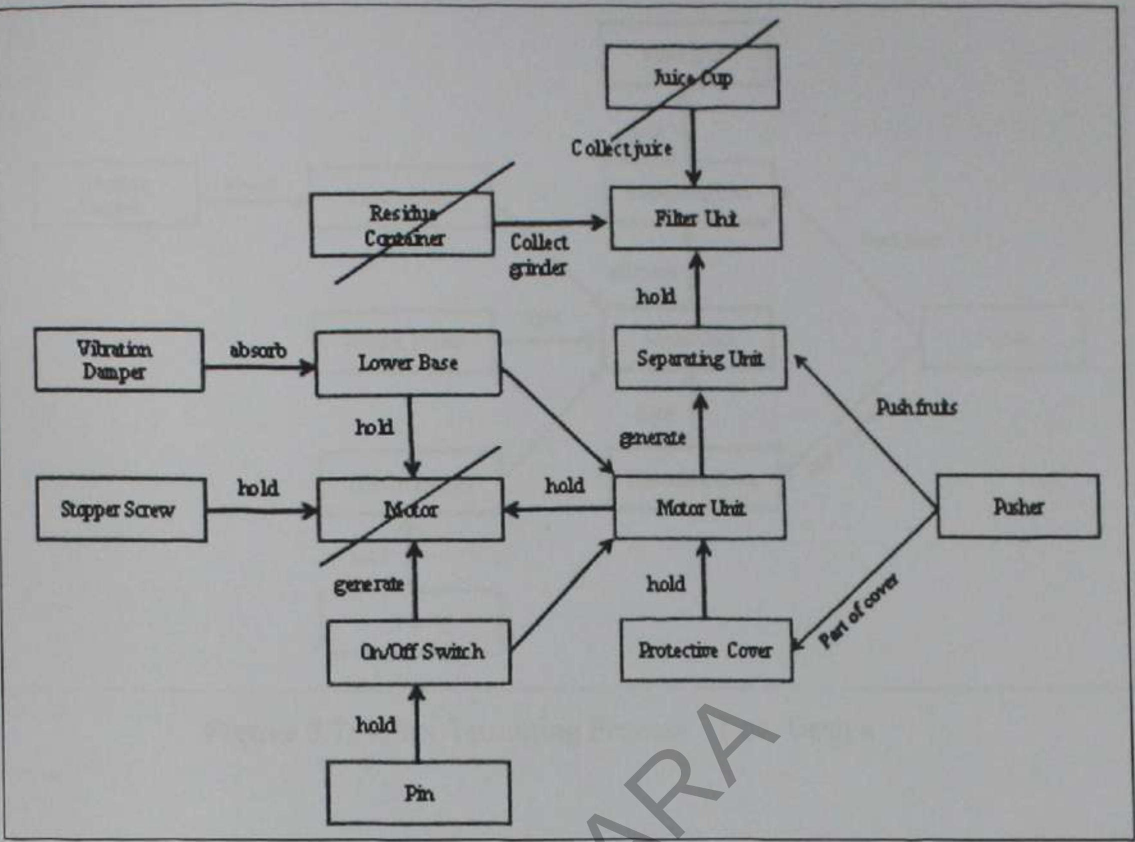


Figure 5.6: Eliminating Component – New Design

This function analysis model shows that there is no harmful function. Therefore, trimming process can be used to eliminate disadvantages function.

Motor is trim and attach to the motor unit since the function of this motor can be transfer to the motor unit. On/Off switch will generate motor unit to process the fruits to get their juice.

The juice collectors and the residue container are separate from the body. For the manufacturing purpose, to reduce cost and assembly, this juice collector can be eliminated. The function for both juice collectors and residue container can be replaced by jug or cup.

Reorganize the function of analysis after trimming process to ensure the trimmed component not disturbs the whole function of juice extractor and occur another problem (Figure 5.7).

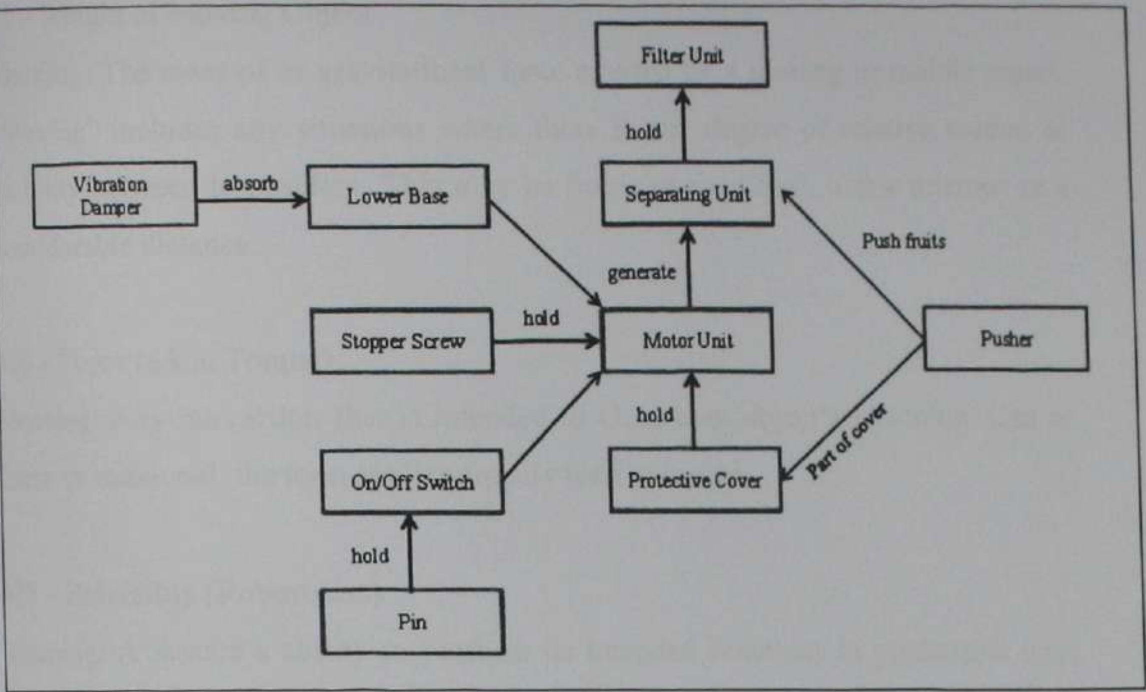


Figure 5.7: After Trimming Process – New Design

5.3.2 Contradiction

If the juicer collector is eliminated, the juice will spill over. Since for the ease of the manufacturing, it is best to eliminate the juice collector and residue cup, it will lower the productivity. This is because we need to find another component to replace it and if it is not prepared it will waste time. So, based on the Contradiction Matrix (Appendix E1) in figure 5.8, the suggested Inventive Principles are;

	Worsening Feature → / Improving Feature ↓	Productivity
		39
32	Ease of Manufacture	35, 1, 10, 28

Figure 5.8: Contradiction Matrix

#1 – Weight of Moving Object

Meaning: The mass of or gravitational force exerted by a moving or mobile object. "Moving" includes any situations where there is any degree of relative motion or mobility between to problem. This may be linear or rotational, a few microns or a considerable distance.

#10 – Force (a.k.a. Torque)

Meaning: Any interaction that is intended to change an object's condition. Can be linear or rotational; the term applies equally well to torque.

#28 – Reliability (Robustness)

Meaning: A system's ability to perform its intended functions in predictable ways and conditions. Also includes durability and issues related to the performance or degradation in performance of an object or system over prolonged periods.

#35 – Adaptability or Versatility

Meaning: The extent to which a system / object is able to respond to external changes. Also, relates to a system capable of being used in multiple ways or under a variety of circumstances. Flexibility of operation or use. Customizability.

From four of parameters stated above, only parameter #35 can be used to solve this problem. That is by adaptability or also known as customizability. Other component can be attached to the juice extractor to make it work as one. In simple word, jug or glass is attached to the juice extractor to collect the juice and also the grater and it will complete as one process.

CHAPTER 6

DESIGN FOR ASSEMBLY (DfA) ANALYSIS FOR NEW DESIGN - TRIZ

6.1 Introduction

This chapter discusses the analysis result of the new design of Juice Extractor analyse by using Boothroyd Dewhurst DfA approach and TRIZ approach. The discussion will look into classification of each part for manual handling and insertion, DFA worksheet analysis, estimated assembly time and cost, and also design efficiency of the New Design-TRIZ of Juice Extractor.

6.2 Parts Identification

To facilitate identifying each part, numbering is used. The parts numbering and are simplified by the following Table 6.1. The Fruit Juice Extractor consists of 13 parts after using the DfA methodology.

Table 6.1: Parts Identification

No	Name of Part	ID No.	Quantity
1	Juice cup	13	1
2	Residue container	12	1
3	Vibration Damper	11	4
4	Motor	10	1
5	Stopper Screw	9	1
6	Lower Base	8	1
7	On/Off switch	7	1
8	Pin	6	2
9	Motor unit	5	1
10	Filter unit	4	1
11	Separating unit	3	1
12	Pusher	2	1
13	Protective cover	1	1

6.3 Parts Assembly Sequence

Figure 6.1 shows the product tree assembly structure for new design. The tree level has reduced from five levels to four levels. The level also represents the number of components. The parts reduced from 21 parts to 13 parts.

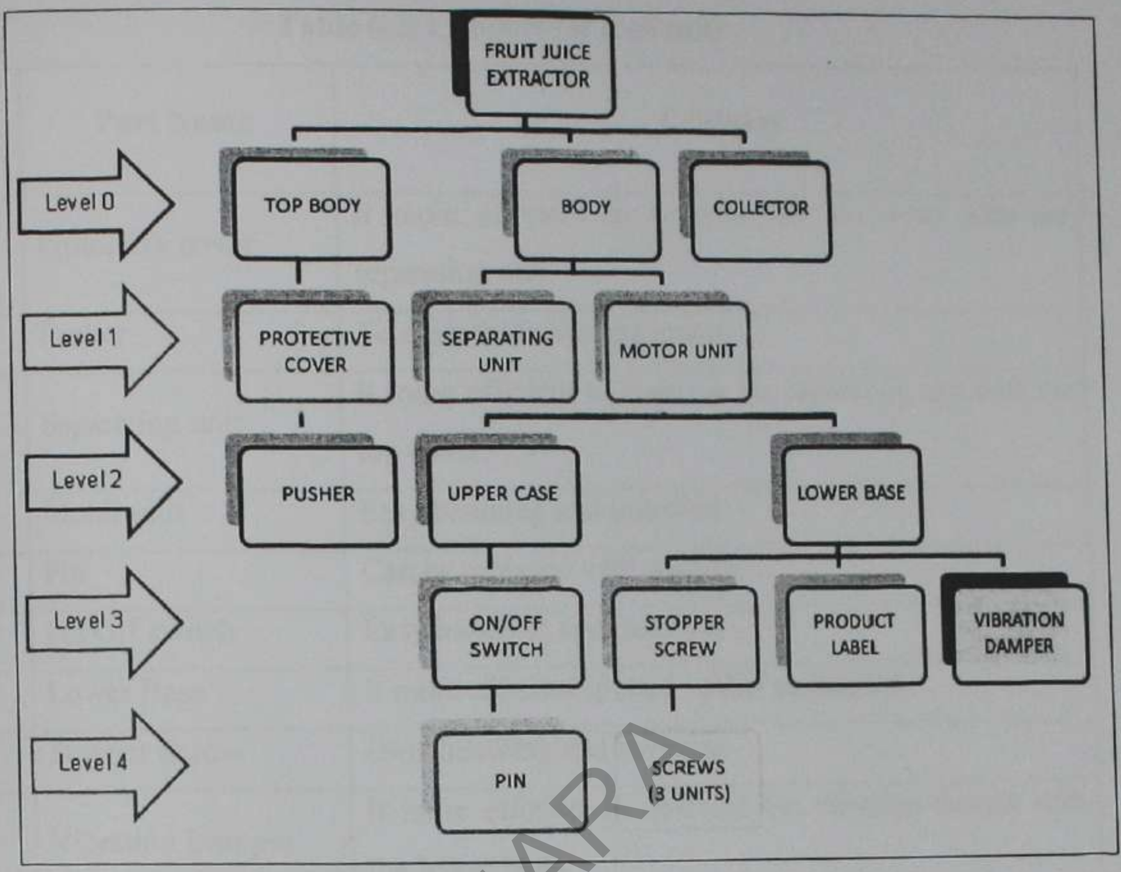


Figure 6.1: Product tree assembly structure – new design

6.4 Part Critiques

In order to understand the product characteristic and what its functions, each part is required to study and comment. Each part named, provided ID number, the function and gives some comment as shown in table 6.2.

Table 6.2: Critiques for each parts

Part No.	Part Name	Critiques
1	Protective cover	It more efficient to combine the top cover with the separating unit.
2	Pusher	To push fruits into the grater.
3	Separating unit	It more efficient to combine the separating unit with the top cover.
4	Motor unit	Easy handling and insertion
5	Pin	Can be replaced with snap fit.
6	On/Off switch	Easy handling and insertion
7	Lower Base	It more efficient to used rubber as material.
8	Stopper Screw	Easy handling and insertion
9	Vibration Damper	It more efficient to combine the vibration damper with the lower base.

6.5 Product Analysis

From the DFA worksheet analysis in table 6.3, the results of the estimated time, cost and design efficiency of the assembly are obtained. Below are the summary of the result for the new design analysis.

Total assembly time, TM = 53.33 seconds.

Total assembly cost, CM = 5.55698 cents.

Theoretical minimum number of part, NM = 12

The design efficiency of the new design is gained by using below formula;

$$DE = \frac{3 \times NM}{TM} \times 100\%$$

$$DE = \frac{3 \times 12}{53.33} \times 100\%$$

$$DE = 0.67504 \times 100\%$$

$$DE = 67.50\%$$

Table 6.3: DFA worksheet analysis for new design - TRIZ

0	1	2	3	4	5	6	7	8	9
Name of Part	Part ID#	# of times the operation is carried out consecutively	Two-digit manual handling code	Manual handling time per part	Two0digit manual insertion code	Manual insertion time per part	Operation time, sec, (2) x [(4) + (6)]	Operation cost, cents, 0.1042 (MYR) x (7)	Estimation of theoretical minimum # of parts, 0 or 1
Vibration Damper	9	4	30	2.70	30	2.00	14.10	1.46922	4
Stopper Screw	8	1	12	2.25	30	2.00	4.25	0.44285	1
Lower Base	7	1	12	2.25	01	2.50	4.75	0.49495	1
On/Off switch	6	1	12	2.25	30	2.00	4.25	0.44285	1
Pin	5	1	10	1.50	01	2.50	8.00	0.8336	1
Motor unit	4	1	02	1.88	30	2.00	3.88	0.404296	1
Separating unit	3	1	30	2.70	30	2.00	4.70	0.48974	1
Pusher	2	1	30	2.70	30	2.00	4.70	0.48974	1
Protective cover	1	1	30	2.70	30	2.00	4.70	0.48974	1
TOTAL							**53.33**	**5.55698**	**12**
							TM	**CM**	**NM**

6.6 Results

Refer to figure 6.2, design efficiency increased from 23.13% for original design to 61.88% through DfA methodology. New design through DfA still can be improved about 5.62% to 67.50% by using TRIZ methodology.

DE of Original Design		
Design Efficiency =	$\frac{(3) * NM}{TM}$ =	**23.13%**
DE of Improved Design through DFMA		
Design Efficiency =	$\frac{(3) * NM}{TM}$ =	**61.88%**
DE of Improved Design through TRIZ		
Design Efficiency =	$\frac{(3) * NM}{TM}$ =	**67.50%**

Figure 6.2: Design efficiency for original design, improved design through DfA and improved design through TRIZ

6.7 Summary

From integration DfA Methodology and TRIZ approach, several parts and problems or contradiction able to be solved. By using the TRIZ approach, it still able to be improved parts or component after the New Design – DfA by trimming and engineering contradiction.

After analysis by TRIZ method, total parts remain is 9 and Design Efficiency for this product has been increased to 67.50%. The use of DfA method and TRIZ approach showed that these product components can be improved the design of efficiency.

Table 6.4: Comparison results between original designs, improvement through DfA and TRIZ

ITEM	ORIGINAL	DfA	TRIZ
Total number of parts	21	13	9
Total of manual assembly time, TM	168.64 s	77.56 s	53.33 s
Total cost of manual assembly, CM	17.57 cents	8.08 cents	5.56 cents
Design efficiency, DE	23.13%	61.88%	67.50%

CHAPTER 7

DISCUSSION

7.1 Introduction

Comparison for both Design for Assembly (DfA) and integration of DfA methodology and TRIZ are discussed in this chapter.

7.2 Comparison between DfA and TRIZ

From the results shown in table 7.1, there are improvements in total number of parts, total of manual assembly time, total cost of manual assembly and also in design efficiency.

The total of manual assembly is reduced from 77.56 seconds to 53.33 seconds which it gives the differences about 30.77%. This is because the number of parts is reduced from 13 to 9. It gives the total differences 9.08% in design efficiency.

Table 7.1: Comparison between DfA and TRIZ methodology

ITEM	DfA	TRIZ	DIFFERENCES %
Total number of parts	13	9	30.77
Total of manual assembly time, TM	77.56 sec	53.33 sec	31.24
Total cost of manual assembly, CM	8.08 cents	5.56 cents	31.18
Design efficiency, DE	61.88%	67.50%	9.08

7.3 Summary

Integration of DfA and TRIZ methodology still can give positive impact to the design improvement even though both of methodologies emphasize two different aspects, quantitative and qualitative. Quantitative done in DfA and qualitative is done in TRIZ give significant impact in design efficiency of this case study product.

CHAPTER 8

CONCLUSION

8.1 Introduction

TRIZ is identified as a complimentary tool to DFMA methodology. This problem solving method based on creativity, logic, and data, which enhance the ability to solve the problem which might be seen tedious if using DFMA. DFMA however is best as quantitative improvement tool while TRIZ is more on qualitative improvement. Combining both methodologies act as complementary to each other which provide better tools to the design engineer in solving problem at early design stage.

The objective to integrate Design for Assembly (DFA) and Theory of Inventive Problem Solving (TRIZ) methodology in order to improve the design of consumer product is achieved. DFA methodology allow for simplifying the design which contribute to the design efficiency increment. Meanwhile, TRIZ concept using functions analysis, trimming method, contradiction philosophy, and inventive principles are systematic problem solving tools.

8.2 Future Recommendations

Integration between of DFA and TRIZ methodologies is used to improve design for the consumer product case study. The main methodology used is DfA and TRIZ methodology used as alternative method. By using the TRIZ methodology it is finding that this method still can improve the design methodology. DfA and TRIZ is not only method can be used as a tool for design improvement.

Below are suggested recommendations to be done in future for design improvement;

i. Implementation of Design for Manufacturing (DFM) methodology.
This method will support the results was obtained in DFA which emphasize on the selection of material and manufacturing process for the parts was designed under DFA and TRIZ methodology. It will ensure that designs are acceptable for ease of manufacturing point of view.

With this combination on DfA and DfM it will relates to the use of information that enables engineers to qualify the benefit of DFMA techniques and it relates to the potential benefits of incorporating the DFMA best practice knowledge base into the TRIZ framework.

ii. Integration of DFA with other design techniques such as axiomatic design, robust design (Taguchi Method) and Quality Function Deployment (QFD)

a. Axiomatic design is a system design methodology which using matrix methods that allows transformation of customer needs into functional requirements, design parameters and process variables systematically (Al Hamilton, 2006). The functional requirement (FRs) has strong interaction with the design parameters (DPs) (Michael S. Slocum, 2006). The name of this method is based on the design parameter or called as design Axiom. The analysis based on two important parameters known as 'The Independence Axiom' and 'The Information Axiom'. The main benefit of this design is it's emphasize on customer needs to the design process which giving more opportunity to the market sales.

b. Robust Design also known as Taguchi Method was introduced by Genichi Taguchi (Genichi Taguchi, 2008), This method focus on the improving to the fundamental function of the product / process by facilitating flexible design and concurrent engineering. According to Taguchi, a robust design is a product whose performance is minimally sensitive to the variations. The first concept in robust design of a product is to select the technical means in order to meet a specific objective function. In designing or developing a new product / design, improvements to the product are depending to the amount of control variables which means that the more complex the higher the degree of improvement. Each control variables then transform to the generic function. The selection of generic function should meet the requirements objective of function. The proper selection of generic functions are based on the following strategies:

- Error-free implementation using a collection of historical of knowledge and experience.
- Generation of new design information used for improving quality, reliability, performance of the product/process as well as reducing the associated cost.

The benefits of this method is allow for flexibility of the product design which enable to scale up or scale down according to the range and optimization required (Madhav S. Phadke, 2010).

c. QFD is a systematic way for developing products based on the needs of the customer which was introduced by Yoji Akao from Tokyo in 1966 Yoji Akao (1990). The goals of this method are to recognize correlations between the customer needs and product characteristics identify the product characteristics that affect specific customer requirements and recognize correlations within the engineering characteristics. House of Quality (HOQ) is an importance matrix technique which studies the relationship between customer requirements and engineering features. The strengths of this method are the product meet the customer needs and provide a competitive in market. However, this method is lack of scientific basis. But, if this method integrates with DFMA it will complement each other (Chung-Shing, W. and Teng-Ruey C., 2007).

iii. Integration TRIZ with other DFA methods such as Hitachi AEM and Lucas-Hull.

a. Hitachi AEM study the motions and operations required to assemble the product. This method use penalty system to the motions that differ from the ideal. The ideal motion is define as easiest and fastest downwards motions. Similar to Boothroyd-Dewhust, assembly are decomposed into parts, then re-assemble. During re-assemble activity, each motion will be recorded into a table and given penalty. Then, the total assembly processes is compared to the ideal assembly process. From the table, several metrics such as Assembly Time, Assembly Cost Ratios and Simplicity Factor can be evaluated. The lack of this method, it is highly confidential.

b. The Lucas Hull method encompasses into three analyses – functional; handling and fitting. Similar to the Hitachi method, penalty factors are assigning and summing to identify potential design problems with the inclusion of handling and insertion. By using standard chart, the penalty factor are combined with an assembly sequence to generate three 'assemblablity' score which are design efficiency, feeding / handling ratio and fitting ratio. Parts undergo functional analysis is categorize into A (essential) part or B (non-essential) part. The design efficiency is derived from the ratio of total essential parts (A / (A+B)). The handling analysis examines each to determine a feeding index. This index has a threshold value. Any value greater than the threshold value will be considered to redesign. Fitting analysis has similar formula as feeding analysis. A fitting index and ratio are determined. The scores then compared to threshold value that established for the previous design. The weakness of this method is lack of scientific basis as compared to the Boothryd-Dewhurst methodology.

8.3 Concluding Remarks

As a conclusion, integration of DFA and TRIZ has significant impact to the design improvement. DfA allow for simplifying the design which contributes to the reduction number of parts and reduction of manual assembly time and costs. Finally, DfA will increase the design efficiency of the product case study.

TRIZ is a systematic methodology as problem solving tool based to the systematic guidelines. TRIZ proposed on 'how to solve' which create potential solution based on inventive principles and creatively work.

8.4 Summary

As a summary, DFMA offers a design evaluation process that measures the economical assemblability and manufacturability of a given product design, indicates its weak points, provides rules that help direct design improvement, and compares the results before and after the improvement.

However, while useful in terms of helping to define problems and opportunities, and good at helping to analyse and rank solutions, between the two, at the "now generate some good ideas" stage, DFMA is somewhat limited. Design teams are expected to resort to the brainstorming and trial-and-error approach. But no amount of favourable environment will draw out solutions that rely on knowledge that none of the participants are aware of, the best solution may even require a "definition shift" i.e. the complete redefinition of the problem. The application of TRIZ offers the solution.

The TRIZ tool may be used on a variety of problems or when a new inventive solution is necessary and it has evolved into a system that can be the cornerstone of a company's innovation practice. It can be used effectively as an iterative tool with DFMA when the initial analysis does not meet the cost target for a given product as set either internally, by the customer, or by market conditions.

Combination of DFMA and TRIZ will help manufacturing organizations apply new technology to their products and processes to be successful in the highly competitive global marketplace.

APPENDIX A – Gantt chart for MP I Session 2012/2013

GANTT CHART

MP I , SESSION 2012/2013

ACTIVITIES	WW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Date	20-26/2	27-4/3	5-11/3	12-18/3	19-25/3	26-1/4	2-8/4	9-15/4	16-22/4	23-29/4	30-6/5	7-13/5	14-20/5	21-27/5	28-3/6	4-10/6	11-17/6	18-24/6	25-1/7
Registration & Project 1 Briefing	Plan																			
	Actual																			
TRIZ and DFMA Review	Plan																			
	Actual																			
Selection of Product Case study- Kettle, Water Sprinkler, Steam iron, **Freshner**	Plan																			
	Actual																			
Design For Assembly for original design- Dismental, Part list &photo,	Plan																			
	Actual																			
Design For Assembly for Redesign	Plan																			
	Actual																			
Draf / Report Writing- Introduction of DFMA	Plan																			
	Actual																			
Project Presentation	Plan																			
	Actual																			

Draf/Report Submission	Plan
	Actual

*The proposed duration of the research is 12 months, from March 2012 to February 2013

** Base on this semester schedule

APPENDIX B – Gantt chart for MP II Session 2012/2013

GANTT CHART

MP II , SESSION 2012/2013

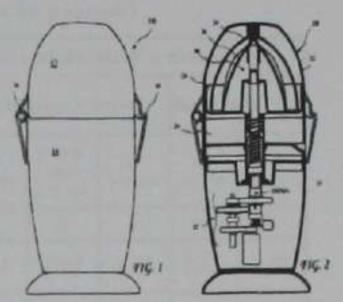
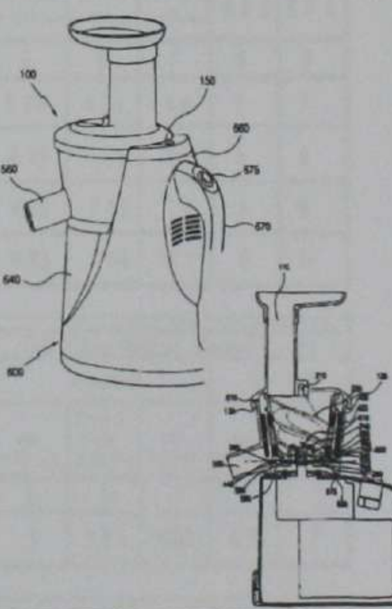
ACTIVITIES	WW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Date	15/9	22/9	29/9	6/10	13/10	20/10	27/10	3/11	10/11	17/11	24/11	1/12	8/12	15/12	22/12	29/12	5/01	12/01	19/01
Design Evaluation using TRIZ	Plan																			
	Actual																			
Design Improvement using TRIZ	Plan																			
	Actual																			
Intergration of DfA and TRIZ (Final Design)	Plan																			
	Actual																			
Report Writing	Plan																			
	Actual																			
Project Presentation Project 2	Plan																			
	Actual																			

Draft Report Submission	Plan
	Actual

*The proposed duration of the research is 12 months, from March 2012 to February 2013

** Base on next semester schedule

APPENDIX C – PATENT

No	Inventor	Summary	Features
1	**AUTOMATED JUICE EXTRACTOR** Adrian Rivera, Whittier CA 2012	An automatic juicer turns and pushes an upward facing juicing cone into a fruit for releasing and collecting juice. The juicer includes a base containing a motor, gear and shaft assembly which rises as a unit with the juicing cone. A fixed guide extends upward from the base and inner and outer shafts reside inside the fixed guide and are driven by the motor and gear assembly to rotate and advance the juicing cone into the fruit. The juicing cone, strainer and a bowl release and catch the juice. The outer shaft includes threads to vertically advance and retreat the outer and inner shafts when the outer shaft turns. The inner shaft rises with the outer shaft and lifts and rotates the juicing cone, thereby releasing juice from the fruit. The bowl is fixed to the base.	
2	**JUICE EXTRACTOR** Young-Ki Kim, Gim hae-si KR 2012	A juice extractor capable of extracting juice from vegetables, fruits or soymilks from beans is disclosed. The extractor includes a housing having a draf outlet port and a juice outlet port, a screw having an upper rotary shaft inserted in a rotary shaft hole of the housing and a lower rotary shaft with a plurality of screw spirals formed on an outer periphery thereof, and a mesh drum for extracting the juice toward the juice outlet port, and a rotary brush mounted between the housing and the mesh drum and having a brush holder. Since the housing accommodating the screw is vertically fixed to an upper portion of a drive unit, the material is automatically moved downward without pressing the material down, and the draft is discharged while squeezing and grinding the materials put in an inlet port.	

APPENDIX D - BOOTHROYD DEWHURST MANUAL HANDLING TIME

MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key:

ONE HAND

		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand without the aid of grasping tools: (α + β) < 360°	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
360° ≤ (α + β) < 540°	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
540° ≤ (α + β) < 720°	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
(α + β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS

		parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
		parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
		parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
		thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand but only with the use of grasping tools: α ≤ 180°, 0 ≤ β ≤ 180°	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
α ≤ 180°, β = 360°	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
α = 360°, 0 ≤ β ≤ 180°	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
α = 360°, β = 360°	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		α ≤ 180°			α = 360°		α ≤ 180°			α = 360°	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS or assistance required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°		
		0	1	2	3	4	5	6	7	8	9
two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

APPENDIX E - BOOTHROYD DEWHURST MANUAL INSERTION TIME

MANUAL INSERTION – ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

			after assembly no holding down required to maintain orientation and location (3): easy to align and position during assembly (4): no resistance to insertion	after assembly no holding down required …: easy to align and position during assembly (4): resistance to insertion (5)	after assembly no holding down required …: not easy to align or position during assembly: no resistance to insertion	after assembly no holding down required …: not easy to align or position during assembly: resistance to insertion (5)	holding down required during subsequent processes to maintain orientation or location (3): easy to align and position during assembly (4): no resistance to insertion	holding down required …: easy to align and position during assembly (4): resistance to insertion (5)	holding down required …: not easy to align or position during assembly: no resistance to insertion	holding down required …: not easy to align or position during assembly: resistance to insertion (5)
			0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately	part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
	part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Key: PART SECURED IMMEDIATELY

			no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.): easy to align and position with no resistance to insertion (4)	no screwing operation or plastic deformation …: not easy to align or position during assembly and/or resistance to insertion (5)	plastic deformation immediately after insertion: plastic bending or torsion: easy to align and position during assembly (4)	plastic deformation …: plastic bending or torsion: not easy to align or position during assembly: no resistance to insertion	plastic deformation …: plastic bending or torsion: not easy to align or position during assembly: resistance to insertion (5)	plastic deformation …: riveting or similar operation: easy to align and position during assembly (4)	plastic deformation …: riveting or similar operation: not easy to align or position during assembly: no resistance to insertion	plastic deformation …: riveting or similar operation: not easy to align or position during assembly: resistance to insertion (5)	screw tightening immediately after insertion: easy to align and position with no torsional resistance (4)	screw tightening immediately after insertion: not easy to align or position and/or torsional resistance (5)
			0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately	part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
	part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

Key: SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion): none or localized plastic deformation: bending or similar processes	mechanical fastening processes …: none or localized plastic deformation: riveting or similar processes	mechanical fastening processes …: none or localized plastic deformation: screw tightening or other processes	mechanical fastening processes …: bulk plastic deformation (large proportion of part is plastically deformed during fastening)	non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion): metallurgical processes: no additional material required (e.g. resistance, friction welding, etc.)	non-mechanical fastening processes …: metallurgical processes: additional material required: soldering processes	non-mechanical fastening processes …: metallurgical processes: additional material required: weld/braze processes	non-mechanical fastening processes …: chemical processes (e.g. adhesive bonding, etc.)	non-fastening processes: manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	non-fastening processes: other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	12	7	8	12	12	9	12

APPENDIX F – TRIZ CONTRADICTION TABLE

What is deteriorated?

	What should be improved?	Weight of movable object (1)	Weight of fixed object (2)	Length of movable object (3)	Length of fixed object (4)	Area of movable object (5)
1	Weight of movable object			15 8 29 34		29 17 38 34
2	Weight of fixed object				10 1 29 35	
3	Length of movable object	8 15 29 34				15 17 4
4	Length of fixed object		35 28 40 29			
5	Area of movable object	2 17 29 4		14 15 18 4		
6	Area of fixed object		30 2 14 18		26 7 9 39	
7	Volume of movable object	2 26 29 40		1 7 35 4		1 7 4 17
8	Volume of fixed object		35 10 19 14	19 14	35 8 2 14	
9	Speed	2 28 13 38		13 14 8		29 30 34
10	Force	8 1 37 18	18 13 1 28	17 19 9 36	28 10	19 10 15
11	Stress, Pressure	10 36 37 40	13 29 10 18	35 10 36	35 1 14 16	10 15 36 28
12	Shape	8 10 29 40	15 10 26 3	29 34 5 4	13 14 10 7	5 34 4 10
13	Object's composition	21 35 2 39	26 39 1 40	13 15 1 28	37	2 11 13
14	Strength	1 8 40 15	40 26 27 1	1 15 8 35	15 14 28 26	3 34 40 29
15	Duration of moving object's operation	19 5 34 31		2 19 9		3 17 19
16	Duration of fixed object's operation		6 27 19 16		1 40 35	
17	Temperature	36 22 6 38	22 35 32	15 19 9	15 19 9	3 35 39 18
18	Illumination	19 1 32	2 35 32	19 32 16		19 32 26
19	Energy expenses of movable object	12 18 28 31		12 28		15 19 25
20	Energy expenses of fixed object		19 9 6 27			

What is deteriorated?

	What should be improved?	6 Area of fixed object	7 Volume of movable object	8 Volume of fixed object	9 Speed	10 Force
1	Weight of movable object		29 2 40 28		2 8 15 38	8 10 18 37
2	Weight of fixed object	35 30 13 2		5 35 14 2		8 10 19 35
3	Length of movable object		7 17 4 35		13 4 8	17 10 4
4	Length of fixed object	17 7 10 40		35 8 2 14		28 10
5	Area of movable object		7 14 17 4		29 30 35 2	19 30 35 2
6	Area of fixed object					1 18 35 36
7	Volume of movable object				29 4 38 34	15 35 36 37
8	Volume of fixed object					2 18 37
9	Speed		7 29 34			13 28 15 19
10	Force	1 18 36 37	15 9 12 37	2 36 18 37	13 28 15 12	
11	Stress, Pressure	10 15 36 37	6 35 10	35 24	6 35 36	36 35 21
12	Shape		14 4 15 22	7 2 35	35 15 34 18	35 10 37 40
13	Object's composition	39	28 10 19 39	34 28 35 40	33 15 28 18	10 35 21 16
14	Strength	9 40 28	10 15 14 7	9 14 17 15	8 13 26 14	10 18 3 14
15	Duration of moving object's operation		10 2 19 30		3 35 5	19 2 16
16	Duration of fixed object's operation			35 34 38		
17	Temperature	35 38	34 39 40 18	35 6 4	2 28 36 30	35 10 3 21
18	Illumination		2 13 10		10 13 19	26 19 6
19	Energy expenses of movable object		35 13 18		8 15 35	16 26 21 2
20	Energy expenses of fixed object					36 37

What is deteriorated?

	What should be improved?	11 Stress, Pressure	12 Shape	13 Object's composition	14 Strength	15 Duration of moving object's operation
1	Weight of movable object	10 36 37 40	10 14 35 40	1 35 19 39	28 27 18 40	5 34 31 35
2	Weight of fixed object	13 29 10 18	13 10 29 14	26 39 1 40	28 2 10 27	
3	Length of movable object	1 8 35	1 8 10 29	1 8 15 34	8 35 29 34	19
4	Length of fixed object	1 14 35	13 14 15 7	39 37 35	15 14 28 26	
5	Area of movable object	10 15 36 28	5 34 29 4	11 2 13 39	3 15 40 14	6 3
6	Area of fixed object	10 15 36 37		2 38	40	
7	Volume of movable object	6 35 36 37	1 15 29 4	28 10 1 39	9 14 15 7	6 35 4
8	Volume of fixed object	24 35	7 2 35	34 28 35 40	9 14 17 15	
9	Speed	6 18 38 40	35 15 18 34	28 33 1 18	8 3 26 14	3 19 35 5
10	Force	18 21 11	10 35 40 34	35 10 21	35 10 14 27	19 2
11	Stress, Pressure		35 4 15 10	35 33 2 40	9 18 3 40	19 3 27
12	Shape	34 15 10 14		33 1 18 4	30 14 10 40	14 26 9 25
13	Object's composition	2 35 40	22 1 18 4		17 9 15	13 27 10 35
14	Strength	10 3 18 40	10 30 35 40	13 17 35		27 3 26
15	Duration of moving object's operation	19 3 27	14 26 28 25	13 3 35	27 3 10	
16	Duration of fixed object's operation			39 3 35 23		
17	Temperature	35 39 19 2	14 22 19 32	1 35 32	10 30 22 40	19 3 39
18	Illumination		32 30	32 3 27	35 19	2 19 6
19	Energy expenses of movable object	23 14 25	12 2 29	19 13 17 24	5 19 9 35	28 35 6 18
20	Energy expenses of fixed object			27 4 29 18	35	

What is deteriorated?

	What should be improved?	16 Duration of fixed object's operation	17 Temperature	18 Illumination	19 Energy expenses of movable object	20 Energy expenses of fixed object
1	Weight of movable object		6 29 4 38	19 1 32	25 12 34 31	
2	Weight of fixed object	2 27 19 6	28 19 32 22	35 19 35		18 19 28 1
3	Length of movable object		10 15 19	32	8 35 24	
4	Length of fixed object	1 40 35	3 35 38 18	3 25		
5	Area of movable object		2 15 16	15 32 19 13	19 32	
6	Area of fixed object	2 10 19 30	35 39 38			
7	Volume of movable object		34 39 10 18	10 13 2	35	
8	Volume of fixed object	35 34 38	35 6 4			
9	Speed		28 30 36 2	10 13 19	8 15 35 38	
10	Force		35 10 21		19 17 10	1 16 36 37
11	Stress, Pressure		35 39 19 2		14 24 10 37	
12	Shape		22 14 19 32	13 15 32	2 6 34 14	
13	Object's composition	39 3 35 23	35 1 32	32 3 27 15	13 19	27 4 29 18
14	Strength		30 10 40	35 19	19 35 10	35
15	Duration of moving object's operation		19 35 39	2 19 4 35	28 6 35 18	
16	Duration of fixed object's operation		19 18 36 40			
17	Temperature	19 18 36 40		32 30 21 16	19 15 3 17	
18	Illumination		32 35 19		32 1 19	32 35 1 15
19	Energy expenses of movable object		19 24 3 14	2 15 19		
20	Energy expenses of fixed object			19 2 35 32		

What is deteriorated?

	What should be improved?	21 Power	22 Waste of energy	23 Loss of substance	24 Loss of information	25 Waste of time
1	Weight of movable object	13 36 18 31	6 2 34 19	5 35 3 31	10 24 35	10 35 20 28
2	Weight of fixed object	15 19 18 22	18 19 28 15	5 8 13 30	10 15 35	10 20 35 26
3	Length of movable object	1 35	7 2 35 39	4 29 23 10	1 24	15 2 29
4	Length of fixed object	12 8	6 28	10 28 24 35	24 26	30 29 14
5	Area of movable object		12 8	6 28	10 28 24 35	24 26
6	Area of fixed object	17 32	17 7 30	10 14 18 39	30 16	10 35 4 18
7	Volume of movable object	35 6 13 18	7 15 13 16	36 39 34 10	2 22	2 6 34 10
8	Volume of fixed object	30 6		10 39 35 34		35 16 32 18
9	Speed	19 35 38 2	14 20 19 35	10 13 28 38	13 26	
10	Force	19 35 18 37	14 15	8 35 40 5		10 37 36
11	Stress, Pressure	10 35 14	2 36 25	10 36 3 37		37 36 4
12	Shape	4 6 2	14	35 29 3 5		14 10 34 17
13	Object's composition	32 35 27 31	14 2 39 6	2 14 30 40		35 27
14	Strength	10 26 35 28	35	35 28 31 40		29 3 28 10
15	Duration of moving object's operation	19 10 35 38		28 27 3 18	10	20 10 28 18
16	Duration of fixed object's operation	16		27 16 18 36	10	28 20 10 16
17	Temperature	2 14 17 25	21 17 35 38	21 36 29 31		35 28 21 18
18	Illumination	32	19 16 1 6	13 1	1 6	19 1 26 17
19	Energy expenses of movable object	6 19 37 18	12 22 15 24	35 24 18 5		35 38 19 18
20	Energy expenses of fixed object			28 27 18 31		

What is deteriorated?

	What should be improved?	Quantity of substance 25	Reliability 26	Measurement accuracy 28	Manufacturing precision 29	Harmful action at object 30
1	Weight of movable object	3 26 18 31	3 11 1 27	28 27 35 26	28 35 26 18	22 21 18 27
2	Weight of fixed object	19 6 18 26	10 28 8 3	18 26 28	10 1 35 17	2 19 22 37
3	Length of movable object	29 35	10 14 29 40	28 32 4	10 28 29 37	1 15 17 24
4	Length of fixed object		15 29 28	32 28 3	2 32 10	1 18
5	Area of movable object	30 29 14	29 9	26 28 32 3	2 32	22 33 28 1
6	Area of fixed object	2 18 40 4	32 35 40 4	26 28 32 3	2 29 18 36	27 2 39 35
7	Volume of movable object	29 30 7	14 1 40 11	25 26 28	25 28 2 16	22 21 27 35
8	Volume of fixed object	35 3	2 35 16		35 10 25	34 39 19 27
9	Speed	10 19 29 38	11 35 27 28	28 32 1 24	10 28 32 35	1 28 35 23
10	Force	14 29 18 36	3 35 13 21	35 10 23 24	28 29 37 36	1 35 40 18
11	Stress, Pressure	10 14 36	10 13 19 35	6 28 25	3 35	22 2 37
12	Shape	36 22	10 40 16	28 32 1	32 30 40	22 1 2 35
13	Object's composition	15 32 35		13	18	35 24 18 30
14	Strength	29 10 27	11 3	3 27 16	3 27	18 35 37 1
15	Duration of moving object's operation	3 35 10 40	11 2 13	3	3 27 16 40	22 15 33 28
16	Duration of fixed object's operation	3 35 10 40	34 27 6 40	10 26 24		17 1 40 33
17	Temperature	3 17 30 39	19 35 3 10	32 19 24	24	22 33 35 2
18	Illumination	1 19		11 15 32	3 32	15 19
19	Energy expenses of movable object	34 23 16 18	19 21 11 27	3 1 32		1 35 6 27
20	Energy expenses of fixed object	3 35 31	10 36 23			10 2 22 37

What is deteriorated?

	What should be improved?	Harmful effect caused by the object 31	Ease of manufacture 32	Ease of operation 33	Ease of repair 34	Adaptation 35
1	Weight of movable object	22 35 31 39	27 28 1 36	35 3 2 24	2 27 28 11	29 5 15 8
2	Weight of fixed object	35 22 1 39	28 1 9	6 13 1 32	2 27 28 11	19 15 29
3	Length of movable object	17 15	1 29 17	15 29 35 4	1 28 10	14 15 1 16
4	Length of fixed object		15 17 27	2 25	3	1 35
5	Area of movable object	17 2 18 39	13 1 26 24	15 17 13 16	15 13 10 1	15 30
6	Area of fixed object	22 1 40	40 16	16 4	16	15 16
7	Volume of movable object	17 2 18 39	15 17 13 16	15 13 30 12	10	15 29
8	Volume of fixed object	30 18 35 4	35		1	
9	Speed	2 24 35 21	35 13 8 1	32 28 13 12	34 2 28 27	15 10 26
10	Force	13 3 36 24	15 37 18 1	1 28 3 25	15 1 11	15 17 18 20
11	Stress, Pressure	2 33 27 18	1 35 16	11	2	35
12	Shape	35 1	1 32 17 28	32 15 26	2 13 1	1 15 29
13	Object's composition	35 40 27 39	35 19	32 35 30	2 15 10 16	35 30 34 2
14	Strength	15 35 22 2	11 3 10 32	32 40 28 2	27 11 3	15 32 3
15	Duration of moving object's operation	21 39 16 22	27 1 4	12 27	29 10 27	1 35 13
16	Duration of fixed object's operation	22	35 10	1	1	2
17	Temperature	22 35 2 24	26 27	26 27	4 10 16	2 18 27
18	Illumination	35 19 32 39	19 35 28 26	28 26 19	15 17 13 16	15 1 19
19	Energy expenses of movable object	2 35 6	28 26 30	19 35	1 15 17 28	15 17 13 16
20	Energy expenses of fixed object	19 22 18	1 4			

What is deteriorated?

	What should be improved?	36 Device complexity	37 Measurement for test complexity	38 Degree of automation	39 Productivity
1	Weight of movable object	26 30 36 34	28 29 26 32	26 35 18 19	35 3 24 37
2	Weight of fixed object	1 10 26 39	25 28 17 15	2 26 35	1 28 15 35
3	Length of movable object	1 19 26 24	35 1 26 24	17 24 26 16	14 4 28 29
4	Length of fixed object	1 26	26		30 14
5	Area of movable object	14 1 13	2 36 26 18	14 30 28 23	10 26 34 2
6	Area of fixed object	1 18 36	2 35 30 18	23	10 15 17 7
7	Volume of movable object	26 1	29 26 4	35 34 16 24	10 6 2 34
8	Volume of fixed object	1 31	2 17 26		35 37 10 2
9	Speed	10 28 4 34	3 34 27 16	10 18	
10	Force	26 35 10 18	36 37 10 19	2 35	3 28 35 37
11	Stress, Pressure	19 1 35	2 36 37	35 24	10 14 35 37
12	Shape	16 29 1 28	15 13 39	15 1 32	17 26 34 10
13	Object's composition	2 35 22 26	35 22 39 23	1 8 35	23 35 40 3
14	Strength	2 13 28	27 3 15 40	15	29 35 10 14
15	Duration of moving object's operation	10 4 29 35	19 29 39 35	6 10	35 17 14 19
16	Duration of fixed object's operation		25 14 6 35	1	20 10 16 38
17	Temperature	2 17 16	3 27 35 31	26 2 19 16	15 28 35
18	Illumination	6 32 13	32 15	2 26 10	15 28 35
19	Energy expenses of movable object	2 29 27 28	35 38	32 2	12 28 35
20	Energy expenses of fixed object		19 35 16 25		1 6

What is deteriorated?

What should be improved?		1 Weight of movable object	2 Weight of fixed object	3 Length of movable object	4 Length of fixed object	5 Area of movable object
21	Power	8 36 38 31	19 26 17 27	1 10 35 37		19 38
22	Waste of energy	15 6 19 28	19 6 18 9	7 2 6 13	6 38 7	15 26 17 30
23	Loss of substance	35 6 23 40	35 6 22 32	14 29 10 39	10 28 24	35 2 10 31
24	Loss of information	10 24 35	10 35 5	1 26	26	30 26
25	Waste of time	10 20 37 35	10 20 26 5	15 2 29	30 24 14 5	26 4 5 16
26	Quantity of substance	35 6 18 31	27 26 18 35	29 14 35 18		15 14 29
27	Reliability	3 8 10 40	3 10 8 28	15 9 14 4	15 29 28 11	17 10 14 16
28	Measurement accuracy	32 35 26 28	28 35 25 26	28 26 5 16	32 28 3 16	26 28 32 3
29	Manufacturing precision	28 32 13 18	28 35 27 9	10 28 29 37	2 32 10	28 33 29 32
30	Harmful action at object	22 21 27 39	2 22 13 24	17 1 39 4	1 18	22 1 33 28
31	Harmful effect caused by the object	19 22 15 39	35 22 1 39	17 15 16 22		17 2 18 39
32	Ease of manufacture	28 29 15 16	1 27 36 13	1 29 13 17	15 17 27	13 1 26 12
33	Ease of operation	25 2 13 15	6 13 1 25	1 17 13 12		1 17 13 16
34	Ease of repair	2 27 35 11	2 27 35 11	1 28 10 25	3 18 31	15 13 32
35	Adaptation	1 6 15 8	19 15 29 16	35 1 29 2	1 35 16	35 30 29 7
36	Device complexity	26 30 34 36	2 26 35 39	1 19 26 24	26	14 1 13 16
37	Measurement for test complexity	27 26 28 13	6 13 28 1	16 17 26 24	26	2 13 18 17
38	Degree of automation	28 26 18 35	28 26 35 10	14 13 28 17	23	17 14 13
39	Productivity	35 26 24 37	28 27 15 3	18 4 28 38	30 14 26 7	10 26 34 31

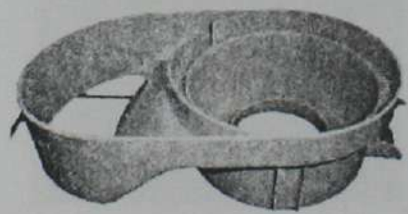
What is deteriorated?

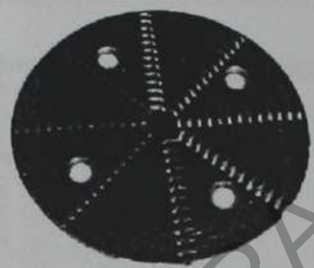
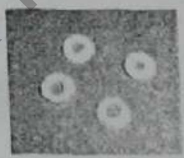
	What should be improved?	Area of fixed object 6	Volume of movable object 7	Volume of fixed object 8	Speed 9	Force 10
21	Power	17 32 13 38	35 6 38	30 6 25	15 35 2	26 2 36 35
22	Waste of energy	17 7 30 18	7 18 23	7	16 35 38	36 38
23	Loss of substance	10 18 39 31	1 29 30 36	3 39 18 31	10 13 28 38	14 15 18 40
24	Loss of information	30 16		2 22	26 32	
25	Waste of time	10 35 17 4	2 5 34 10	35 16 32 18		10 37 36 5
26	Quantity of substance	2 18 40 4	15 20 29		35 29 34 28	35 14 3
27	Reliability	32 35 40 4	3 10 14 24	2 35 24	21 35 11 28	8 28 10 3
28	Measurement accuracy	26 28 32 3	32 13 6		28 13 32 24	32 2
29	Manufacturing precision	2 29 18 36	32 28 2	25 10 35	10 28 32	28 19 34 36
30	Harmful action at object	27 2 39 35	22 23 37 35	34 39 19 27	21 22 35 28	13 35 39 18
31	Harmful effect caused by the object					
32	Ease of manufacture	16 40	13 29 1 40	35	35 13 8 1	35 12
33	Ease of operation	18 16 15 39	1 16 35 15	4 18 39 31	18 13 34	28 13 35
34	Ease of repair	16 25	25 2 35 11	1	34 9	[illegible] 10
35	Adaptation	15 16	15 35 29		35 10 14	15 17 20
36	Device complexity	6 36	34 26 6	1 16	34 10 28	26 16
37	Measurement for test complexity	2 39 30 16	29 1 4 16	2 18 26 31	3 4 16 35	36 28 40 19
38	Degree of automation	[illegible]	35 13 16		28 10	2 35
39	Productivity	10 35 17 7	2 6 34 10	35 37 10 2		28 15 10 36

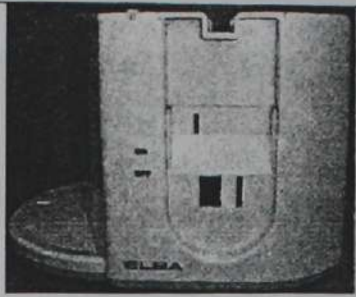
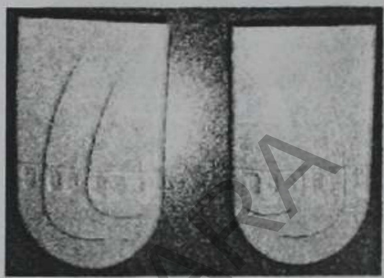
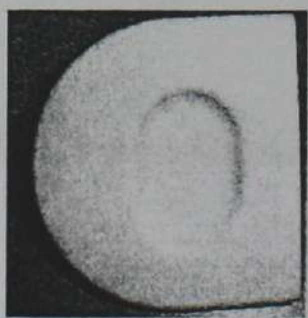
What is deteriorated?

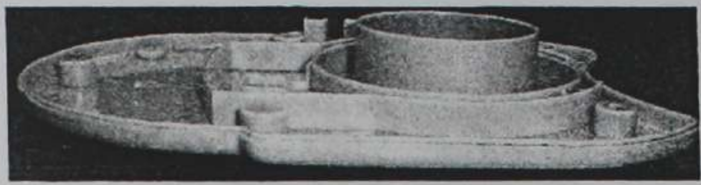
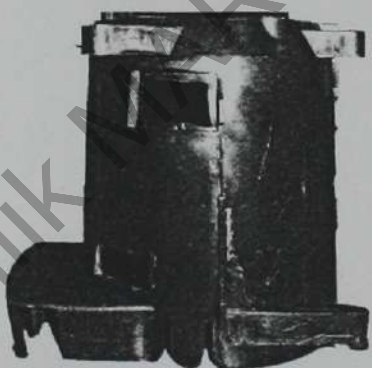
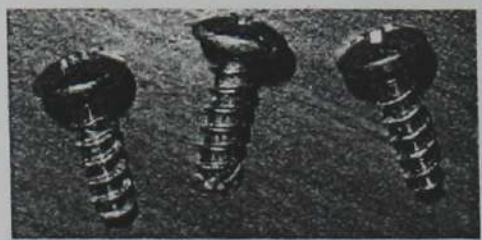
	What should be improved?	11 Stress, Pressure	12 Shape	13 Object's composition	14 Strength	15 Duration of moving object's operation
21	Power	22 10 35	29 14 2 40	35 32 15 31	26 10 28	19 35 10 38
22	Waste of energy			14 2 39 6	26	
23	Loss of substance	3 36 37 10	29 35 3 5	2 14 30 40	35 28 31 40	28 27 3 18
24	Loss of information					10
25	Waste of time	36 37 4	4 10 34 17	35 3 22 5	29 3 28 18	20 10 28 18
26	Quantity of substance	10 36 14 3	35 14	15 2 17 40	14 35 34 10	3 35 10 40
27	Reliability	10 24 35 19	35 1 16 11		11 28	2 35 3 25
28	Measurement accuracy	6 28 32	6 28 32	32 35 13	28 6 32	28 6 32
29	Manufacturing precision	3 35	32 30 40	30 18	3 27	3 27 40
30	Harmful action at object	22 2 37	22 1 3 35	35 24	18 35 37 1	22 15 33 28
31	Harmful effect caused by the object				15 35 22 2	15 22 33 31
32	Ease of manufacture	35 19 1 37	1 28 13 27	11 13 1	1 3 10 32	27 1 4
33	Ease of operation	2 32 12	15 34 29 28	32 35 30	32 40 3 28	29 3 8 25
34	Ease of repair	13	1 13 2 4	2 35	1 11 2 9	11 29 28 27
35	Adaptation	35 16	15 37 1 8	35 30 14	35 3 32 6	13 1 35
36	Device complexity	19 1 35	29 13 28 15	2 22 17 19	2 13 28	10 4 28 15
37	Measurement for test complexity	35 36 37 32	27 13 1 39	11 22 39 30	27 3 15 28	19 29 25 39
38	Degree of automation	13 35	15 32 1 13	18 1	25 13	6 9
39	Productivity	10 37 14	10 10 34 40	35 3 22 39	29 28 10 18	35 10 2 18

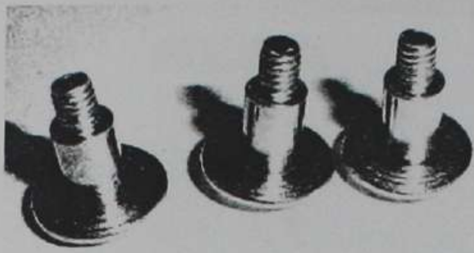
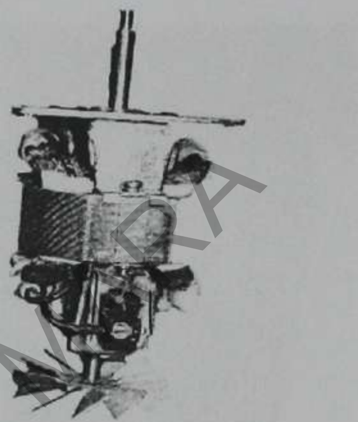
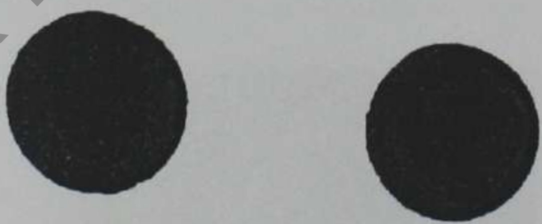
APPENDIX G – PRODUCT COMPONENT

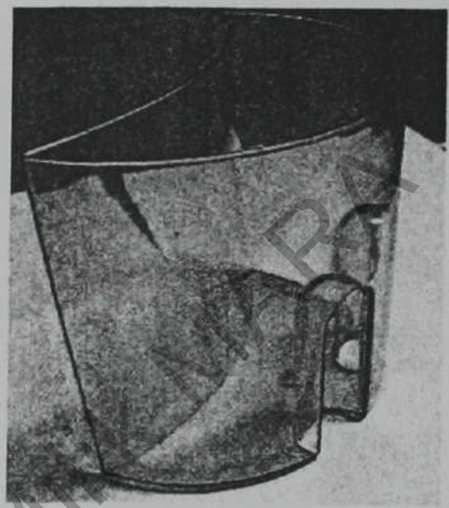
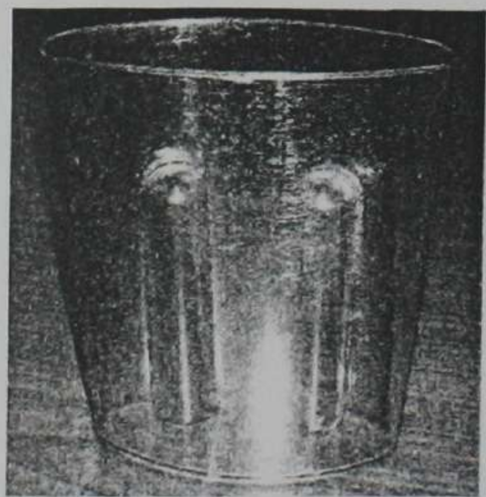
Part No.	Part Name
1	 Protective cover
2	 Pusher
3	 Separating unit

4	 Filter unit
5	 Grater
6	 Washer
7	 Juice spout

8	 Motor unit
9	 Safety lock
10	 Pin
11	 On/Off switch

12	 Lower Base
13	 Stopper Screw
14	 Motor Casing
15	 Screw

16	 Screw
17	 Motor
18	 Vibration Damper
19	 Screw

20	 Product Label
21	 Residue container
22	 Juice cup