PRODUCT DESIGN OPTIMIZATION USING DESIGN FOR MANUFACTURE AND ASSEMBLY APPROACHES

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A report submitted in partial fulfillment of the requirement for the award of the degree of Bachelor of Mechanical Engineering
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I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering (Design-Innovation).

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I declare that this report entitled "PRODUCT DESIGN OPTIMIZATION USING DESIGN FOR MANUFACTURE AND ASSEMBLY APPROACHES." is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Design for Manufacture and Assembly (DFMA) were developed in order to help designers identify the manufacturing and assembly difficulties during the early stage of designing process. By applying DFMA, the assembly cost and time can be reduced and DFMA also ensure a smooth transition from design to production phase. Based on this fact, this thesis will presents a case study done to a selected product by using two DFMA methodologies that are Lucas-Hull DFA and Boothroyd-Dewhurst DFA methods. Based on the result of the analysis done, a new design will be proposed and both methods will be compared to identify the strength and weakness of each method. It is found from the study that by applying DFMA on the selected product, the product design had been optimized in term of assembly and manufacturing process and material selection.

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GLOSSARY

DFA	=	Design for Assembly
DFM	=	Design for Manufacture
DFMA	=	Design for Manufacture and Assembly
BD-DFA	=	Boothroyd-Dewhurst Design for Assembly
AEM	=	Assembly Evaluation Method
AREM	=	Hitachi Assembly Reliability Method
FA	=	Functional Analysis
MA	=	Manufacturing Analysis
HAND	=	Handling Analysis
ASF	=	Assembly Sequence Flowchart
QFD	=	Quality Function Deployment
Con-Con	=	Concept Convergence
FMEA	=	Failure Modes and Effect Analysis
DTC	=	Design To Target Cost
PSM I	=	Projek Sarjana Muda I
PSM II	=	Projek Sarjana Muda II
UTeM	=	Universiti Teknikal Malaysia Melaka
ABS	=	Acrylonitrile-Butadiene-Sytrene

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO DESIGN FOR MANUFACTURE AND ASSEMBLY

In this new era of technology, there are many techniques that are developed and applied by manufacturer in order to improve their product quality along with reducing the cost to manufacture their product. One of the most famous methods is by applying Design for Manufacture and Assembly (DFMA) to the product during the design stage. This project title is "Product Design Optimization Using Design for Manufacture and Assembly Approaches".

DFMA is the combination of Design for Manufacture (DFM) and Design for Assembly (DFA). Roughly, DFMA can be defined as a set of guideline that was used by designers during the early designing stage to produce a product that is easily manufactured and assembled with a minimum cost, time and effort. One of the most important characteristics of DFMA is all factors that will affect the final output of the product will be considered and analyzed as early as possible in the design cycle [1].

Any product design that is using DFMA should have higher quality and reliability than product that is using traditional method because the main goals of DFMA are to make fabrication and assembly easier, less costly, simpler, faster and more reliable. Geoffrey Boothroyd and his colleagues had defined DFM as a design for the ease of manufacture of the collection of parts of a product. The main objective of DFM is the assimilation of product design and process planning into one common activity by embracing some principles that will help maintaining communication between all manufacturing systems. This will allow the flexibility for the designers to modify the design during any stage of the product's realization [2].

DFM help the engineers in making selection among many different types of technology and materials by identifying the limitations that related to manufacturing at the early stage of the design process. This will also help the designers in estimating the manufacturing time and the production cost rapidly among different schemes. Xiao Fen Xie in her study titled Design for Manufacture and Assembly indicates that the three main goals of DFM are:

1. To decrease the cost including the cost of design, technology, manufacturing, delivery, technical support, discarding and others.
2. To shorten the developing cycle time, including the time of design, manufacturing preparing and repeatedly calculation.
3. To increase the quality of the product in term of design, manufacturing, technology and other important factors.

DFA is a process to improve a product design for the ease of assembly. Mainly, DFA focused on reducing the parts in a product because the total number of parts in a product plays a big role in product assembly quality. Fewer parts mean less time needed to assemble, thus reducing the assembly cost. In DFA, the designers will use all kinds of method to resolve the possible problems during the early stage of the design so the part can be assembled with high speed, low cost and productivity without affecting the functions of the final product.

Xiao Fen Xie has indicates that DFA can be used in two ways: as a tool for assembly analysis and as a guide for assembly design. DFA can be used as a tool for assembly analysis because by applying DFA, the engineers will make estimation at the beginning of a product design process on all factors that will affect the assembly process.

DFA also can be used as a guide for assembly design because DFA collect the knowledge and experience from many assembly experts and this compilation of knowledge is then used as a design guide. These guides are very important and useful because they helped the engineers to choose the design plan and determining the product construction efficiently.

1.2 HISTORY OF DFMA

The history of DFMA starts even before World War II. Henry Ford was one of the first people who consider the assembly process during the design stage. This is the reason why the cars produced by Henry Ford have simpler designs and fewer parts when compared with his competitors. Ford focused mostly on design simplification and standardization; because of this his method was widely used in the US during WWII for the design and manufacturing process of weapons, tanks and other military products.

In WWII, US, Russian and British applied simple standard design such as Ford's method in producing their military products. By applying this method, the product can be produced in a huge quantities and this contrasted sharply with the German's method, which keep improving their current designs thus making the logistic, training and field repair become difficult.

Starting from 1960's, various rules and methods were introduced to help the designers in considering assembly problems during the design process. Most of these methodologies were presented along with practical example to show their effectiveness in analyzing and improving assembly difficulty. Geoffrey Boothroyd and his colleagues, Alan Redford and Ken Swift are the first persons who systematized DFA. This DFA method is later known as The Boothroyd-Dewhurst DFA method and it can be used to estimate the time for manual assembly of a product and the cost of assemblability of the product on an automatic assembly machine.

Hitachi also developed a set of assemblabilty evaluation method at this time as well. The assembly evaluation method was based on the principle of one motion for one part. For the complicated parts, the evaluation is made by subtracting the penalty point due to difficulty from the base point.

In 1980's and 1990's, a lot of DFMA methodologies were introduced. Among them are: the Lucas DFA Evaluation method, the Westinghouse Calculator, Sony DFA method, Toyota Ergonomics and Effort Flow Analysis. All of this methodologies aim for the same purpose, which is to improve the assemblability of a product.

1.3 BENEFIT OF DFMA

The main reason why DFMA was widely applied in the manufacturing area is because of the benefits that can be gained from the well structured DFMA principles. The most important benefit of DFMA is that it can lower the assembly cost and shorter the assembly time by improving the design and analyzing every increased the reliability of the product and lessen the total time to market the difficulty that will affect the assemblability of the product. This will also indirectly product.

DFMA ensure a smooth and rapid transition from design phase to production phase by providing a systematic procedure for analyzing a proposed design from the point of view of assembly and manufacturing.

DFMA tools will encourage communication between the designers and the manufacturing engineers and other individual that have a role in determining the final product cost; thus teamwork are needed to successfully achieved the concurrent engineering benefit.

1.4 OBJECTIVE OF PROJECT

The objectives of this research are:

- To study and analyze the current design of the selected product.
- To understand each DFMA methodologies that was chosen.
- To improve the design of the selected product by using different DFMA methodology.
- To compare Lucas Hull DFMA and Boothroyd Dewhurst DFMA based on case study made.

1.5 SCOPES OF PROJECT

Scope of research is an important stage because it is the elements to the researcher to know what actually are the needs in their project. This project's scope can be divided into three, which are using different DFMA approaches to improve the selected product design, presenting the study of existing and new design and comparing different methodology in DFMA. The product that has been chosen for the case study in this project is a bread toaster that was manufactured by MEC and it will be analyzed using two famous DFMA methods that are Lucas-Hull DFMA and Boothroyd-Dewhurst DFMA.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter describe about design for manufacturing and assembly in term of literature review. This also includes the case study from peoples all over the world on the subject of DFMA.

2.1 DESIGN FOR MANUFACTURING AND ASSEMBLY

Through out these two decades, DFMA techniques have played a very important role in reducing costs of manufacturing. Various types of DFMA methodologies have been developed in order to get the perfect design that will improve assembly ease and reducing the assembly time along with reducing the manufacturing cost.

Redford and Chai in their book, Design for Assembly, state that a good DFMA method should have the following characteristics:

a) Complete as regards to procedures for evaluating assemblability and should be creative enough to obtain procedures to improve the assembly
b) Systematic step-by-step procedures and must consider all relevant issue.

c) Capable of measuring the assemblability objectively, accurately and completely.
d) User friendly and have a good quality

Current DFMA methodologies can be classified into four types depend on their analysis method. The four basic types are:

a) DFMA systems that using design principles and design rules.
b) DFMA systems employing the quantitative evaluation procedures.
c) DFMA methods that employ a knowledge-based approach.
d) DFMA methods that used a computer-aided design methods.[2]

2.1.1 DFMA System Using Design Principles And Design Rules

Design rules can be defined as empirical truths verified by extensive design practice that was done by various engineers through out these years. All of the data collected from countless good and bad design were combined and used to convert assembly knowledge into design principles, design rules and guidelines [2]. The example of DFMA system that is using design principles and design rules is Boothroyd-Dewhurst DFMA method.

2.1.2 DFMA System Employing Quantitative Evaluation Procedures

Quantitative DFMA analysis allows the designer to evaluate their design by rating the assemblability of their product design quantitatively. These quantitative DFMA methodologies are systematic and more accurate, thus ensuring the DFMA rules are correctly applied and the influence factors are being correctly evaluated and improved [2]. The example of the DFMA system that employed the quantitative evaluation procedures is IPA Stuttgart method.

2.1.3 DFMA Methods Employing A Knowledge-Based Approach

Knowledge based systems are defined as those that provide new information processing capabilities such as inference, knowledge-based management, or search mechanism combined with conventional computer capabilities [2]. The example of a DFMA system that employed knowledge-based is Lucas-Hull DFMA.

2.1.4 Computer-aided DFMA Methods

Computer-aided DFMA methods mean that the assemblability evaluation processes are being developed by using DFMA systems that are integrated with CAD [2]. Nowadays, some DFMA methodologies have been enhanced into CAD software, such as Lucas-Hull DFMA was integrated into TeamSET and Boothroyd-Dewhurst into DFMA software.

.2 DFA METHODOLOGIES

Design for assembly (DFA) focuses on simplifying the assembly process by :ducing parts number, reducing the assembly time and cost. In these four decades, various types of methodologies were introduced. Some of the famous DFA methodologies are:

i. The Boothroyd-Dewhurst Method
ii. The Lucas-Hull DFA Evaluation Method
iii. The Hitachi Assembleability Evaluation Method
iv. The Westinghouse DFA Calculator
v. The Toyota Ergonomic Evaluation Method
vi. Sony DFA Methods
vii. The Effort Flow Analysis (EFA)

2.2.1 The Boothroyd-Dewhurst DFA Method

Boothroyd and Dewhurst have formulated one of the most widely used DFA methodologies. Boothroyd-Dewhurst method is based on two principles:

- The application of criteria to each part to determine whether it should be separated from other parts or not.
- Using appropriate assembly process to estimate the handling and assembly cost for each part [3]

Boothroyd-Dewhurst DFA method generally follows these four steps in order to get the best result:

1. Each part is identified and selects an appropriate assembly method for the part.
2. Each part is then analyzed according to the assembly method.
3. The design is studied and improved according to the analysis result.
4. Step 2 is repeated until the design meets the criteria needed [3].

Boothroyd-Dewhurst DFA method is generally applied by using a worksheet as in Figure 2.1. Special tables and charts that are based on two-digit code that represent the size, weight and geometric characteristics of the parts are used in estimating the handling and insertion time for each part.

1	2	3	4	5	6	7	8	9
Part No	No. of operation	Manual handling code	Manual handling time (s)	Insertion code	Insertion time (s)	Total operation time (s)	Theoretical minimum no. of parts	Part name
1	1	30	1.95	00	1.5	3.45	1	Plastic support
2	1	30	1.95	30	2.0	3.95	0	Hammer guide
3	1	23	2.36	30	2.0	4.36	1	Hammer

Figure 2.1: Example of Boothroyd-Dewhurst DFA Worksheet (Robert B. Stone et al [3])

The designers also need to evaluate the parts base on these three questions:

1. Does the part move relative to other parts in the assembly?
2. Are the material properties of the part necessary to make the product function?
3. Does the part need to be separate in order for the product to function? [4]

These questions are asked in order to identify the minimum number of theoretically needed parts.

A part with the theoretical part number of 1 is an essential part and it is vital to the product to function meanwhile a part with the theoretical part number of 0 is a non-essential parts and will be analyzed whether it will be eliminated or combined with other parts [4].

Figure 2.2 show the sample of tables for manual insertion estimated time.

MANUAL INSERTION – ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	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

PART SECURED IMMEDIATELY

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			riveting or similar operation				
					not easy to align or position during assembly			not easy to align or position during assembly			
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	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

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	riveting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	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	3.5	7	8	12	12	9	12

Figure 2.2: Example Of Tables For Manual Insertion (Boothroyd G. et al, [4])

As one of the most famous DFMA method in the world, Boothroyd-Dewhurst introduced their own DFMA software to help the designers applying DFMA in more convenient way.

2.2.2 The Lucas-Hull DFMA Evaluation Method

This knowledge-based DFMA evaluation technique was developed by Lucas Organization and University of Hull based on the assembly sequence flowchart (ASF) [2]. This DFMA method works with CAD system and it requires minimum effort and time to get the information for analysis work. The Lucas DFMA principles are integrated into software named TeamSet. Figure 2.3 shows the architecture of the Lucas DFMA system.

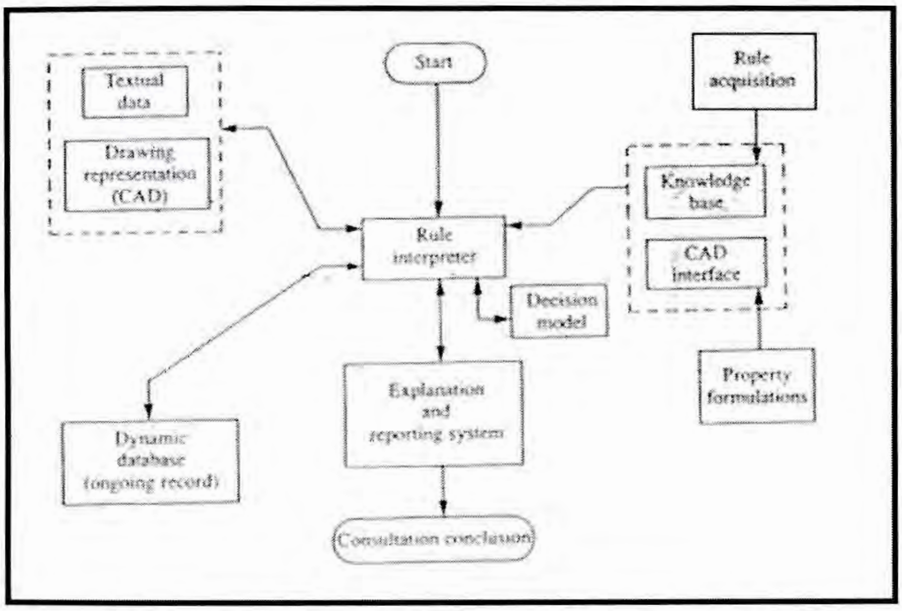


Figure 2.3: Architecture of The Lucas DFMA system (Alan Redford and Ian Chai, [2])

The functional analysis was done to each part according to the rules of value analysis to determine whether the part is category A (essential) or category B (non-essential). The aspects that are considered in a functional analysis are relative motion, special material properties and assemblability issue of the part [2].

The evaluation procedures are shown in Figure 2.4:

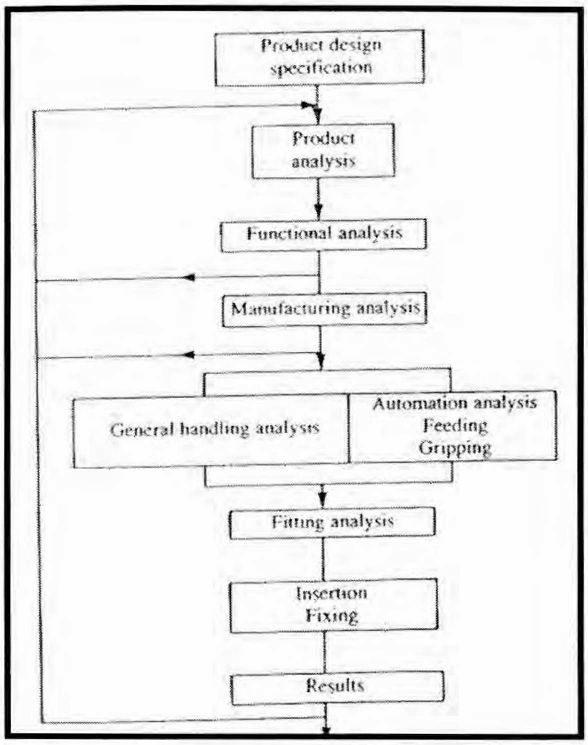


Figure 2.4: The Lucas DFMA Procedure (Alan Redford and Ian Chal, Design for Assembly)

After the categories of all the parts have been determine, the design efficiency can be calculated by finding the ratio of category A to all category (A/ (A+B)). The suggested design efficiency is 60% but if it is lower, it is advisable for the product to be redesign before detailed analysis is carried out [2]. This phase is very important because this is still an early stage of design that involves important manufacturing and marketing criteria.

The B parts can be eliminated or combined with other parts in the product to reduce the assembly cost. Redford and Chal had indicates that the importance of the functional analysis is because some assembly problems can be solved by designing a few complex parts to replaced many simple parts. But by designing this few complex parts, there will be some changes in the manufacturing requirements. Thus, manufacturing analysis was developed to overcome this problem by allowing the exploration of alternative materials and manufacturing technologies to the part alternative design.

Manufacturing analysis will allow the designer to choose the materials and technologies for the parts to get the best effect and value. The next stage of evaluation in Lucas-Hull DFA Evaluation Method is determining the feeding index by finding whether the parts have any characteristics that will cause problems in parts conveying. The feeding index should be less than 1.5 and if not, the designers must discuss how to get a better feeding index [2].

The sums of all the feeding indices are then divided by the total number of essential parts (A parts) to get the feeding ratio. The feeding ratio should be less than 2.5 and if it is more, every parts that have the feeding index more than 1.5 should be study again and the usage of the non-essential parts (B parts) should also be re-evaluate [2]. The feeding index is very useful in comparing alternative design for the product as to determine which product is better to be manufacture.

After the feeding analysis was completed, the product will under do the fitting analysis. In the fitting analysis, the designer must generate an assembly sequence flowchart for the product based on six processes. The processes are work-holding process, insertion process, non-assembly process, sub-assembly process, assembly total and gripping process [2].

By doing the fitting analysis, the designers then can determine which fitting processes are expansive and give them the ideas as how to change the processes to reduce the production cost. Each activity that gets the fitting index more than 1.5 should be study again to improve the design. All of the individual fitting indices will be divided by the total number of essential parts (A parts) to get the fitting ratio and it should be less than 2.5. If the fitting ratio is higher than 2.5, it is recommended that the individual activities or processes should be examined along with the non-essential parts (B parts) [2].

2.2.3 The Hitachi Assemblability Evaluation Method

The Hitachi Assemblability Evaluation Method (AEM) was introduced by Hitachi Ltd in 1976 to improve the product assemblability. AEM is refined year by year and it is mainly about identifying weakness in the earliest stage of design by using:

i. Assemblability evaluation score, E
ii. Assembly cost ratio, K

In AEM, the assembly operations are categorized into 20 different operational circumstances each with its own symbol or icon that clearly indicates their tasks. Each circumstance has its own penalty score according to the level of difficulty for the task [5].

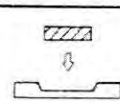
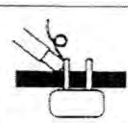
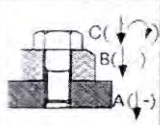
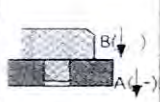
Category	Basic Element Example		AEM Symbol	Coefficient
Movement	Downward Movement		↓	1.0
Joining	Soldering		S	2.2

Figure 2.5: Examples of AEM Symbols and Penalty Scores. (Daniel E. Whitney, [5])

The perfect part or assembly operation get the maximum score, usually 100 and deducted by the element of difficulty. After all the parts have been evaluated, every penalty from all the part will be added and the perfect score of 100 will be deducted according to the sum of penalties. When the score for the product is less than target score, usually 80, the product will be analyzed to improve its score [2]. Usually the evaluation method was done by comparing the current design with the ideal or previous design of the similar product.

By doing this evaluation, it is possible to have a better score with increasing number of parts and to avoid this, assembly cost ratio, K are used to compare the estimated assembly cost of the redesign product with the assembly cost of the original product.

In overall, the evaluation procedures in AEM are divided into four stages. The first stage is preparatory work in identifying various tasks to be analyzed. Stage two involving part attaching sequences and matching the elementary task symbols with the operations. In stage three, the evaluation indices are calculated and in stage 4, the effectiveness of the design will be judge [2].

Examples	Product Structure and Assembly Operations		Part AEM Score E_i	Product AEM Score E	AEM Cost Ratio K	Part to Be Improved
Structure 1 (before improvement)		1. Set base A.	100	76	100	C
		2. Bring down block B and hold it to maintain its orientation.	79			
		3. Fasten bolt C.	50			
Structure 2		1. Set base A.	100	88	Approx. 0.8	B
		2. Bring down and press-fit block B.	75			
Structure 3		No assembly.	100	100	0	—

2.6: Examples of Assemblability Evaluation and Improvement. (Daniel E. Whitney, [5])

Figure 2.7 shows the assembly of a product before the analysis using AEM and Figure 2.8 shows the redesign of the same product by applying AEM.

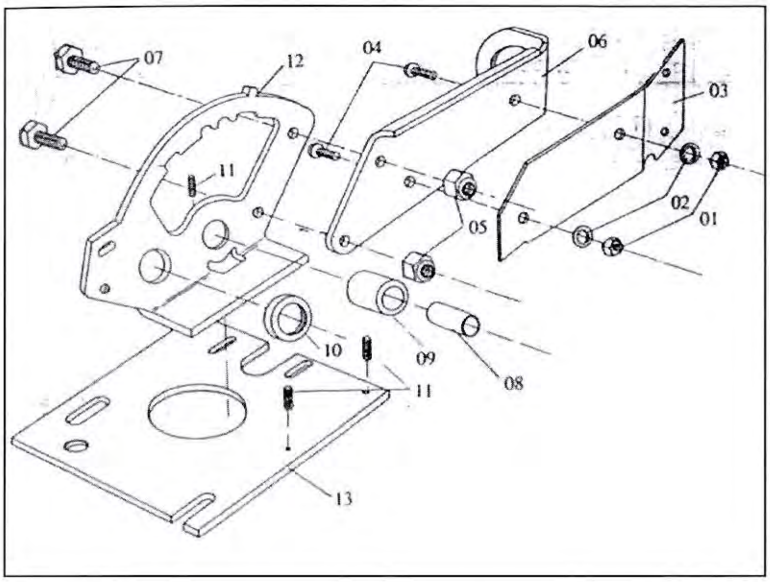


Figure 2.7: Original Design Of Base Sub-Assembly (Alan Redford and Ian Chai, [2])

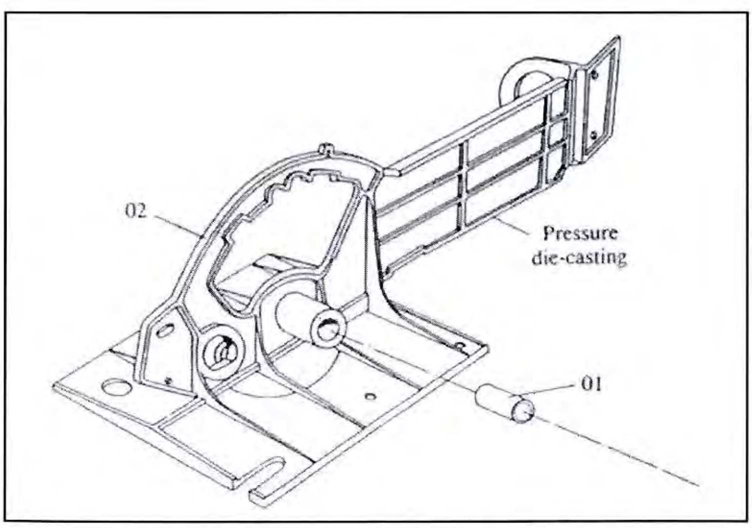


Figure 2.8: The Redesign Of Base Sub-Assembly After Applying AEM (Alan Redford and Ian Chal, [2])

2.2.4 The Westinghouse DFA Calculator

The Westinghouse DFA Calculator is used to estimate the handling and insertion difficulty of a product by using the concept of a rotary slide ruler. This calculator was introduced by Sturges at Westinghouse and it consists of two discs [5]. There are transparent cursors on each disc that was used as the indicator for the value of difficulty on the selected criteria.

The smaller disc can be rotated independently of the large disc and the cursor. On one side of the disc, the user calculates the handling difficulty and the other side are used to estimate the assembly time. The factors that will affect the difficulty index are part shape, symmetry, size of features to be grasped or mated with, direction of insertion, clearance and fastening method [5]. Figure 2.9 shows the example of Westinghouse DFA Calculator.

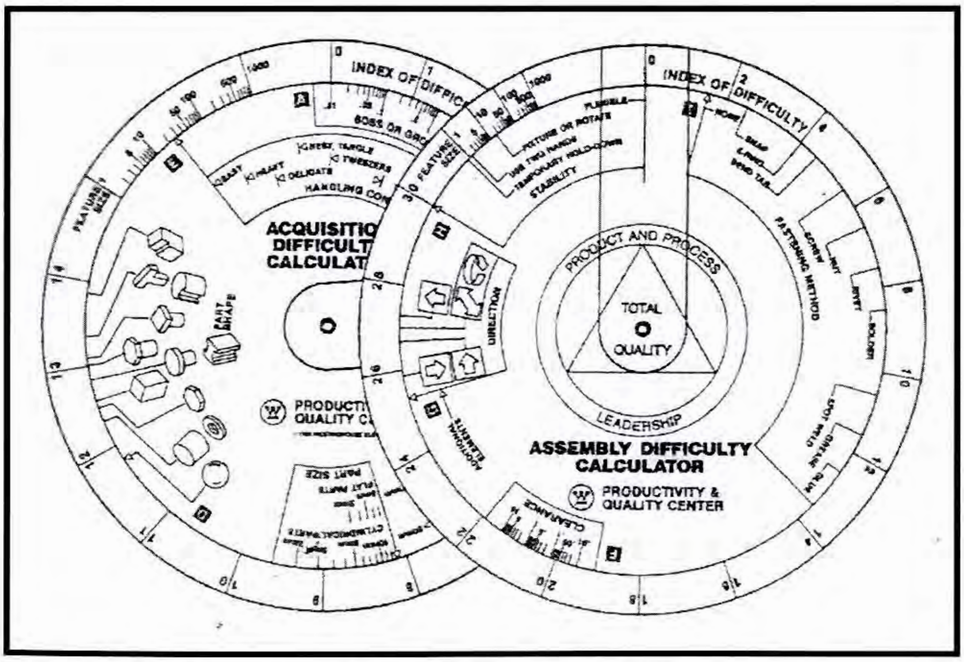


Figure 2.9: The Westinghouse DFA Calculator (Daniel E. Whitney, [5])

2.2.5 The Toyota Ergonomic Evaluation Method

Toyota has determined that the product of the weight of a part and the time it must supported by a worker is a good indicator of physical stress. Toyota Verification of Assembly Line (TVAL) was developed by Toyota in order to reduce the physical stress in assembly operations [5].

The worker's position is important when determining the stress, standing position is less stressful than bending position when the same part weight and duration being applied on a same person.

$$TVAL = d_1 \log(t) + d_2 \log(W) + d_3$$

d_1, d_2, d_3 = Constant

t = Time

W = Part Weight [5]

Before TVAL was applied to an assembly line, TVAL for the line varies from 30 to 48. After TVAL was applied and the worst station has been redesign, TVAL ranges from 22 to 35 [5].

2.2.6 Sony DFA Methods

Each engineer in Sony that involves in a certain project must prepare exploded drawings on all concepts. This is to make sure that the assembly of each concept is studied even before the detail design begins.

Each concept will then be analyzed by using Sony's own DFA software [5]. Figure 2.6 shows a Sony Walkman exploded drawing that was generated during the product design. There are various concepts on each product and each concept will then be analyzed to get the best result.

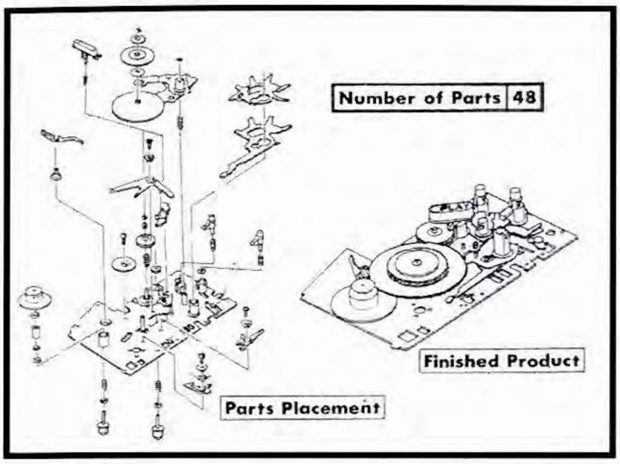


Figure 2.10: Exploded View of Sony Walkman (Daniel E. Whitney, [5])

2.2.7 Effort Flow Analysis

Effort flow analysis is one of DFA approach that was used to improve the assemblability of a product by making component combination [6]. Component combination is the combination of various parts into a single part without affecting the part functions. Component combination is one of the best methods to reduce the part numbers and this is also the best way to improve the assemblability [6].

With a minimum number of parts, lots of benefit will be gained; fewer operations, less handling and faster assembly are some of them but Douglas Commercial Aircraft Co. had discovered that other than cost of assembly, the cost for fabrication, quality assurance, overhead-inventory levels, tracking and purchasing also depend on piece count.

Effort flow analysis is a new method in DFA that was used to guide the designer in part combinations as to reduce the part numbers thus improving the assemblability of the product.

Effort flow analysis is the evolution of force flow analysis and it focused on identifying the parts that have the opportunities to be combined with other parts by using rigid body or compliant mechanisms. This DFA method used effort flow diagram to show the effort transfer through product components. The effort flow diagram is a semantic network that consists of nodes that represent the component in product and link that represent the interface between the components that are described by the use of graph theory [6].

The main benefit of effort flow analysis is the user can determine which components in a product have opportunities to be combined with other components. Figure 2.11 shows the example of effort flow diagram.

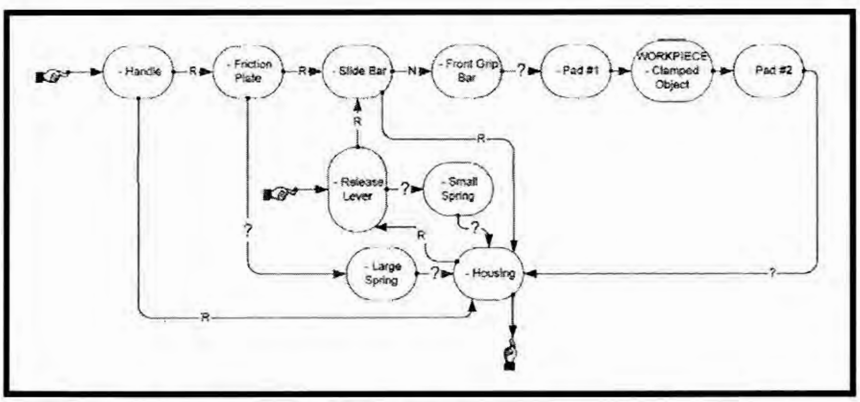


Figure 2.11: Example Of Effort Flow Diagram (James L. Greer et al, [6])

In the effort flow diagram, the links between the components will be labeled when there are relative motions at the interface of the connected components. Relative motion can be defined as a motion between two components that might happen either at the interface, away from the interface or both during the operation of a device [6]. The N labels means that there are no relative motions between components meanwhile R means that there are relative motions at the interface and between other regions.

James L. Greer and Kristin L. Wood indicates that once the link labeling and relative motion determining process was completed, the effort flow guideline will be applied on the design. In effort flow guideline, a certain group of components will be choose as the candidates for combination when there are no relative motion within the groups (no R-links connecting members in the group) as long as there is no problem involving material or assembly/disassembly issue. The guideline also indicates that the combinations between components that are linked by R-links are also possible, but it will require a complex redesign process.

The components that are connected by non-relative motion links (N-links) will then be identify and will under do a further investigation to determine whether they are a suitable candidates for the component combination.

2.3 CASE STUDY FROM PREVIOUS RESEARCH

There were already several case studies made by researchers and manufacturers involving DFMA to prove that by applying DFMA, comes a lot of benefit.

2.3.1 Stapler Evolution

Figure 2.12 shows the differences between three heavy duty staplers. Stapler A was manufactured in mid 1950s and consists of 34 parts. Stapler B and C both were manufactured in 1994 but the design for both staplers are different. Stapler B consists of 29 parts meanwhile stapler C consists of 21 parts. All of the staplers are functions in equal quality.

Stapler A has the most parts. It has a linkage that is riveted to the handle to perform the upward motion of the hammer. A high stiffness spring was used to store the energy when the hammer moves upward. The spring that was compressed during the upward motion of the hammer will be released when actuated by the linkage. Stapler A need the highest amount of human force to make it functional.

Stapler B has simpler design than stapler A. the linkage mechanism or high stiffness of spring from stapler A does not present in this design due to the applications of the lifters that is carried by the plastic pin that moves in the handle. The lifters than release the leaf spring in order to create force to move the hammer.

Stapler C has the simplest design. The lifters and leaf spring of stapler B are combined into single part to lift the hammer. This design requires the lowest human force to operate due to its well structured design. This is the result of intensive application of DFMA during the designing process.

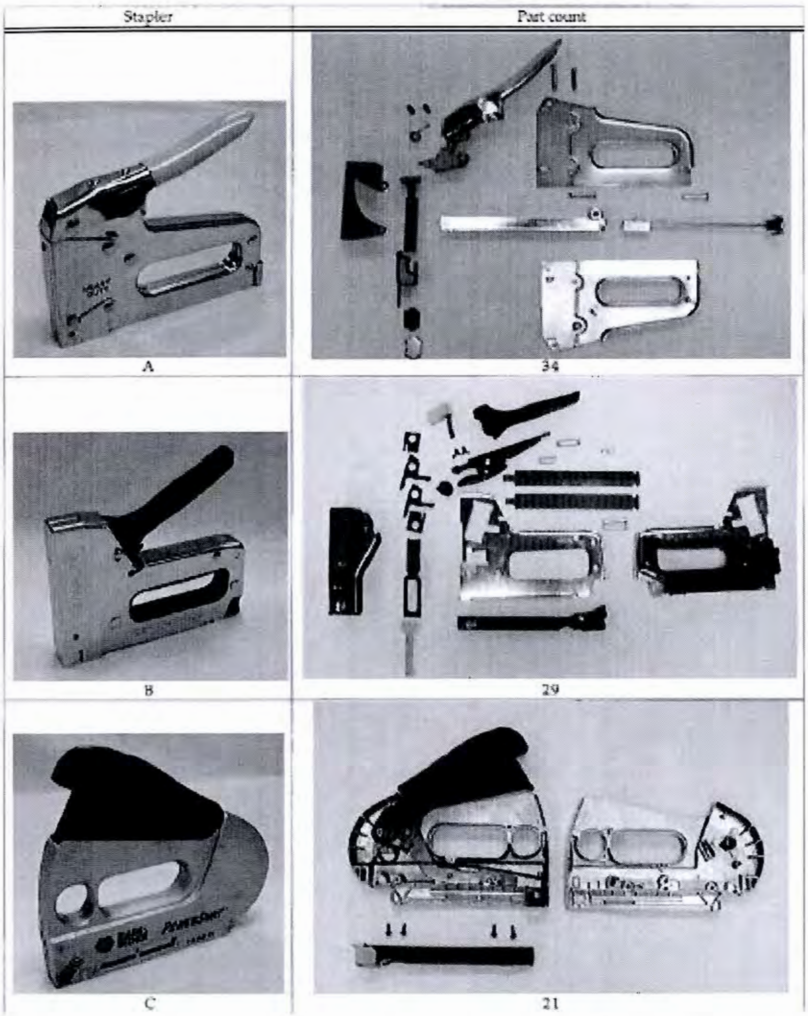


Figure 2.12: The Comparisons Of Three Heavy Duty Staplers (Robert B. Stone et al, [3])

This case study was made by Robert B. Stone, Daniel A. McAdams and Varghose J. Kayyalethekkel in their journal titled "A Product Architecture-Base Conceptual DFA Technique".

2.3.2 Texas Instruments

Figure 2.13 shows the original design of thermal gunsight that is used in a ground-based armor vehicle.

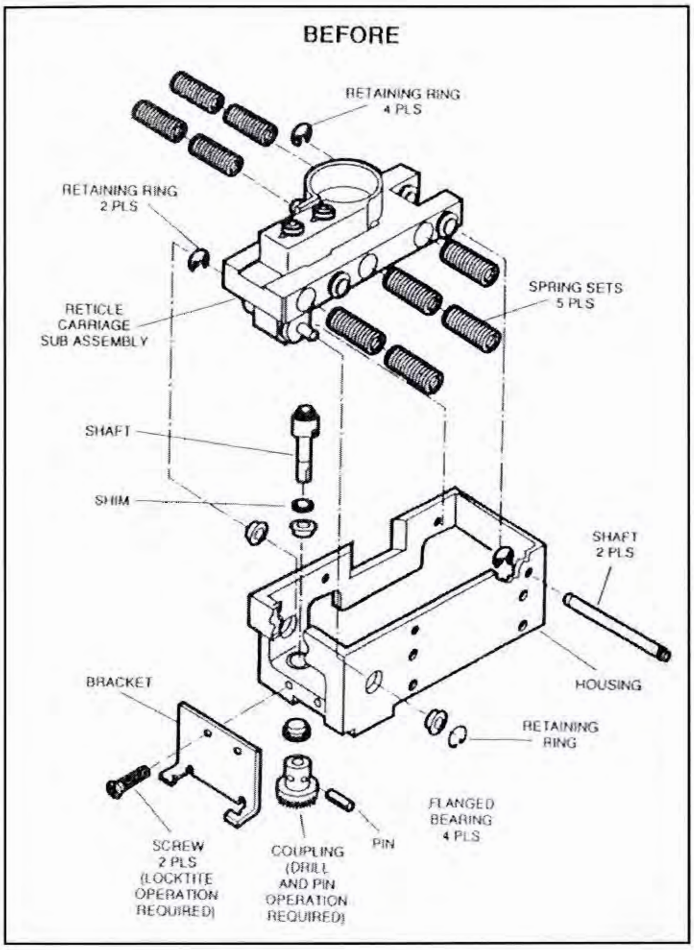


Figure 2.13: The Baseline Design Of The Thermal Gunsight (G. Boothroyd et al, [4])

The thermal gunsight is used to track and sight target at night and ensuring accurate remote-controlled aiming for the weapon. The original design consists of 24 different parts and requires over 20 hours of metal fabrication time and more than two hours of assembly time. Most of the assembly time was spent on fasteners, reorientations of the assembly and special operations such as drilling and applying adhesive to screws. After the redesign process by applying DFMA analysis, the new design such as in Figure 2.14 was introduced.

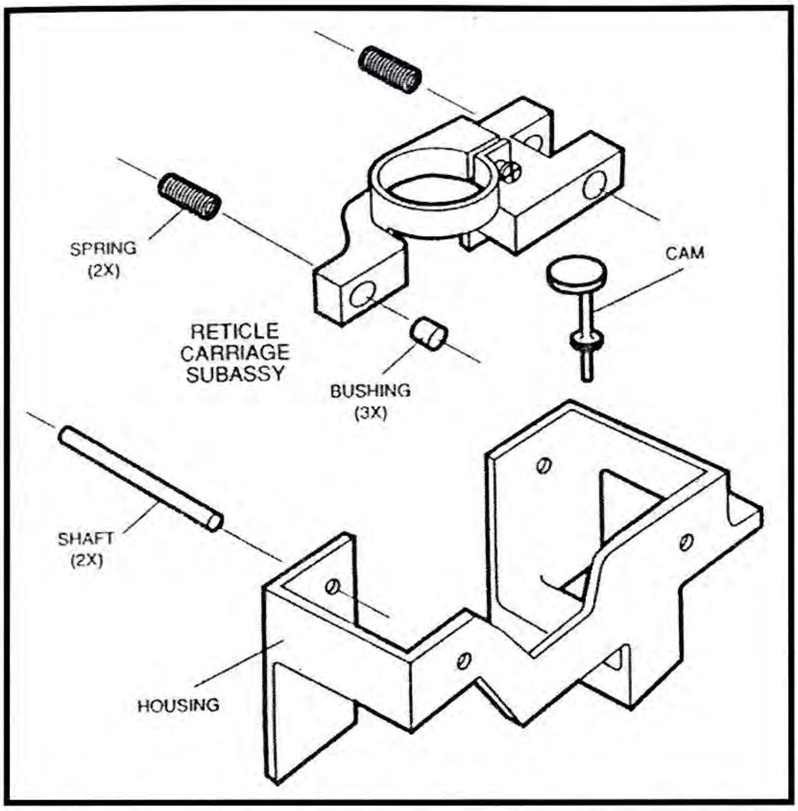


Figure 2.14: The Proposed Design Of The Thermal Gunsight (G. Boothroyd et al, [4])

This new design consists of eight parts. By replacing the gear box with cam in the design, coupling, drill and pin operation are not needed anymore. The fasteners were all eliminated by reducing the parts that need securing and giving the self securing ability to the parts such as press fit and bushings.

The fabrication time also had been reduced because the machined components were replaced by casting components. Table 2.1 shows the comparison between the original and the new design of the thermal gunsight.

This case study was mentioned in Product Design For Manufacturing And Assembly written by Geoffrey Boothroyd, Peter

Dewhurst and Winston Knight.

Table 2.1: Comparison Of Original Design And Redesign For The Thermal Gunsight (G. Boothroyd et al, [4])

	Original Design	Redesign	Improvement (%)
Assembly Time (H)	2.15	0.33	84.7
No Of Different Parts	24	8	66.7
Total No Of Parts	47	12	74.5
Total No Of Operations	58	13	77.6
Metal Fabrication Time (H)	12.63	3.65	71.1
Weight (Ib)	0.48	0.26	45.8

2.3.3 Digital

Figure 2.15 shows the original design of mouse made by Digital Equipment Corporation.

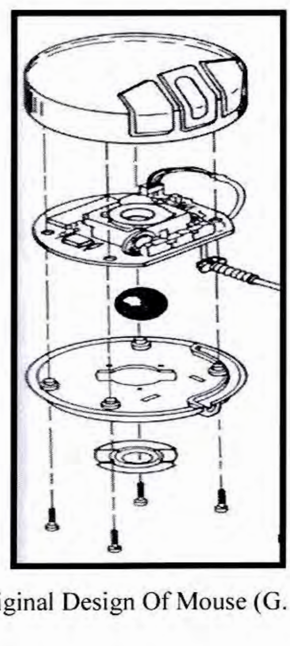


Figure 2.15: The Original Design Of Mouse (G. Boothroyd et al, [4])

The design team had used DFMA software to compare their mouse design with their competitor's products to get a better view on the design requirements. By applying DFMA, the design team is able to focus on the vital aspects that will affect the design. Figure 2.16 shows the new design of the mouse.

In the original design, time taken to assemble a ball cage is 130 seconds but the new design had introduced a new device to replace it and the device takes only 15 seconds to be assembled. All screws in the old design were replaced by snap-fits parts. By applying DFMA, the total number of assembly operation also had been reduced from 83 to 54 operations.

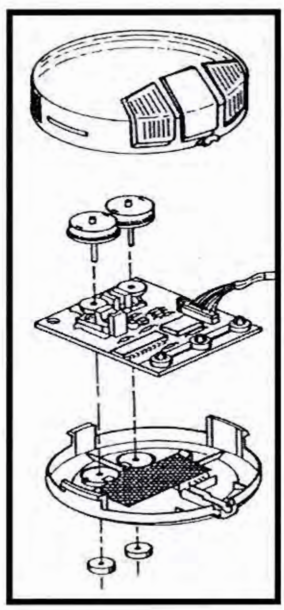


Figure 2.16: The New Design Of The Mouse (G. Boothroyd et al, [4])

This case study also mentioned in Product Design For Manufacturing And Assembly written by Geoffrey Boothroyd, Peter Dewhurst and Winston Knight.

2.3.4 FASTRAC Turbopump Case Study

The FASTRAC 60K Turbopump Assembly (TPA) is a prototype fuel and oxidant pump with integral gas turbine power source that is used to feed the main engine of a space flight booster rocket. NASA had developed a team to improve the design of the TPA. The design objectives include minimal maximum efficiency and reliability, and minimum total life-cycle cost. Figure 2.17 shows the baseline design of the TPA.

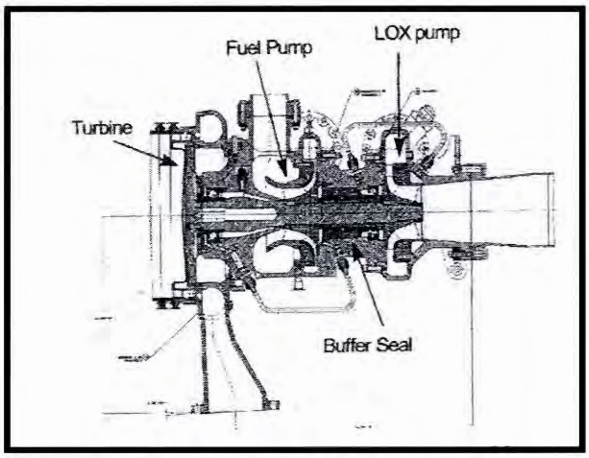


Figure 2.17: The Baseline Design of FASTRAC (Gauthier B. et al, [7])

The analysis was done to the baseline design by using BDI-DFA 82 software and based on the analysis, less than a quarter of the total assembly time is spent on the necessary operation. Figure 2.18 shows the assembly operations profile for baseline design by dividing the total product assembly time with six categories of operations.

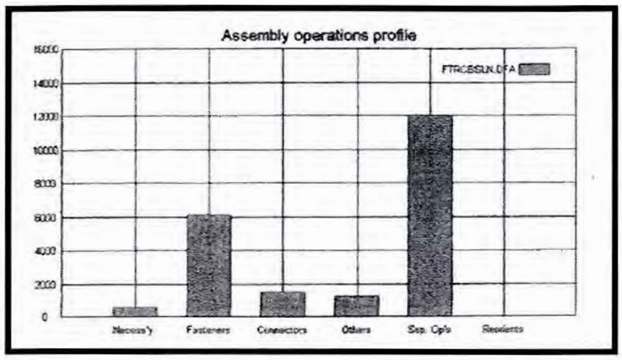


Figure 2.18: The Assembly Operation Profile for the Original Design (Gauthier B. et al, [7])

A further detail DFA analysis was done to the baseline and the focus is on the assembly process that had taken much time. Based on the result of the analysis, a new design was proposed. The comparison between the baseline and proposed design assembly operations profile is shown in Figure 2.19.

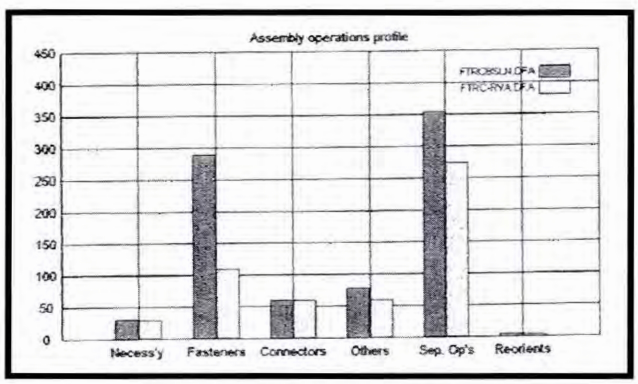


Figure 2.19: The Comparison between the Original and Proposed Design (Gauthier B. et al, [7])

Based on the chart, the total time for other operations had been reduced. The assembly complexity is reduced by combining parts or by redesigning interface to minimize fastener count and simplify the assembly. The comparison of total assembly time for the baseline and proposed design is as shown as in Figure 2.20.

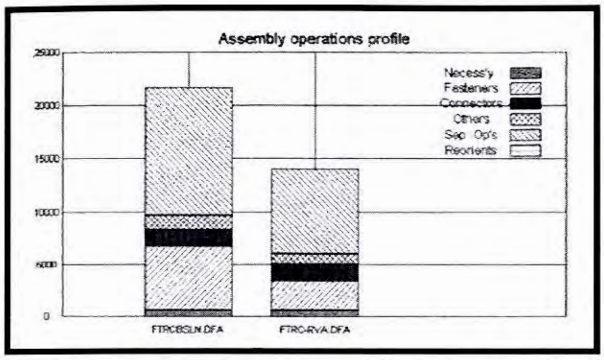


Figure 2.20: The Total Assembly Time Comparison of the Baseline and Proposed Design (Gauthier B. et al, [7])

From the case study made, it can be proved that by applying DFMA, lots of time and cost can be saved. This case study was done by Benoit Gauthier, Dr. Peter Dewhurst and Dr. David Japikse in their journal titled "Application of Design for Manufacturing and Assembly Methodologies to Complex Aerospace Products".

2.4 INTRODUCTION TO TEAMSET

For the first DFA method, which is Lucas-Hull DFA Evaluation method, TeamSet software was be used for the analysis process. TeamSET is a software developed by Computer Sciences Ltd. in order to help the designers in improving the product designing process. TeamSET provides a set of tools that focuses on the early design activity.

2.4.1 Benefit of TeamSET

The reason why the TeamSET software was chosen as the method to analyze the design in the first analysis process is because this software had the ability to compare between the original design with the redesign product. All aspects of designing and manufacturing will be considered in the analysis process. This software also applied the logic of Lucas-Hull Evaluation method in its analyzing process.

2.4.2 The Tool Set

There are six tool set that available in TeamSET software. They are:

1. Quality Function Deployment (QFD)
2. Concept Convergence (Con-Con)
3. Design For Assembly (DFA)
4. Manufacturing Analysis (MA)
5. Failure Modes And Effect Analysis (FMEA)
6. Design To Target Cost (DTC)

But for PSM project, only DFA toolset will be used.

2.5 SUMMARY

In this chapter, various methods of DFMA were discussed. Design for manufacture and assembly had been applied since the world war two and its application had been growing from time to time. There are many types of DFMA methodology that had been introduced throughout this world and this application varied from a product as simple as a pen to a high technology product such as rockets.

CHAPTER 3

METHODOLOGY

3.0 INTRODUCTION

The product will be analyzed by using to DFMA methods. These two methods are Lucas DFA and Boothroyd-Dewhurst DFMA methodologies. This project requires manual analysis for Boothroyd-Dewhurst DFMA and software analysis for Lucas-Hull DFMA. For the software analysis of Lucas DFA, TeamSET is used.

The first analysis is done to the original design of the product. Based on the result of the analysis, new design will be proposed.

3.1 LUCAS-HULL DFMA

In Lucas-Hull DFMA methodology, there are four main analyses that will affect the score of the product. These analyses are:

- Functional Analysis
- Manufacturing Analysis
- Handling Analysis
- Fittin Analysis (ASF)

3.1.1 STARTING TEAMSET

To click the TeamSET software, double click on the desktop or select from the Start Programs menu on the Windows Start button.

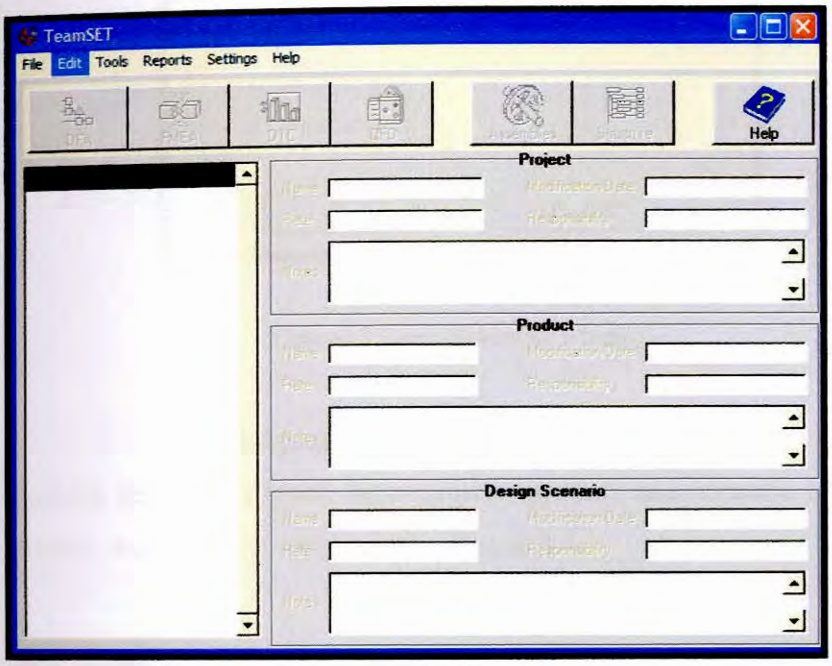


Figure 3.1: TeamSET Main Window

To create a new database, open file and create new database. A menu will shown up and put the desired name for the database. A database can be defined as a physical file on the disc. The database contains all the data for the projects.

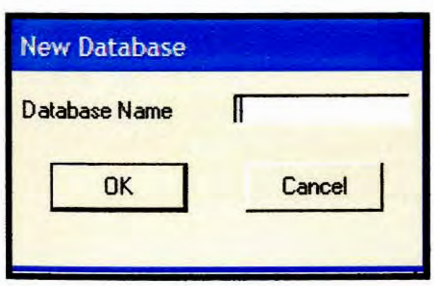


Figure 3.2: New Database Window

After creating a database, select edit and choose create to create a project level. A project is a group of products.

Figure3.3: Level Selection Window

To create the product level and scenarios, choose the same method as creating the project level. After project, product and scenario level have been created, the TeamSet will look like Figure 3.4.

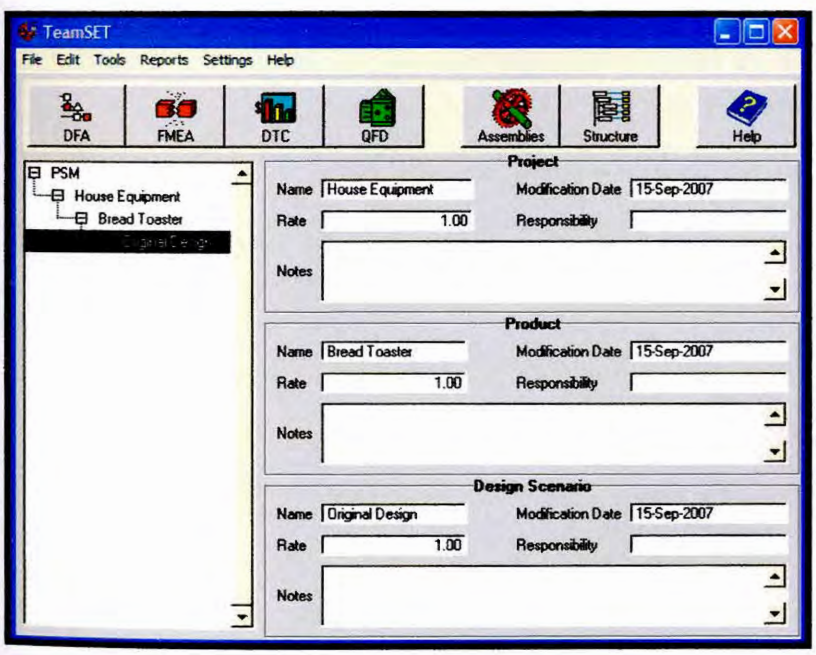


Figure 3.4: The TeamSET Main Window After Project, Product And Scenario Have Been Created

To create an assembly, choose the Assemblies option on the toolbar. A new window will pop-up. Choose edit and create to create a new assembly. Give the name for the newly-created assembly. By making an assembly, the DFA toolbar can now be access.

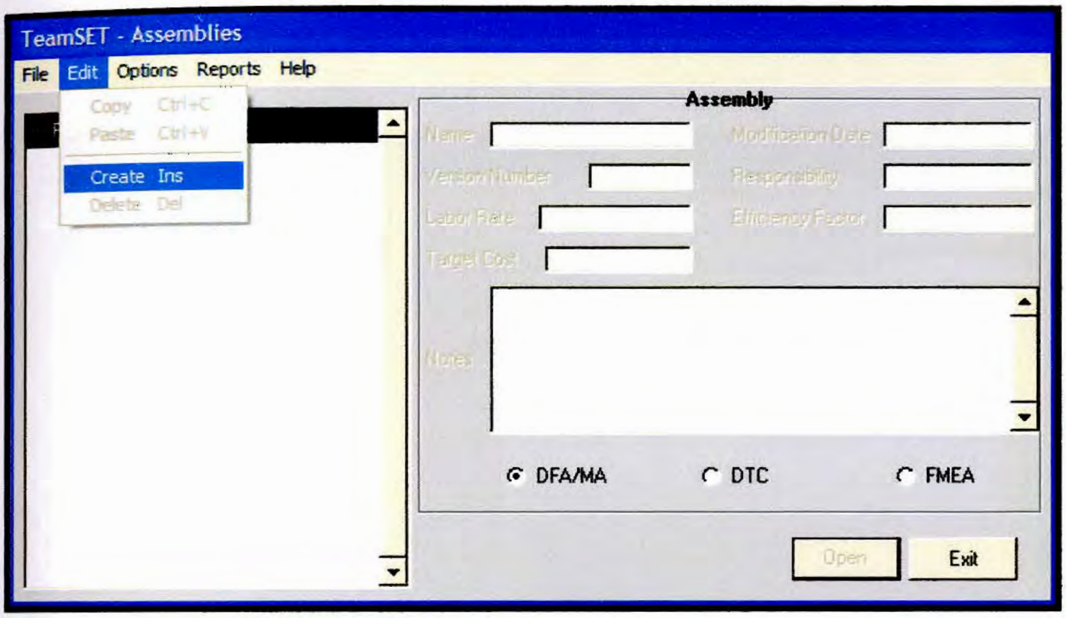


Figure 3.5: Assembly Window

3.1.2 USING DFA TOOL SET

To access the DFA toolset, exit from the assembly window to the TeamSET main window. Choose the DFA option among the toolset. A window identical to the assembly window will pop-up. Choose the assembly that will be analyzed and select open. Figure 3.6 shows the DFA assembly window.

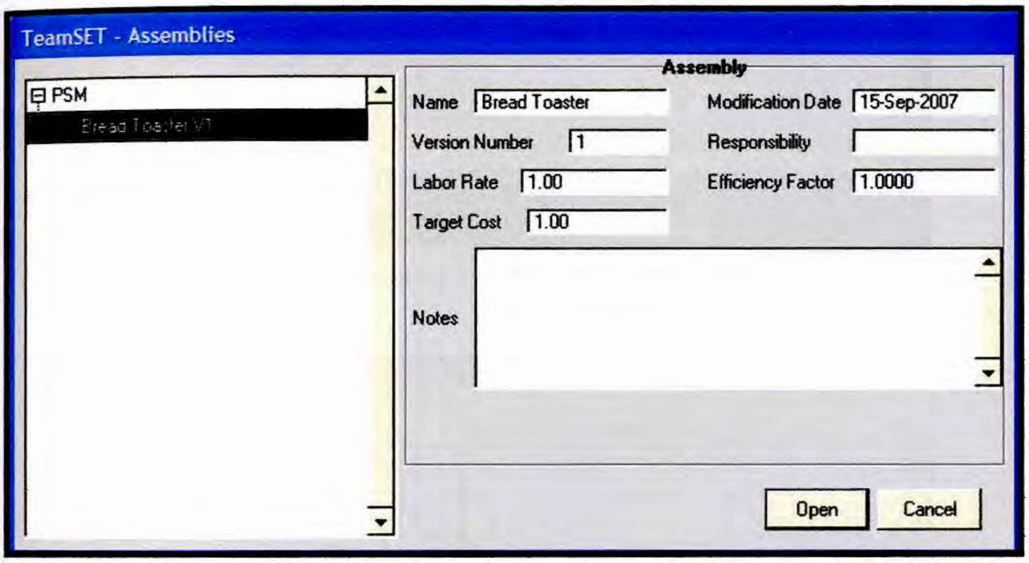


Figure 3.6: DFA Assembly Window

The DFA window is as shown as Figure 3.7. To create a new part, double click on the selected row in the Part name list. The same method applied when inserting the quantity.

After all parts name have been created, any parts that is subassembly can be demoted to show that they are the sub-assembly of the product. Figure 3.8 show the example of how to give a name to a part.

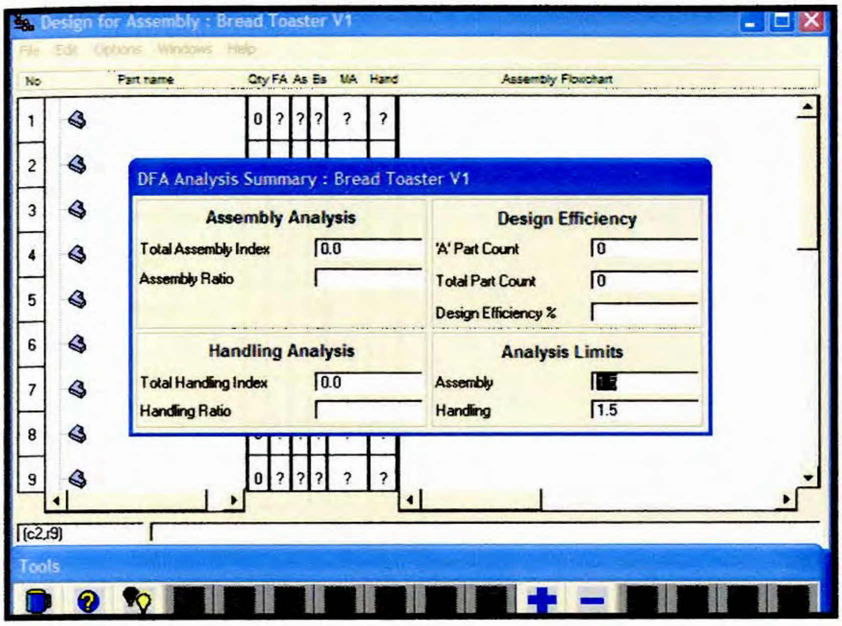


Figure 3.7: DFA Window

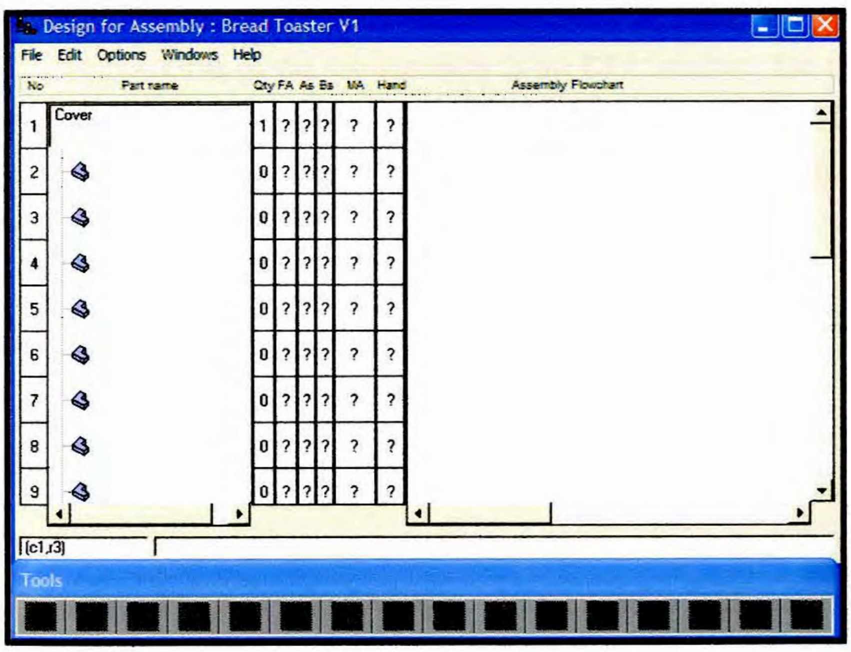


Figure 3.8: Naming The Part

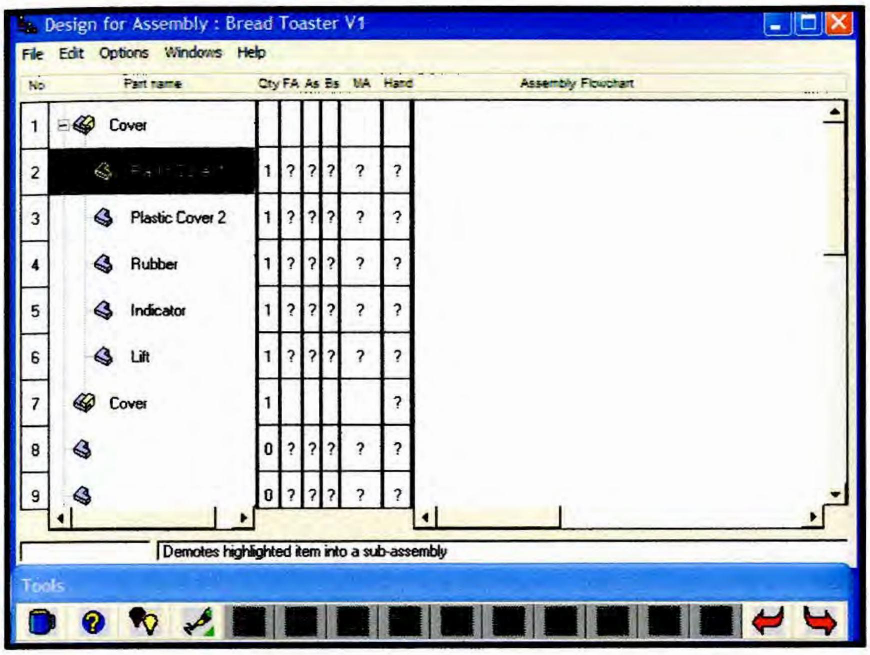


Figure 3.9: The Sub-Assembly

Figure 3.9 show the sub-assembly in the DFA window. The red arrow at the bottom right of the window is the promote and demote arrow. The arrow to the right is promote button meanwhile the arrow pointing to the left is the demote arrow.

3.1.2.1 Using Functional Analysis (FA)

Once all the parts name, quantities and sub-assembly had been made. The Functional Analysis can be done to each part to determine whether the part is 'A' part or 'B' part. Double click on the FA column for the selected parts will access to the new window. Figure 3.10 show the Functional Analysis window.

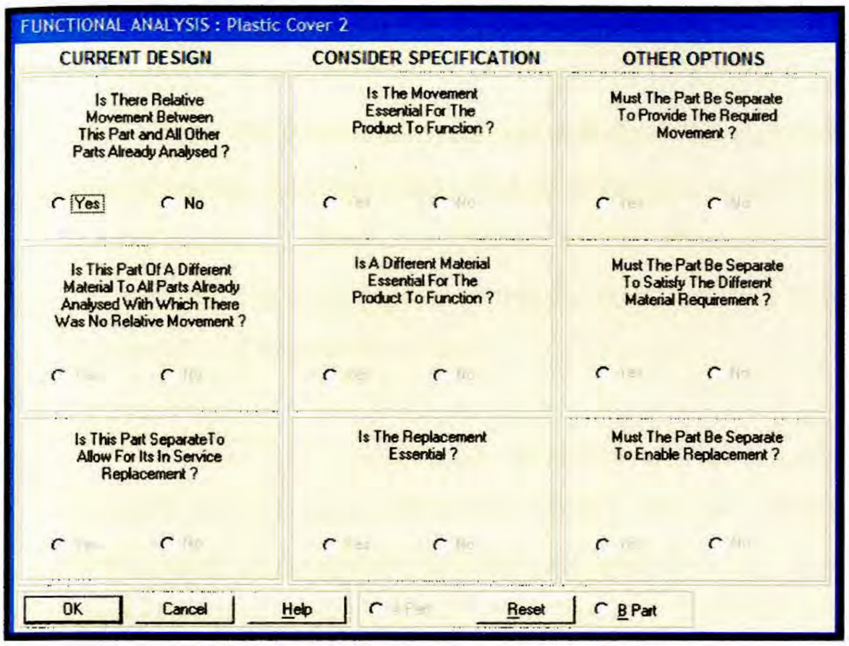


Figure 3.10: Functional Analysis Window

In determining the category of the part, the question must be answered. When the question is first displayed, only the first question at the top left box can be answered. Each time a question is answered, a new box of question will become active.

But for the first part that was analyzed, the part will automatically become 'A' part. 'A' parts are defined as parts that carry out functions vital to the performance of assembly. Meanwhile 'B' parts are parts that are not essential to the assembly function.

If the part categorized as 'A' part has a quantity more than one, only one part will be considered 'A' part and the others will be categorized as 'B' parts. Not all questions will be answered, once the program had identify the category of the parts, the entire question boxes will become grey. To reset the analysis, click on the Reset button. To continue with the result, click OK. To cancel the analysis, click Cancel.

3.1.2.2 Using Manufacturing Analysis (MA)

After the Functional Analysis was done, the parts will under go Manufacturing Analysis (MA). MA is important in product designing process because it allows the designer to find alternative materials and manufacturing process by comparing the manufacturing index value of the current and alternative design.

To start MA, double click on the column of the selected parts. This will allow the access of the MA window. The MA allows the user to enter a range of parameters to define the manufacturing method for the selected part.

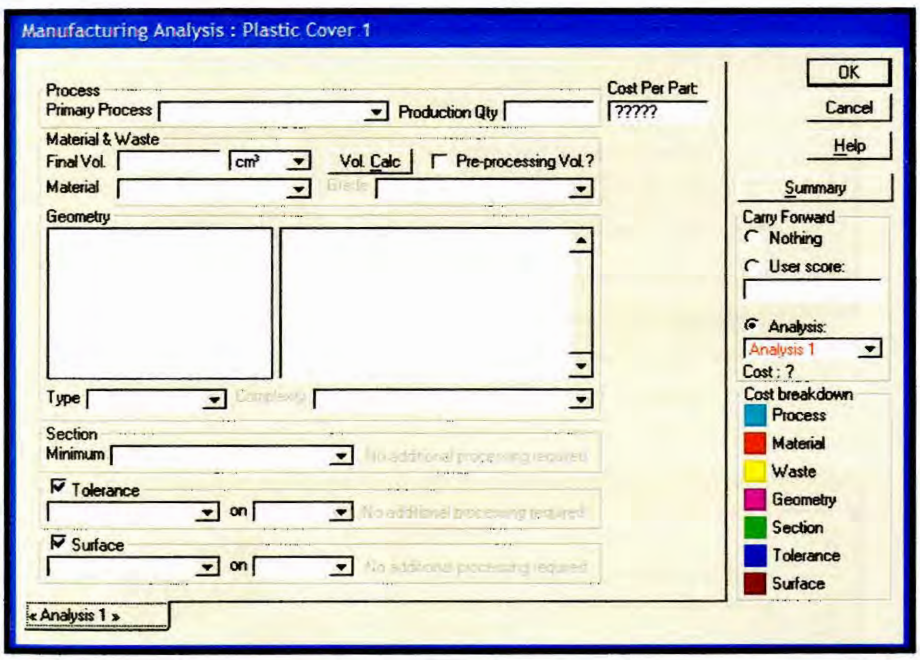


Figure 3.11: MA Window

The primary process is determined along with the material, final volume and production quantity. The geometry of the part will be chosen from three basic functional shapes. Each of them is split into five levels of complexity. Figure 3.12 to Figure 3.15 shows the example of geometry selection for the MA. The minimum section is the thinnest section of the part. The tolerance is the allowable deviation of the part and the surface is the specification of the required finished surface for the part. This three criteria need to be filled based on the selected part in order to get the analysis result.

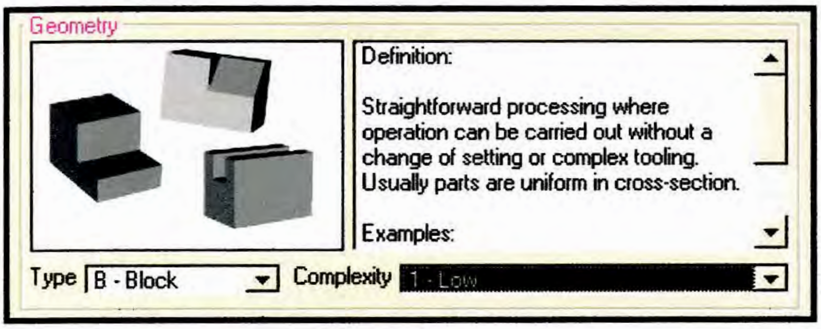


Figure 3.12: Low Block Geometry

Figure 3.13: Medium-Low Cylindrical Geometry

Figure 3.14: High Cylindrical Geometry

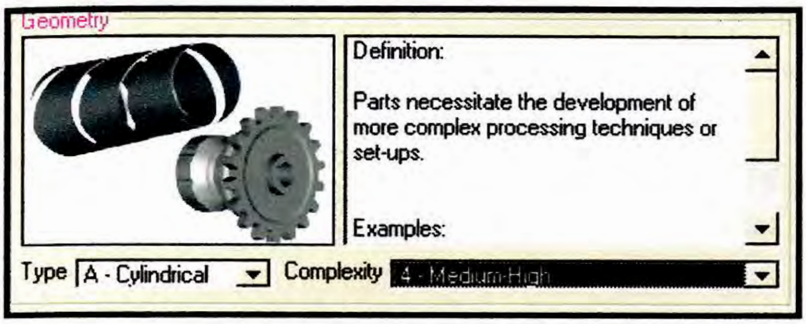


Figure 3.15: Medium-High Cylindrical Geometry

3.1.2.3 Using Handling Analysis (HAND)

To perform handling analysis to the selected part, double click on the HAND column. The handling analysis window will be open. Handling analysis is used to identify the relative cost of handling every part in the assembly. There are three criteria that will be judged in handling analysis. They are: the size and weight of the part, handling difficulties and the orientation of the part. Figure 3.16 shows the handling analysis window.

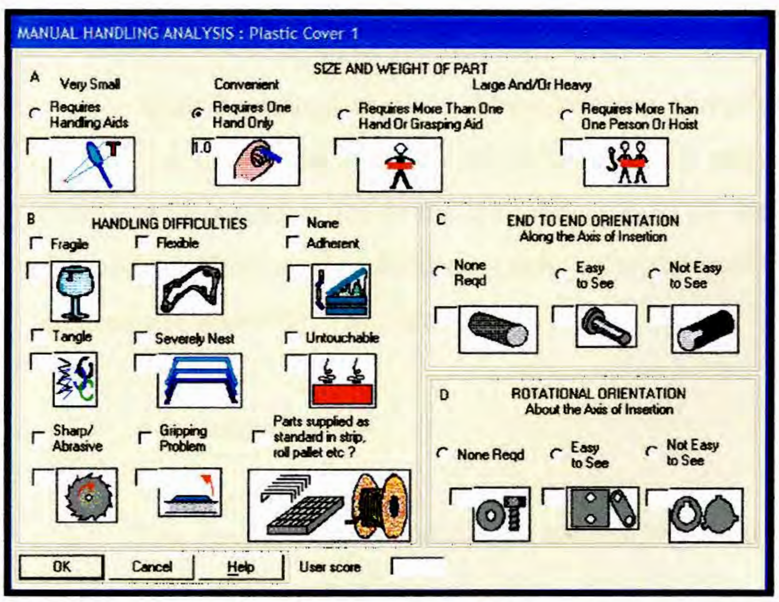


Figure 3.16: Handling Analysis Window

- Section A is used to determine the size and weight of the part. Select the category that most closely describe the part in term of size and weight.
- Section B is used to determine the handling difficulties for the part. Select as many categories that describe the part and if there are no handling difficulties, select None. If no category was selected, the program will assume None.
- Section C is used to determine the end to end orientation along the axis of rotation.
- Section D is for rotational orientation about the axis of insertion. Select the appropriate category for both sections and if no category is selected, the program will assume None Reqd.

Click the OK button to return to DFA window with the handling analysis result or click Cancel to abort the analysis.

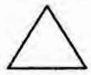
3.1.2.4 Creating Assembly Sequence Flowchart (ASF)

After functional analysis, manufacturing analysis and handling analysis are completed, it is time to create assembly sequence flowchart (ASF). ASF is used to decide the assembly process for the whole parts in the product. There are five different symbols that are used to represent the elements of assembly. They are:

i) Insertion Process

The insertion process symbol is used to represent the addition of parts to the assembly.

ii) Secondary Operation



The secondary operation symbol is used to represent fixing process or other process that is not directly associated with the assembly.

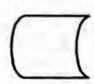
iii) Work Holding Process

The work holding process symbol is used to represent the action of placing a part in a suitable position to accept further part in the assembly.

iv) Remove Tool/ Disassembly

The remove tool/disassembly symbol represents a tool removal process such as removing a clamp or to dissemble a part that had been assembled earlier.

v) Insert Tool/ Reassembly



The insert tool/ reassembly symbol represent a tool insertion process or reassembly a part that have been dissembled before.

To add the symbol to the flowchart area, right click and hold the right mouse button. The window such as figure 3.17 will be displayed. Drag the cursor to the required symbol and release the mouse button.

Figure 3.17: Symbol Selection Menu

To add a link to flowcharts, press and hold the Shift key. Then move the cursor to one of the selected symbol and right click on the symbol and hold the mouse button. Drag the cursor to the second symbol and release the mouse button.

When drawing link lines, there are three rules to be remembered.

i) The upper end of the vertical line must be drawn from the last symbol on the link.
ii) The lower end of a vertical link must be terminate at an insertion process symbol.
iii) Within a sub-assembly, vertical links cannot bypass-rows. Only symbols on adjacent rows can be joined.

To remove the link, use the same method as creating the link.

3.1.2.5 Analyzing the Flowchart

After the flowcharts have been drawn, the activities now can be analyzed to determine the level of difficulties for the assembly. Each symbol has its own analysis windows that will determine the score for each operation.

Insertion Process

To access the analysis window for insertion process, double click on the insertion process symbol in the flowchart area. Figure 3.18 show the insertion process analysis window.

Select all the answers that suit the part criteria. If the process is to be repeated, enter the number of repetitions in the box labeled Repetitions. Click OK to once the analysis is complete or select Cancel to abort the analysis.

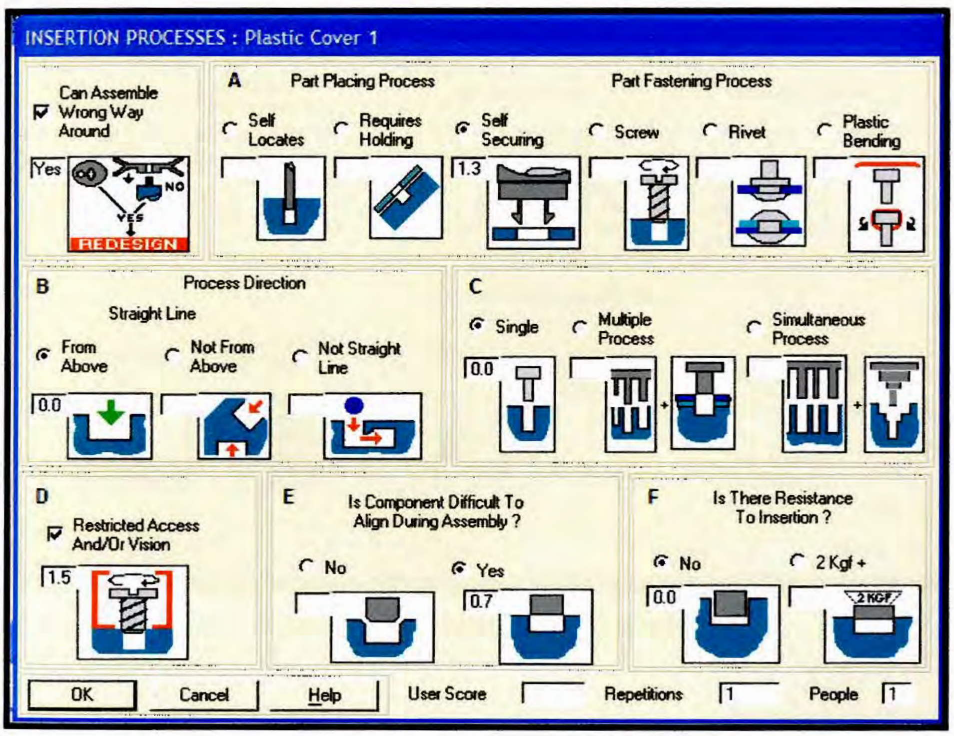


Figure 3.18: Insertion Process Window

Secondary Operation

To access the analysis window for insertion process, double click on the insertion process symbol in the flowchart area. Figure 3.19 show the secondary process analysis window.

Select all the answers that suit the part criteria. All options in secondary operation window are mutually exclusive. If the process is to be repeated, enter the number of repetitions in the box labeled Repetitions. Click OK to once the analysis is complete or select Cancel to abort the analysis.

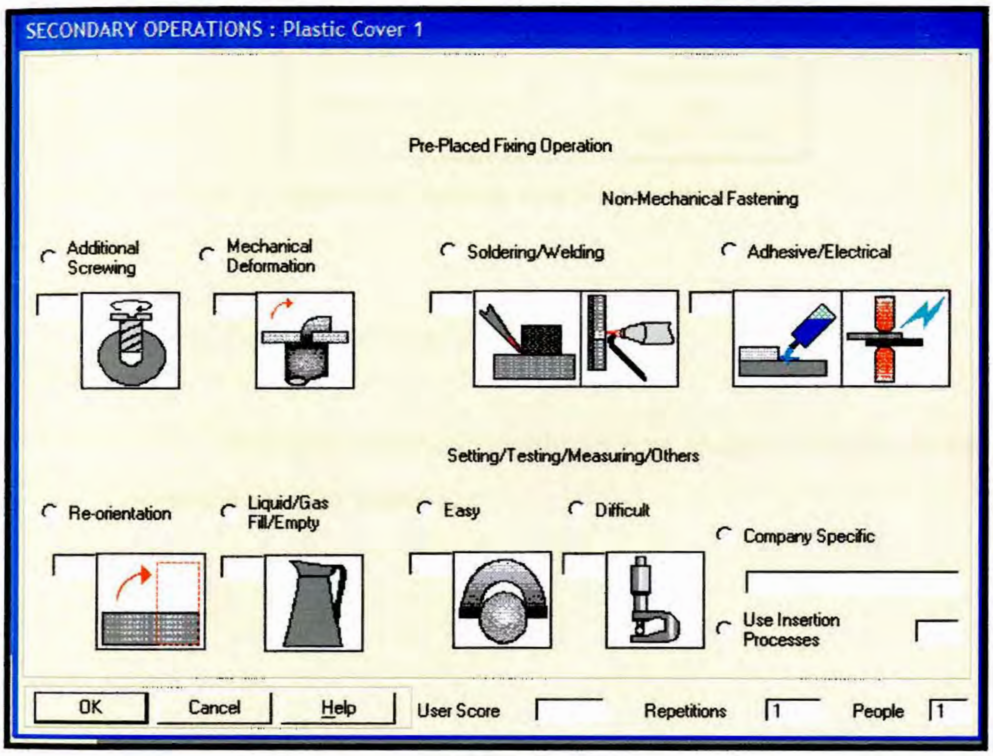


Figure 3.19: Secondary Operation Window

Work Holding Process

The work holding process analysis window is same as insertion process window.

Remove Tool/Disassembly Process

The user score in the remove tool/disassembly window is always shown as one but it can be change by double clicking on the score. Figure 3.20 shows the remove tool/disassembly window.

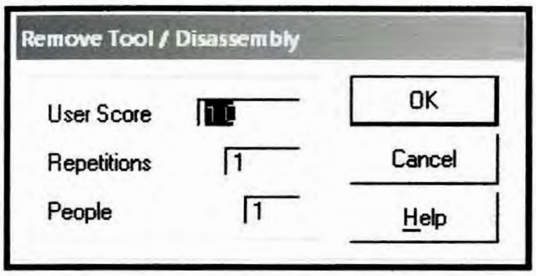


Figure 3.20: Remove Tool/Disassembly Window

Insert Tool/Reassembly Process

The insert tool/reassembly process analysis window is same as insertion process window.

3.1.3 LUCAS-HULL DFMA ANALYSIS SUMMARY

DFA analysis summary windows show the result of the analysis done. Figure 3.21 show the DFA analysis window.

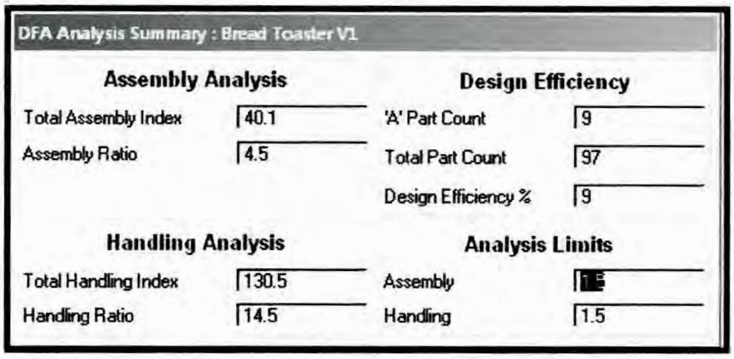


Figure 3.21: The DFA Analysis Summary Window

In the assembly analysis, the total assembly index and assembly ratio is shown. The total assembly index is the total score obtained from all the parts in the assembly sequence flowchart. The assembly ratio is the calculated by dividing the total assembly index with the total number of 'A' parts.

In the handling analysis, the total handling index and handling ratio is shown. The total handling index is the total of all parts in the handling analysis. The handling ratio is the total handling index divided by the total number of 'A' parts.

In the design efficiency, the total number 'A' parts, total part count and design efficiency are shown. The total 'A' part is got from the functional analysis. The design efficiency is calculated by dividing the total number of 'A' parts with the total number of all parts.

In the analysis limit, assembly and handling limit is shown. The default limit for both assembly and handling is 1.5 and it can be change by clicking on the old value and enter the new value.

3.2 THE BOOTHROYD DFMA METHOD

The second DFMA methodology that was used to analyze the product was the Boothroyd DFMA methodology. This method will be used in manual analysis. Manual analysis for Boothroyd DFMA is consisting of two main parts that are DFA and DFM. In DFA, the main analysis is done on the handling and insertion process meanwhile in DFM, the materials and process selections are considered in order to get the best cost in term of quality and saving. Before the analysis is done, the bills of materials should be prepared in order to identify the part count and the part name.

3.2.1 MANUAL HANDLING ANALYSIS

Manual handling analysis is the first part of the Design for Assembly (DFA) in Boothroyd DFMA methodology. The part features that will be analyzed in this section are the size, thickness, weight, nesting, tangling, fragility, flexibility, slipperiness, stickiness, necessity of using two hands, necessity of using grasping tools, necessity of optical magnification and necessity of mechanical assistance [4].

Figure 3.22 shows the Manual Handling-Estimated Times table that will be used in the manual handling analysis. Firstly, the part should be study in order to determine whether it can be manipulated by one hand, one hand with grasping aid, two hands or two hands required for large size. This criterion is based on the parts size and geometry. After that, the part's alpha and beta rotational symmetries are determined by referring to figure 3.23. Alpha is referring to the vertical rotational of the parts meanwhile Beta represents the horizontal rotational of the parts. This rotational angle of symmetry is determined to identify the second possibility of the parts during the insertion time. Less total angle of symmetry means the part is easier to handle and less time is required in handling them.

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
parts can be grasped and manipulated by one hand without the aid of grasping tools		0	1	2	3	4	5	6	7	8	9
(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

Key: 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		
parts can be grasped and manipulated by one hand but only with the use of grasping tools		0	1	2	3	4	5	6	7	8	9
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

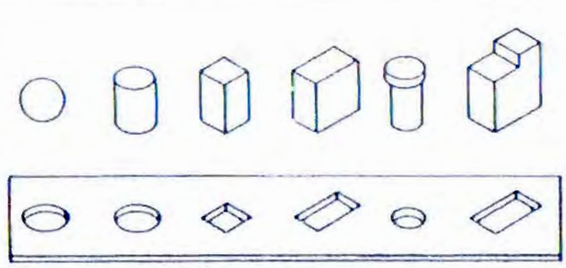
Key: TWO HANDS for MANIPULATION

		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

Key: TWO HANDS 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

Figure 3.22: Manual Handling Estimates Times Table [4]



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

Figure 3.23: Alpha and Beta Orientation Table [4]

After that, the parts handling difficulties should be determine whether the part is easy to grasp and manipulate, present handling difficulties, need tweezers for grasping and manipulation, need optical magnification for manipulation and can be handled by one person without mechanical assistance.

By identifying all these attributes, the part will then be scored based on the handling analysis and the estimates handling time for the part can be determine from the scored code.

3.2.2 MANUAL INSERTION ANALYSIS

MANUAL INSERTION – ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	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

PART SECURED IMMEDIATELY

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			riveting or similar operation				
					not easy to align or position during assembly			not easy to align or position during assembly			
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	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

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	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	3.5	7	8	12	12	9	12

Figure 3.24: Manual Insertion Estimated Times Table [4]

After the manual handling analysis was done, the parts then will under do the insertion analysis. Figure 3.24 shows the Manual Insertion-Estimated Times table that will be used in the manual insertion analysis. The part features that will be considered in this analysis are the accessibility of assembly location, ease of operation of assembly tool, visibility of assembly location, ease of alignment and positioning during assembly and depth of insertion [4].

Firstly, the part is identified whether it is added but not secured, secured immediately or separate operation. After that, the part will be study to determine whether the part is easily reach, have any obstructed access or restricted vision. Other attributes such as requires holding down, riveting operation, plastic bending operation, no screwing operations, screws, non-mechanical fastening process, mechanical fastening process and non fastening process are then identified on each part in order to get the code.

3.2.3 BOOTHROYD DFA ANALYSIS RESULT

After both manual handling and manual insertion analysis was done. The handling time and the insertion time will be added to get the assembly time. To get the assembly cost, a labor cost will need to be estimated. In this case, RM 800 is the labor cost for a month and RM 0.00139 per second. To get the assembly cost for a part, multiply the total assembly time for a part with the labor cost per seconds. To get the total assembly time for the product, add up all the total assembly time of each part. Another important aspect that needs to be identified is the theoretical minimum numbers of parts. Theoretical minimum numbers of parts means a situation where separate parts can be combined into a single part unless one of the following criteria is met:

1) There are relative movements between the analyzed part and any other different parts that have been assembled during the normal operating

mode of the final product.

2) The part is made of different material or must be isolated from any other part already assembled.
3) The part is separated from all other assembled parts otherwise the assembly of parts meeting one of the above criteria would be prevented.[4]

If the part has one of the criteria above, the part will then marked as 1 that means an essential part that is needed for the product to operate. If not, the part will be marked as 0 meaning a non-essential part.

To get the design efficiency, the total theoretical minimum number of parts will be multiply by the basic assembly time for one part and divided by the estimated total assembly time. Boothroyd and his colleagues had determined that the basic assembly time for one part is 3 seconds [4].

3.2.4 BOOTHROYD DFM MANUAL ANALYSIS

DFM analysis is done to compare the materials and process cost in order to get the most suitable materials and process for the part by considering the part's shape and complexity. There are three main sections in Boothroyd DFM that are the general shape attributes, process selection and material selection.

3.2.4.1 General Shape Attributes

Basically there are eight general shape attributes that will be considered in the DFM analysis. These eight attributes are depressions

(Depress), uniform wall (UniWall), uniform cross section (UniSect), axis of rotation (AxisRot), regular cross section (RegXSec), captured cavities (CaptCav), enclosed (Enclosd) and draft free surface (NoDraft). The meanings of these attributes are as follows:

a) Depressions: The ability to form recesses or grooves in the surfaces of the part.
b) Uniform wall: Uniform wall thickness.
c) Uniform cross section: Parts where any cross sections normal to a part axis are identical, excluding draft.
d) Axis of rotation: Part that was shaped by the rotation about a single axis.
e) Regular cross section: Cross sections normal to the part's axis contain a regular pattern.
f) Captured cavities: The ability to form cavities with reentrant surfaces.
g) Enclosed: Parts which are hollow and completely enclosed.
h) Draft free surfaces: The capability of producing constant cross section in the direction of tooling motion.[4]

These attributes will then be identified on a part. As an example, a part with a groove will be identified as a part with depressions attributes. Same goes to other attributes. Figure 3.25 shows an example of a part that have some of the attributes such as depressions, uniform wall, uniform cross section and no draft. A table such as in table 3.1 should be made in order to get a better view of the attributes.

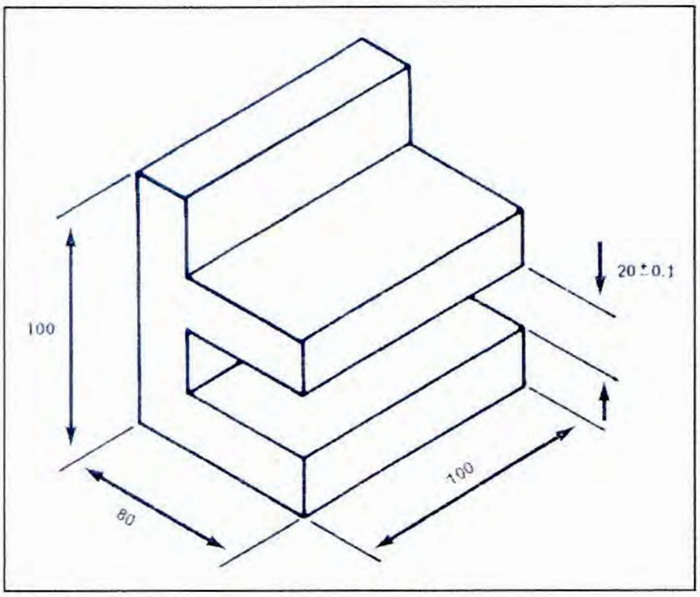


Figure 3.25: Example of Part [4]

Table 3.1: General Shape Attributes of figure 3.25 [4]

Shape Attributes	Condition
Depressions	Yes
Uniform Wall	Yes
Uniform Cross Section	Yes
Axis of Rotation	No
Regular Cross Section	No
Captured Cavity	No
Enclosed Cavity	No
No Draft	Yes

3.2.4.2 Process Selection

After the general shape attributes was identified, a table as in figure 3.26 will be used to check the capability of the process that can make the selected attributes.

	Depress		UniWall	UniSect	AxisRot	RegXSec	CaptCav	Enclosed	NoDraft	PControl	Alignmt	IntFast	
Sand casting	Y	Y	Y	Y	Y	Y	Y	N	N	4	3	1	Solidification processes
Investment casting	Y	Y	Y	Y	Y	Y	Y	N	N	5	5	2	
Die casting	Y	Y[a]	Y	Y	Y	Y	N	N	N	4	5	3	
Injection molding	Y	Y[a]	Y	Y	Y	Y	N[b]	N	N	5	5	5	
Structural foam	Y	Y[a]	Y	Y	Y	Y	N	N	N	4	4	3	
Blow molding (extr)	Y	Y[a]	M	N	Y	Y	M	Y	N	3	4	3	
Blow molding (inj)	Y	Y[a]	M	N	Y	Y	M	N	N	3	4	3	
Rotational molding	Y	Y[a]	M	N	Y	Y	N	M	N	2	2	4	
Impact extrusion	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	Bulk deformation processes
Cold heading	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	
Closed die forging	Y	Y[a]	Y	Y	Y	Y	N	N	N	3	2	1	
Power metal parts	Y	N	Y	Y	Y	Y	N	N	Y	3	3	1	
Hot extrusion	Y[d]	N	Y	M	Y	Y	N	N	Y	2	2	3	
Rotary swaging	N[c]	N	N	N	M	N[c]	N	N	N	1	1	1	
Machining (from stock)	Y	Y	Y	Y	Y	Y	Y	N	Y	2	3	2	Material removal processes
ECM	Y	Y[c]	Y	Y	Y	Y	N	N	N	3	4	1	
EDM	Y	Y[c]	Y	Y	Y	Y	N	N	N	3	4	1	
Wire-EDM	Y[d]	N	Y	Y	Y	Y	N	N	Y	2	2	3	Profile generating processes
Sheetmetal stamp/bend	Y	Y	M	Y	Y	Y	N	N	N	4	3	4	Sheet forming processes
Thermoforming	Y	Y[a]	M	N	Y	Y	N	N	N	3	3	3	
Metal spinning	N	N[c]	M	N	M	N	Y	N	N	1	1	1	

[a] Possible at higher cost.
[b] Shallow undercuts are possible without significant cost penalty.
[c] Possible with more specialized machine and tooling.
[d] Only constant, open-ended possible.
Y, Process is capable of producing parts with this characteristic; N, Process is not capable of producing parts with this characteristic; M, Parts produced with this process must have this characteristic. An underlined entry indicates that parts using this process are easier to form with this characteristic.
The last three columns refer to DFA guidelines and are rates on a scale of 1 to 5, with 1 assigned to processes least capable of incorporating the respective guideline.

Figure 3.26: Shape Generations Capability of Processes Table [4]

For an example, the part in figure 3.25 has uniform wall attributes and from the table, it is shown that rotary swaging process did not have the capability to produce a part with uniform wall thickness, so the process will be blackened in the selection of materials and processes sheet. Figure 3.27 shows the selection of materials and processes sheet.

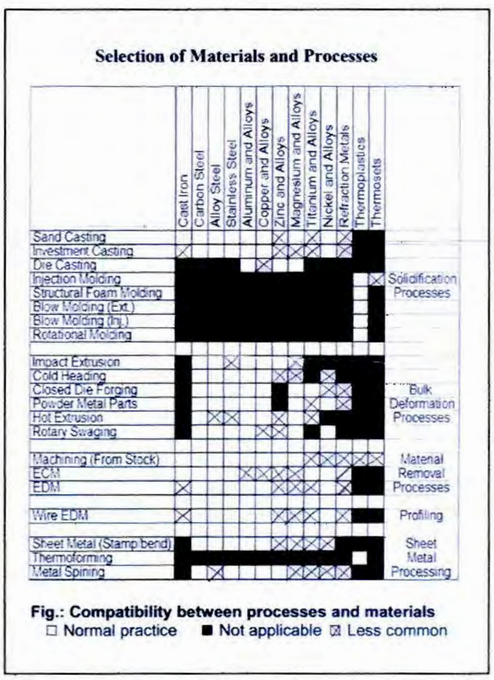


Figure 3.27: Selection of Materials and Processes Table [4]

All other attributes also need to be analyzed in the same way to get the best way of producing the parts.

3.2.4.3 Material Selection

After the process selection had been determined, the material selection process will be done on the part. Every process has its own selection of materials. Table 3.2 shows the material selection table for commonly used polymers in injection molding process.

Table 3.2: Commonly Used Polymers in Injection Molding [4]

Thermoplastic	Yield Strength (MN/m^2)	Elastic modulus (MN/m^2)	Heat deflection temperature (°C)	Cost ($/kg)
High-density polyethylene	23	925	42	0.90
High-impact polystyrene	20	1900	77	1.12
Acrylonitrile-butadiene-styrene (ABS)	41	2100	99	2.93
Acetal (homopolymer)	66	2800	115	3.01
Polyamide (6/6 nylon)	70	2800	93	4.00
Polycarbonate	64	2300	130	4.36
Polycarbonate (30% glass)	90	5500	143	5.54
Modified polyphenylene oxide (PPO)	58	2200	123	2.75
Modified PPO (30% glass)	58	3800	134	4.84
Polypropylene (40% talc)	32	3300	88	1.17
Polyester teraphhalate (30% glass)	158	11000	227	3.74

From this table, the most suitable materials can be selected based on cost and other criteria that are important to ensure the part will be in good quality and performance. As for the bread toaster, it is suggested that ABS is used due to its high heat deflection temperature and low cost. After the material was selected the machine selections and others preparation for the manufacturing process will be done based on the selected process.

3.3 SUMMARY

In this chapter, step by step method of analysis using the software, TeamSET and manual analysis of Boothroyd Dewhurst DFMA is shown. Each method has its own principles and guidelines in analyzing the product. In Lucas-Hull DFMA, there are four main categories of analyses that are: functional analysis, manufacturing analysis, inserting or handling analysis and fitting analysis.

Meanwhile in Boothroyd-Dewhurst DFMA, there are two main analyses that are DFA and DFM. In DFA, the cost and times for manual insertion and handling are estimated and in DFM, each parts is analyzed based on general shape attributes in order to select the best materials and processes. This chapter can be a reference for anyone that is interested in using the DFMA methodology.

CHAPTER 4

DFA ANALYSIS AND DISCUSSION

4.0 INTRODUCTION

This chapter will describe the DFA analysis result and the discussion of the original design. A new design will be proposed from the result of the analysis. The original and new design analysis result will then be compared in order to identify the changes and the differentiation after the DFMA methodology was applied.

4.1 THE SELECTED PRODUCT

The product that has been chosen for this project is a bread toaster manufactured by MEC. The bread toaster consists of 97 parts including screws and rivets. The product was selected due to its potential to be improved and less costly if compared with other products. Before the analysis was done, the product was disassembled so all of the parts can be seen clearly. Each part then will be analyzed using TeamSET software to get the data needed in this project. Figure 4.1 shows the overall view of the product.

Figure 4.1: The Overall View Of The Bread Toaster

Figure 4.2 to figure 4.13 show the parts and sub-assemblies of the product.

Figure 4.2: Plastic Cover 1

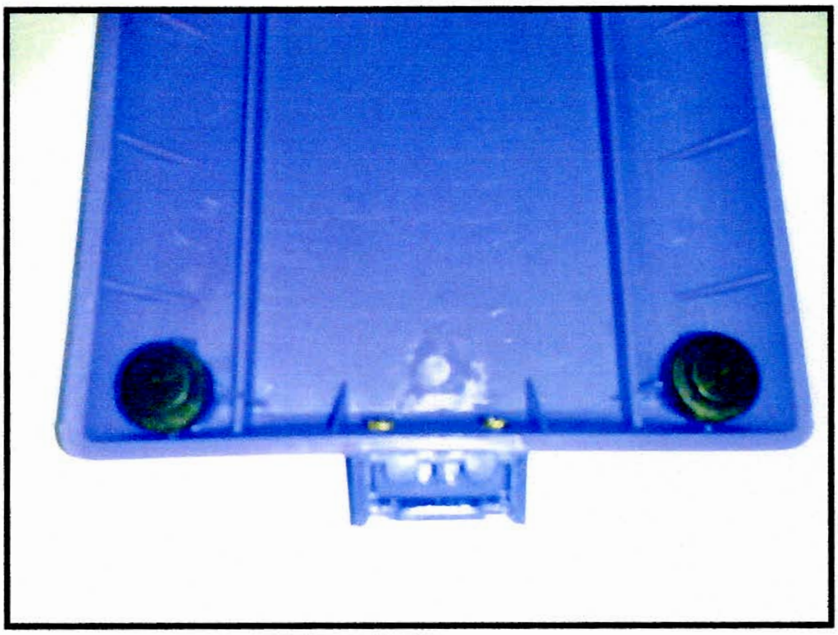


Figure 4.3: Rubber

Figure 4.4: Plastic Cover 2

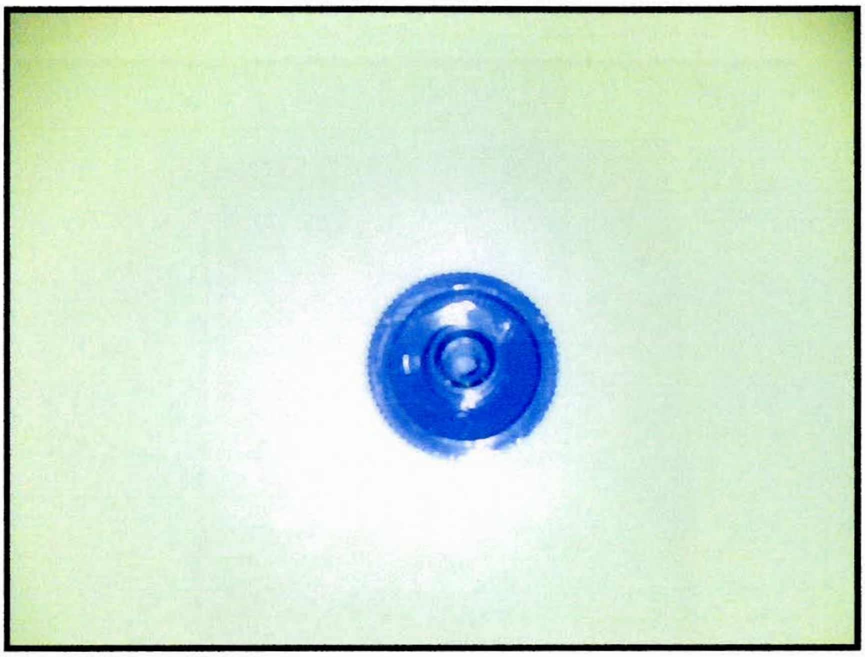


Figure 4.5: Indicator

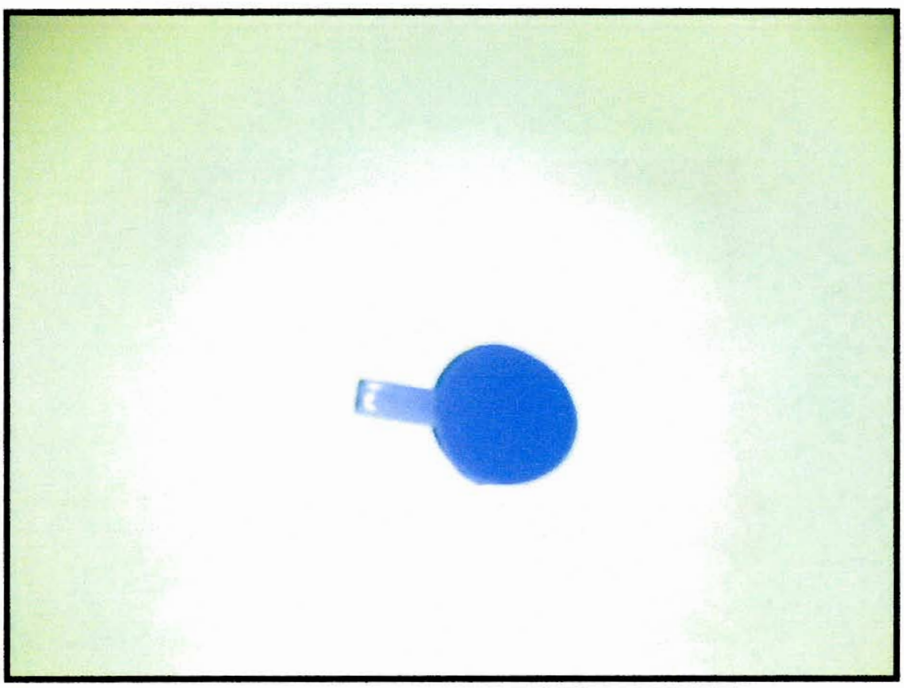


Figure 4.6: Lift Handle

Figure 4.7: Side Plate Cover

Figure 4.8: Top Plate Cover

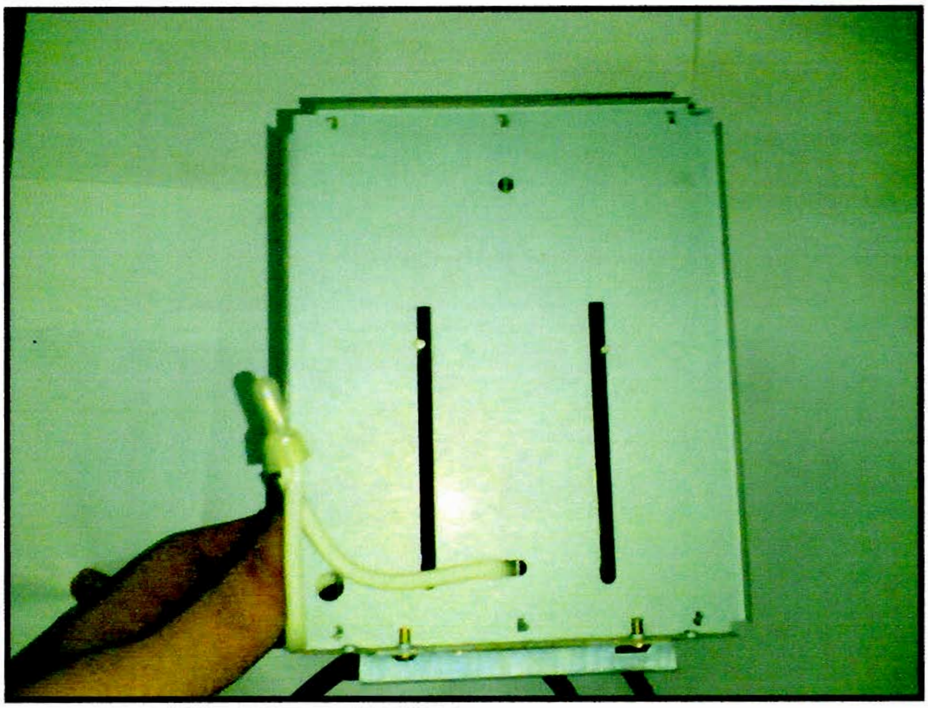


Figure 4.9: Plate Core

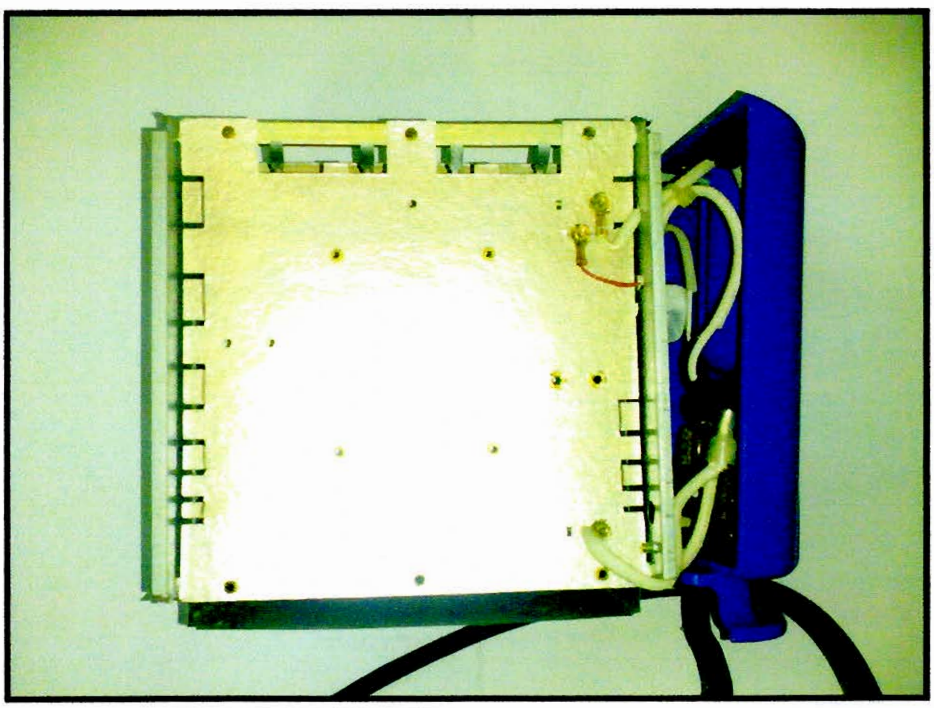


Figure 4.10: Heat Conductor

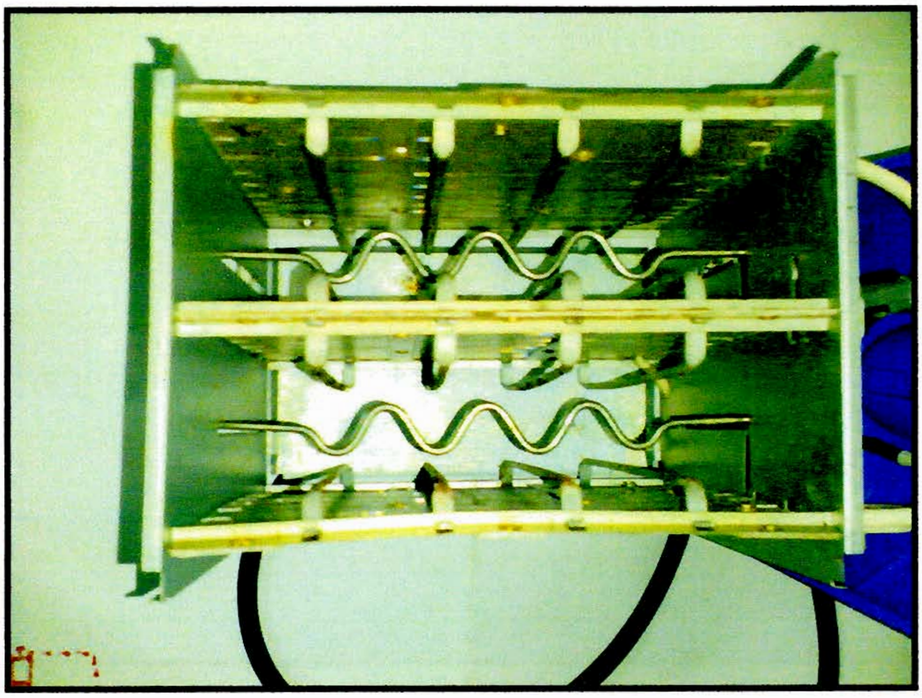


Figure 4.11: Core Sub-Assembly

Figure 4.12: Ash Tray Main Body

Figure 4.13: Ash Tray Sub-Assembly

ıre 4.14 shows the detail drawing of the original design. The drawing is made using ia V5 R10.

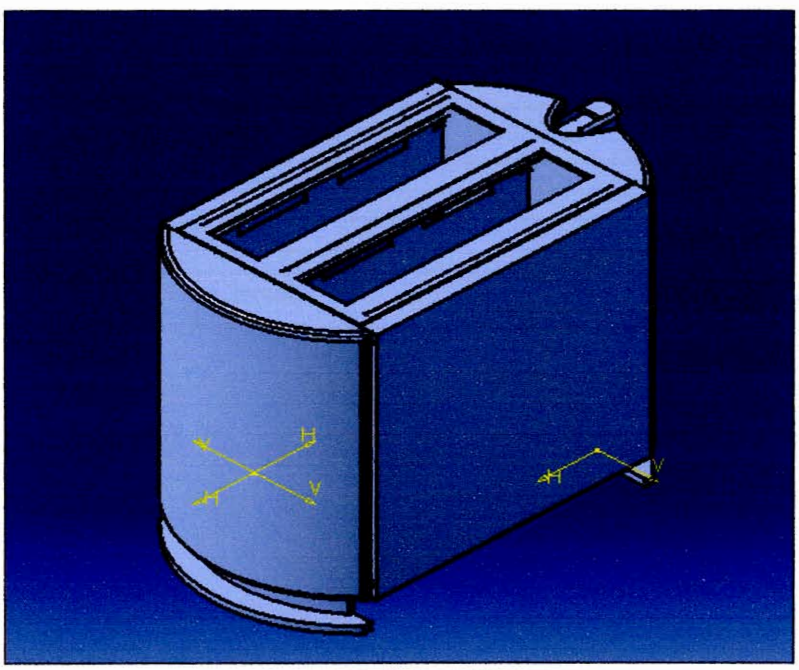


Figure 4.14: The Old Design of the Toaster

ıe bill of materials for the original design is as in Table 4.1 below.

Table 4.1: Bill of Materials for the Old Design

Part Number	Quantity	Part Name	Material
1	3	Conductor	Thermoplastic
2	8	Main Frame	Metal
3	16	Heater	Metal
4	2	Plate Core	Metal
5	2	Cover	Plastic
6	4	Rubber	Thermoplastic
7	1	Indicator	Plastic
8	1	Lift Handle	Plastic
9	1	Ash Tray Main Body	Metal
10	1	Top Plate Cover	Metal
11	2	Side Plate Cover	Metal
12	1	Tray	Metal
13	1	Handle	Plastic
14	2	Lift Bar	Metal
15	10	Screws	Metal
16	42	Rivets	Metal
17	1	Spring	Metal
18	1	Circuit	Standard Part

.2 RESULT AND DISCUSSION FOR THE ORIGINAL DESIGN

The old design of the bread toaster was analyzed by two DFMA methods that are ucas-Hull DFMA and Boothroyd-Dewhurst DFMA methodology. The results for both ıethods are not the same because the principles that have been applied are different. ased on the result of the analysis, a new design will be proposed based by applying the FMA principles.

4.2.1 Analysis on the Original Design Using Lucas Hull DFMA

In this Lucas Hull DFMA analysis, TeamSET software was used to analyze all the parts. Figure 4.15 shows the analysis result for the analysis done.

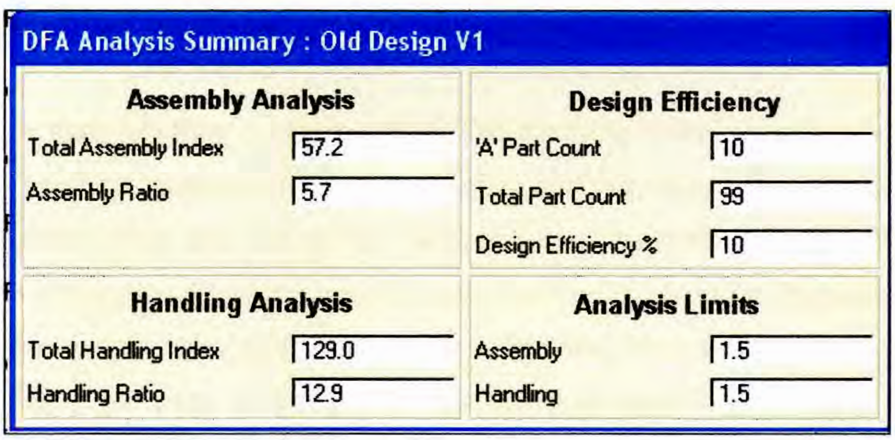


Figure 4.15: Analysis Result of the Original Design

There are 99 parts that were analyzed using TeamSET software. From 99 parts, 10 parts were identified as 'A' parts and the other 89 parts are 'B' parts. To determine whether a part is 'A' or 'B' part, functional analysis must be done. Basically, 'A' parts can be define as parts that carry out functions that are vital to the performance of the assembly meanwhile 'B' parts can be define as parts that are not essential to the assembly function.

The important factors that will be considered in functional analysis are:

1) The relative movements between the part and any other parts.
2) The differentiation of material of the part.
3) The separation of the part.

The design efficiency for the product is 10% and this was calculated by dividing the total number of 'A' parts with the total number of all parts. The suggested design efficiency when designing a product is 60% and if it is lower, a redesign should be make. This product has too many 'B' parts and some of them could be eliminated or combined with other parts to reduce the part count. If the same type of part has more than one quantity, the other parts of the same type will be considered 'B' parts even though it is essential for the product to function. As an example, heaters in the core sub-assembly are important to make the bread toaster function. The quantity of the heaters in the design is 16 but only one heater will be considered an 'A' part and the others will be 'B' parts. The design of the heater could be improve to reduce the part count.

The total handling score is 129.0. The handling score determined by doing the handling analysis. During the handling analysis, the parts are valued based on three areas; the size of the parts, the handling difficulties and the orientation of the parts. From the analysis done, the handling ratio for the product is 12.9. To calculate the handling ratio, the total handling score is divided by the total number of 'A' parts. It is suggested that the handling limit for a design is 2.5. Higher handling ratio means difficulties during the assembly processes and the design should be revised.

The individual score on most parts in handling analysis are good. This is because most parts are easy to handle due to its small size and not requiring any handling aid in order to handle the parts during assembly. But the handling ratio for the whole product is high because the total numbers of 'A' parts are very small compared to the total handling score. To reduce the handling ratio, some of the 'B' parts should be eliminated or combined with other parts. By reducing the part count, the handling score will automatically be reduced.

The total assembly score for the product is 57.2. The assembly score is the value of all processes in the assembly sequence flowchart. Mainly, there are five types of processes in assembly sequence flowchart. These processes are work holder process, insertion process, secondary operation, remove tool/disassembly process and insert tool/reassembly process.

The assembly ratio for the product is 5.7 and it is calculated by dividing the total assembly score with the total number of 'A' parts. The suggested assembly ratio is 2.5 and if more, parts with the assembly score more than 1.5 should be revised and redesign should be make.

Basically, the assembly operation depends on the part count. Less parts means less assembly operation. In this old design, the main factor why the assembly score is high is because of the part fastening process that using screws and rivets. There are 10 screws and 42 rivets that are used in the assembly process and lots of times are wasted during the process because it requires additional tool to insert the screws and rivets. Mainly, each operation that requires part fastening process such as screw and rivet will give 4.0 score without other additional features. If there are multiple screwing or riveting processes, the score will be as high as 4.7 for each operation. This will affect the total assembly score.

Generally, the other parts assembly score are quite decent with range from 1.0 to 2.8. in order to reduce the assembly score, the part fastening process such as screws, rivets and plastic bending should be replace by self securing process such as snap fits. By snap fitting a part, less time is needed because there is no additional tool needed during the assembly process.

4.2.2 Analysis on the Original Design Using Boothroyd Dewhurst DFMA

The product also has been analyzed by the manual application of Boothroyd Dewhurst DFMA. The result of the analysis is as in table 4.2.

Table 4.2: Result of Botthroyd DFMA Manual Analysis of the Old Design

Part Name	Qty.	Handling Code	Handling Time	Insertion Code	Insertion Time	Total Time	Minimum Part Count	Assembly Cost
Heat Breaker	3	23	2.36	06	5.5	7.86	1	0.0109
Main Frame	8	23	2.36	35	7.0	9.36	0	0.0130
Heater	16	23	2.36	36	8.0	10.36	1	0.014
Plate Core	2	33	2.51	32	4.0	6.51	1	9.0417e-3
Cover	2	30	1.95	06	5.5	7.45	1	0.0103
Rubber	4	10	1.5	31	5.0	6.5	0	9.0279e-3
Indicator	1	10	1.5	30	2.0	3.5	1	4.8612e-3
Lift Handle	1	30	1.95	30	2.0	3.95	1	5.4862e-3
Ash Tray Main Body	1	33	2.51	38	6.0	8.51	0	0.0118
Top Plate Cover	1	23	2.36	00	1.5	3.86	0	5.1682e-3
Side Plate Cover	2	33	2.51	30	2.0	4.51	1	6.2639e-3
Tray	1	33	2.51	30	2.0	4.51	1	6.2639e-3
Handle	1	30	1.95	38	6.0	7.95	0	0.0110
Lift Bar	2	13	2.06	08	6.5	8.56	1	0.0119
Screws	10	40	3.6	38	6.0	9.6	0	0.0133
Rivets	42	40	3.6	35	7.0	10.6	0	0.0147
Spring	1	30	1.95	38	6.0	7.95	1	0.0110
Circuit	1	23	2.36	32	4.0	6.36	1	8.8333e-3

From the result of the analysis, it is determined that the total assembly time is 127.9 seconds. To get the design efficiency, the total number of minimum part count will be multiply by the basic assembly time for one product and divided by the total assembly time. Boothroyd, from his experience had determined that the basic assembly time for a product is 3 seconds. The design efficiency of the old design is 25.80%.

The estimated labor cost for this is product is RM 800.00 per month. This estimated labor cost is based on 20 working days and eight hours of work per day. From the analysis done, the total assembly cost for this old design is RM 0.1768 per product.

3 THE NEW DESIGN

From the result of the analysis done to the original product, a new design was ·oposed. The new design was made from the combination of certain parts that is ›nsidered not essential in the original design. Some of the part also had been eliminated ıd replaced by new parts. This new design consists of 15 parts that had been designed operate same as in the original design. Figure 4.16 shows the new design of the ·oduct.

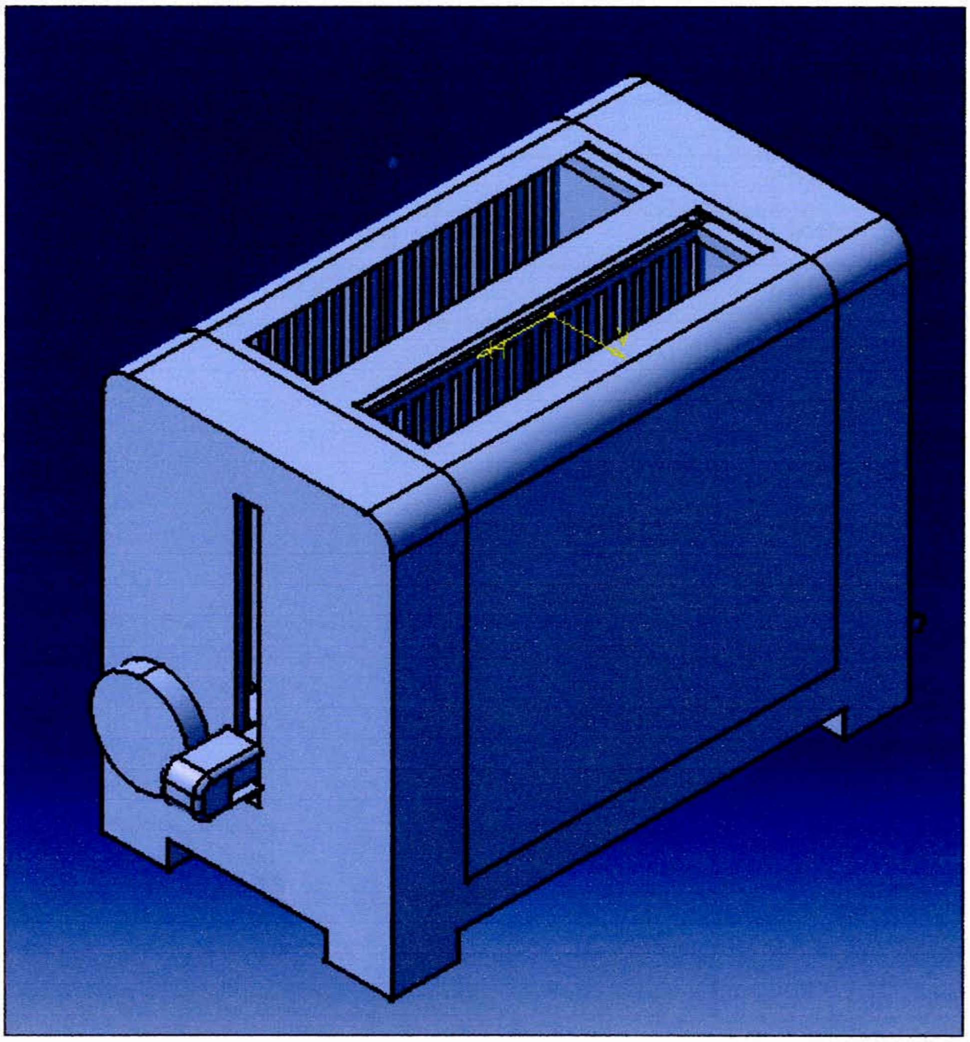


Figure 4.16: The New Design

ble 4.3 shows the bill of materials for this new design.

Table 4.3: Bill of Materials for the New Design

rt Number	Quantity	Part Name	Material
	1	Core	Metal
	3	Heater	Metal
	2	Heat Breaker	Thermoplastic
	2	Lift Bar	Metal
	1	Main Body	Plastic
	1	Indicator	Plastic
	1	Lift Handle	Plastic
	1	Ash Tray	Plastic
	1	Plate Cover	Metal
	1	Spring	Metal
	1	Circuit	Standard Part

RESULT AND DISCUSSION OF THE NEW DESIGN

This new design also need to be analyzed using both Lucas and Boothroyd 'MA methodologies in order to determine whether this new design is fulfilling the teria of a good design after using DFMA method. The results of the original and new sign then will be compared in order to identify the improvements made by applying 'MA methodology.

4.4.1 Analysis on the New Design Using Lucas Hull DFMA

For the analysis of the new design, the same software, TeamSET will be used. Figure 4.17 shows the result analysis for the new design using TeamSET software.

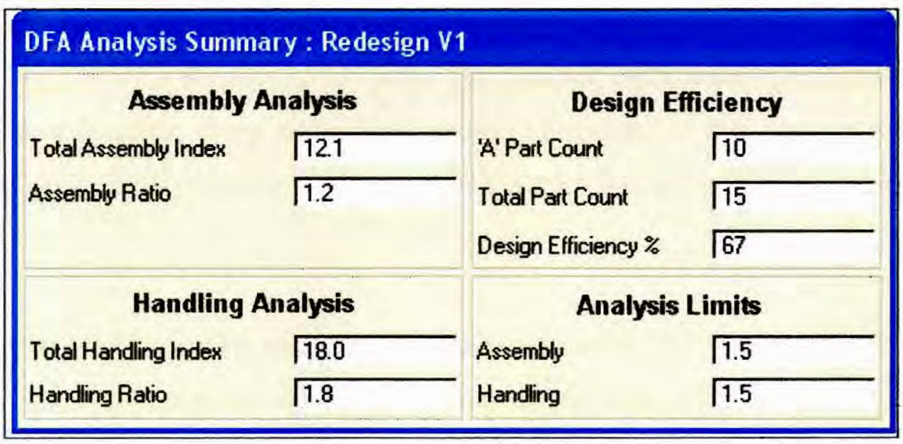


Figure 4.17: Analysis Result for the New Design

In this new design, there are 15 parts that were analyzed using the Teamset software. 10 of the parts were identified as 'A' parts and the other 5 were considered 'B' parts. The part count had been reduced greatly from the total of 99 parts in the original design to 15 parts in this new design. This 84 parts reduction had been achieved by eliminating some parts from original design by considering the three main criteria that was stated in Lucas Hull DFA method.

The design efficiency of this product is 67% and based on the guidelines provided by Lucas Hull, the requirement for a design to be classified as a good design is 60% of design efficiency.

Most of the original parts in the original design were combined in this new design. As an example, the heaters in the original design were redesign so that only 3 heaters are used instead of 16. The change of the design is essential to ensure the assembly process become much easier. In the original design, the 16 heaters were riveted into the main frame one by one. In this new design, a bigger heater is used to cover all area of that need heating.

The total handling score for this new design is 18.0. Meanwhile the handling ratio is 1.8. The handling score are greatly reduced from 129.0 in the original design to 18.0 in this new design. The handling ratio also had been reduced from 12.9 to 1.8. The handling limit that had been stated in Lucas Hull DFMA method is 2.5 and the score reduction in the handling analysis is achieved by reducing the total number of 'B' parts. The size and other handling difficulties such as part tangling, sharp and others are also considered in this analysis. This new design is mostly consist of big parts and not having any difficulties during handling.

The total assembly score for this new design is 12.1 and the assembly ratio is 1.2. The assembly score had been reduced from 57.2 in the original design to 12.1 in this new design. The assembly ratio also had been reduced from 5.7 in the original design to 1.2 in this new design. The assembly ratio for the new design had been reduced because all of the rivets and screw in had been replaced by snap fits connectors. By replacing the screws and rivets with snap fits, a lot of time can be saved because no tools are required during the assembly process. The sub-assembly for the new design also had been reduced from 4 in the original design to 2 sub-assemblies.

4.4.2 Analysis on the New Design Using Boothroyd Dewhurst DFMA

The results of the analysis made on the new design using manual approach of Boothroyd Dewhurst DFMA are as in table 4.4.

Table 4.4: Result of Botthroyd DFMA Manual Analysis of the New Design

No	Part Name	Qty	Handling Code	Handling Time	Insertion Code	Insertion Time	Total Time	Minimum Part Count	Assembly Cost
1	Core	1	20	1.8	00	1.5	3.3	1	4.583e-3
2	Heater	3	20	1.8	30	2.0	3.8	1	5.2774e-3
3	Heat Breaker	2	13	2.06	30	2.0	4.06	1	5.6385e-3
4	Lift Bar	2	10	1.5	06	5.5	7.0	1	9.7216e-3
5	Main Body	1	20	1.8	00	1.5	3.3	1	4.583e-3
6	Indicator	1	13	2.06	30	2.0	4.06	1	5.6385e-3
7	Lift Handle	1	33	2.51	30	2.0	4.51	1	6.2635e-3
8	Ash Tray	1	30	1.95	30	2.0	3.95	1	5.4858e-3
9	Plate Cover	1	23	2.36	30	2.0	4.36	1	6.0552e-3
10	Spring	1	30	1.95	38	6.0	7.95	1	0.0110
11	Circuit	1	23	2.36	32	4.0	6.36	1	8.8333e-3

From the result of the analysis, it is determined that the total assembly time is 52.65 seconds. The total amount of 75.25 seconds has been reduced from the original design. This time reduction had been achieved by combining the non essential parts and eliminating the screws and rivets. The design efficiency of the new design is also increased from 25.80% for the original design to 62.67%. The design efficiency is increasing because the total assembly time had been reduced due to the part reduction and fasteners (screws and rivets) elimination.

The assembly cost for the new design also had been reduced from RM 0.1768 for the original design to RM 0.0730. This cost estimation also using the same rate of labor cost of RM 800.00 per month. Basically, the cost reduction is achieved by the total assembly time reduction. The improvement that had been showed from this analysis had shown that the time reduction also play a big role in reducing the assembly cost.

Table 4.5 shows the summary of design change for this product along with the parts that had been combined in making this new design.

Table 4.5: Summary of Design Change

No	Design Changes	Items	Time Saving (seconds)
1	Combined main frame with plate core and eliminate 18 rivets.	2, 4, 16	18.21
2	Redesign all heaters so that only 3 heaters are used instead of 16 and eliminate 30 rivets.	3, 16	14.16
3	Combined cover, rubber and ash tray main body and eliminate 8 screws.	5, 6, 9, 15	20.76
4	Combined top plate cover and side plate cover.	10, 11	4.01
5	Combined ash tray and the ash tray handle and eliminate 2 screws.	12, 13, 15	18.11

4.5 SUMMARY

From the result of the analysis, it has been determine that the design efficiency for both Lucas DFMA and Boothroyd DFMA is increasing when the total part count number is reduced. Figure 4.18 shows the exploded drawing of the original design and Figure 4.19 shows the exploded drawing of the new design.

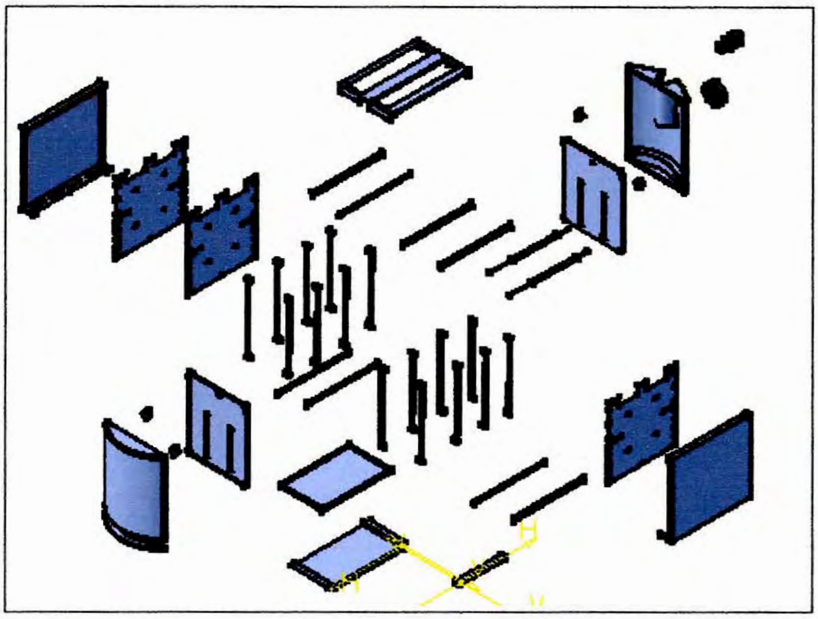


Figure 4.18: Exploded Drawing of Original Design

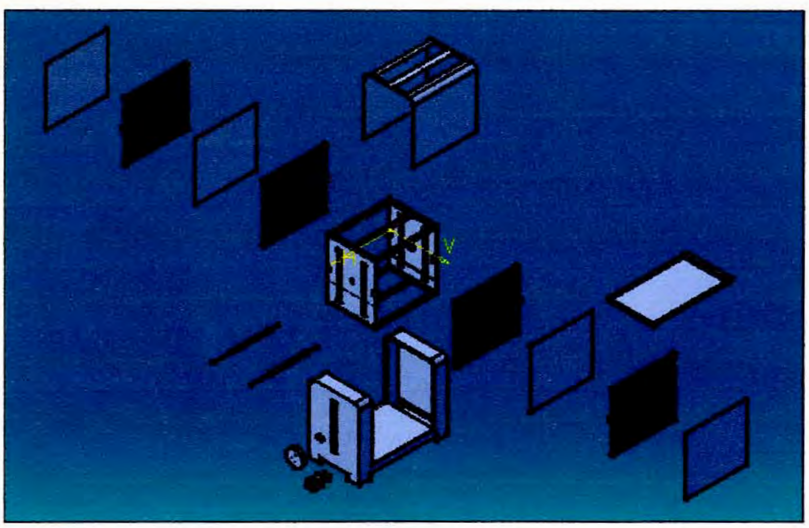


Figure 4.19: Exploded Drawing of New Design

Table 4.6 shows the comparison between the original and new design for the Lucas-Hull DFMA method and Table 4.7 shows the comparison between the original and new design for the Bootroyd-Dewhurst DFMA method.

Table 4.6: Comparison between Original and New Design For Lucas DFMA

Criteria	**Original Design**	**New Design**
Part Count	99 parts	15 parts
Design Efficiency	10%	67%
Handling Score	129.0	18.0
Assembly Score	57.2	12.1
Relative Cost Index	RM 13.24	RM 6.52

Table 4.7: Comparison between Original and New Design For Boothroyd DFMA

Criteria	**Original Design**	**New Design**
Assembly Time	127.9 seconds	52.65 seconds
Design Efficiency	25.80 %	62.67 %
Assembly Cost	RM 0.1768	RM 0.0736

CHAPTER 5

DFM ANALYSIS AND DISCUSSION

5.0 INTRODUCTION

In this chapter, the DFM analysis will be discussed and the comparison between the old and new design manufacturing cost index for Lucas DFMA will be compared. For Boothroyd DFMA, the detail selection of materials and processes will be done and the example of injection molding and sheet metal working analysis will be included.

5.1 DFM ANALYSIS ON LUCAS HULL DFMA METHOD

In Lucas DFMA, the DFM analysis focused on the geometry complexity, waste, processes, materials, section, tolerance and surface. Figure 5.1 shows the DFM analysis window in the TeamSET software.

The result of the analysis is then represented by the relative manufacturing cost index. The relative manufacturing index is not the real value of the price but it act as an indicator of how much value for the process.

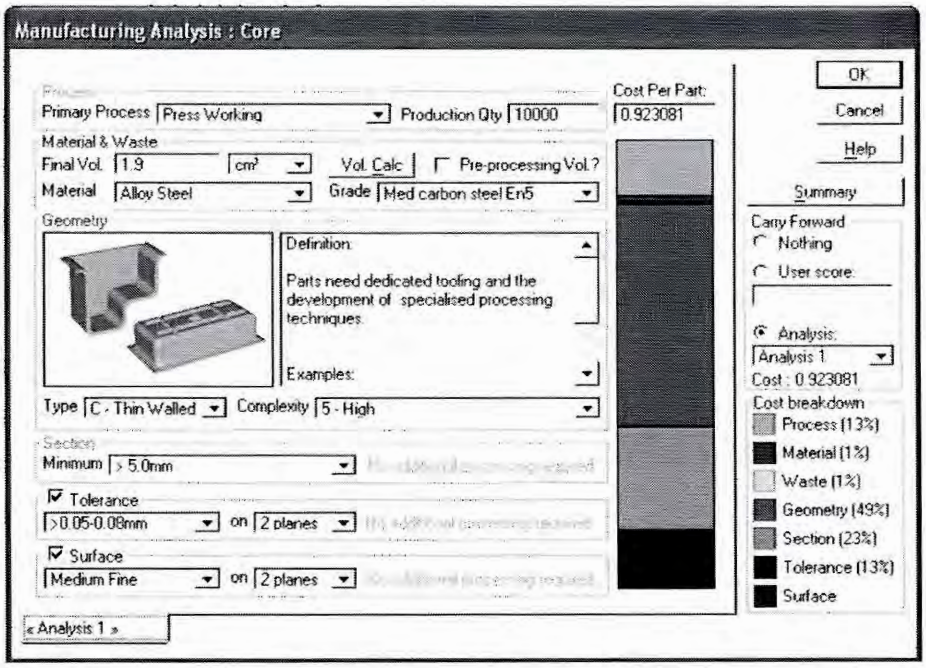


Figure 5.1: DFM Analysis Window

The total relative manufacturing cost index in the original design is RM 13.24. Meanwhile in the new design, the total relative manufacturing cost index is RM 6.52. From this analysis, it has been determine that a total of RM 6.72 has been reduced in the manufacturing cost for the new design.

This cost reduction has been achieved by reducing the number of parts and choosing the most suitable material for the part by considering the cost and attributes needed for the part to avoid waste.

5.2 DFM ANALYSIS ON BOOTHROYD DEWHURST DFMA METHOD

In Boothroyd DFMA methodology, the selection of manufacturing process of a part is depending on the attributes of the part and the capability of the processes. There are eight main attributes in the Boothroyd DFMA. They are:

1) Depressions: The ability to form recesses or grooves in the surfaces of the part.
2) Uniform wall: Uniform wall thickness.
3) Uniform cross section: Parts where any cross sections normal to a part axis are identical, excluding draft.
4) Axis of rotation: Part that was shaped by the rotation about a single axis.
5) Regular cross section: Cross sections normal to the part's axis contain a regular pattern.
6) Captured cavities: The ability to form cavities with reentrant surfaces.
7) Enclosed: Parts which are hollow and completely enclosed.
8) Draft free surfaces: The capability of producing constant cross section in the direction of tooling motion. [4]

Before proceeding with the process selection, all of the parts in the new design will be analyzed to determine the attributes that is available on the part. This process is important because from the attributes, the most suitable process can be determined and if there is mistake in assigning the attributes, it may caused the process that was selected did not capable to produce the wanted part.

Part 2: Heater

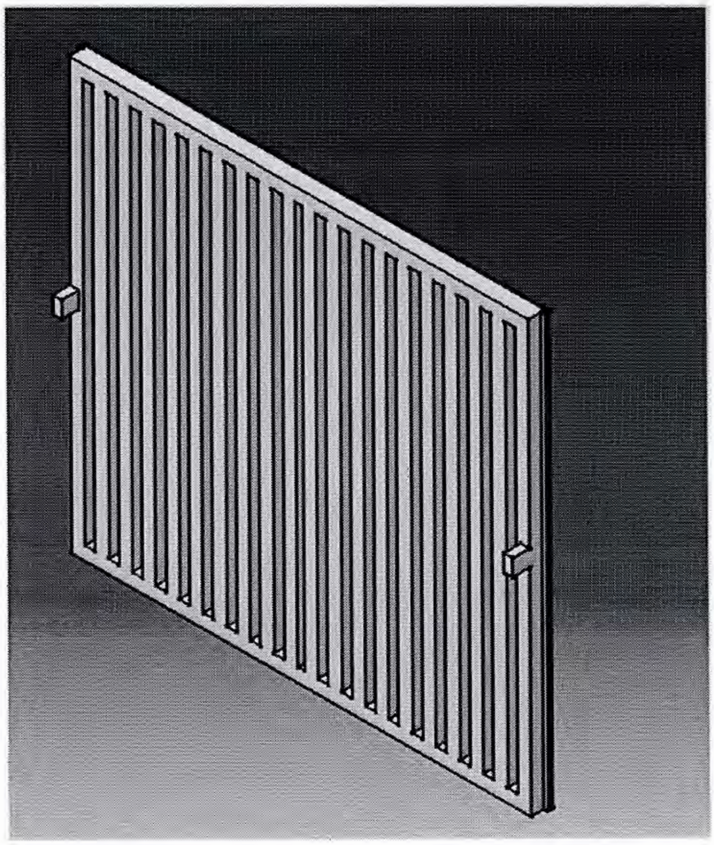


Figure 5.3: Heater

General Shape Attributes for Heater

1) Depress No
2) UniWall Yes
3) UniSect No
4) AxisRot No
5) RegXSec No
6) CaptCav No
7) Enclosed No
8) NoDraft No

Part 3: Heat Breaker

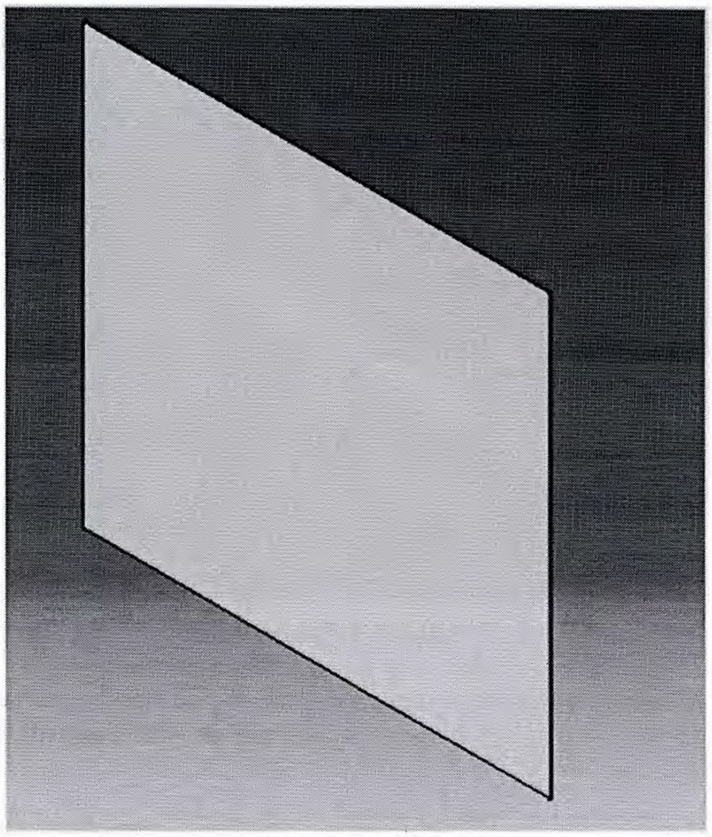


Figure 5.4: Heat Breaker

General Shape Attributes for Heat Breaker

1) Depress No
2) UniWall Yes
3) UniSect No
4) AxisRot No
5) RegXSec No
6) CaptCav No
7) Enclosed No
8) NoDraft No

Part 4: Lift Bar

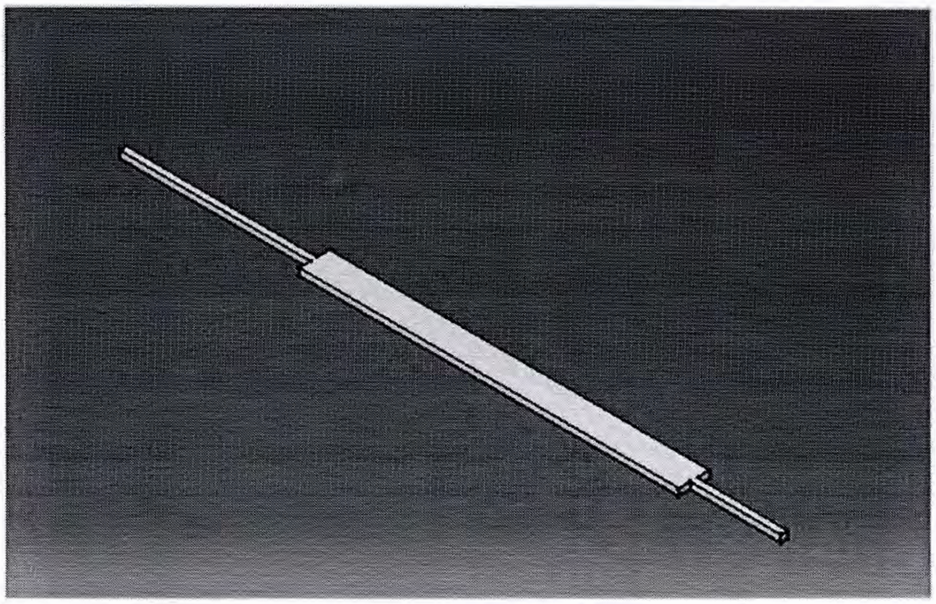


Figure 5.5: Lift Bar

General Shape Attributes for Lift Bar

1) Depress No
2) UniWall No
3) UniSect Yes
4) AxisRot Yes
5) RegXSec No
6) CaptCav No
7) Enclosed No
8) NoDraft No

Part 5: Main Body

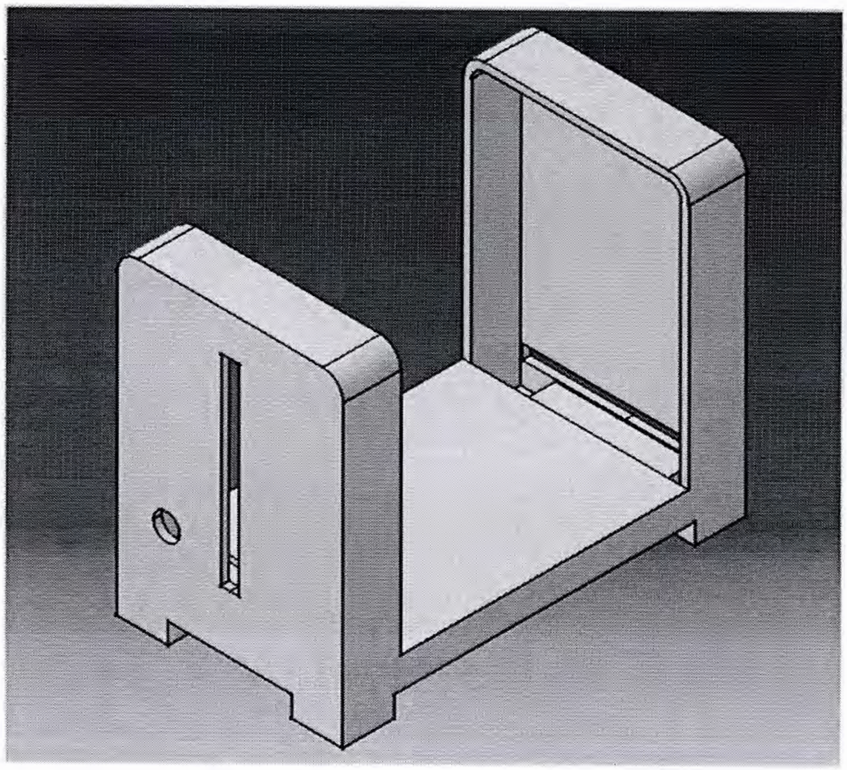


Figure 5.6: Main Body

General Shape Attributes for Main Body

1)	Depress	Yes
2)	UniWall	No
3)	UniSect	No
4)	AxisRot	No
5)	RegXSec	No
6)	CaptCav	No
7)	Enclosed	No
8)	NoDraft	No

Part 6: Indicator

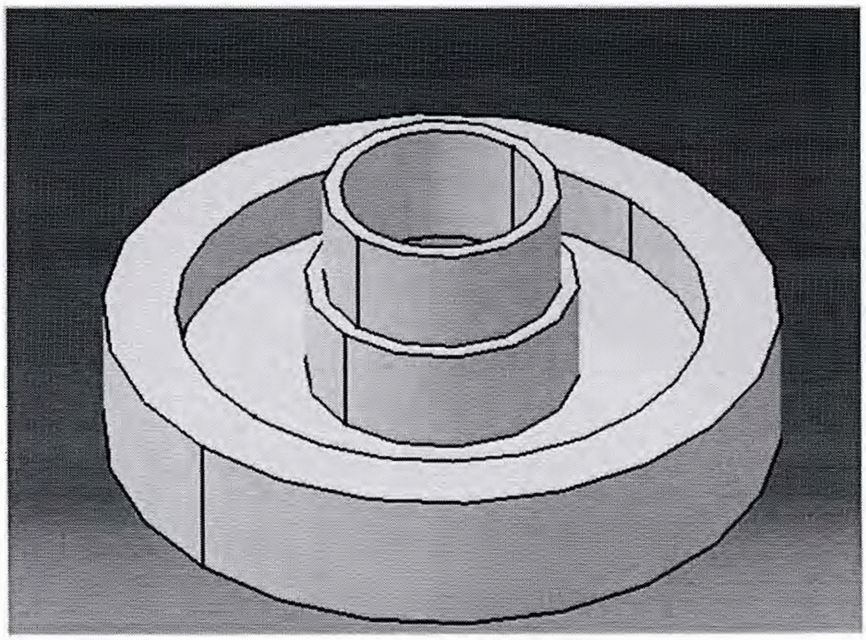


Figure 5.7: Indicator

General Shape Attributes for Indicator

1) Depress Yes
2) UniWall No
3) UniSect Yes
4) AxisRot Yes
5) RegXSec No
6) CaptCav No
7) Enclosed No
8) NoDraft No

Part 8: Ash Tray

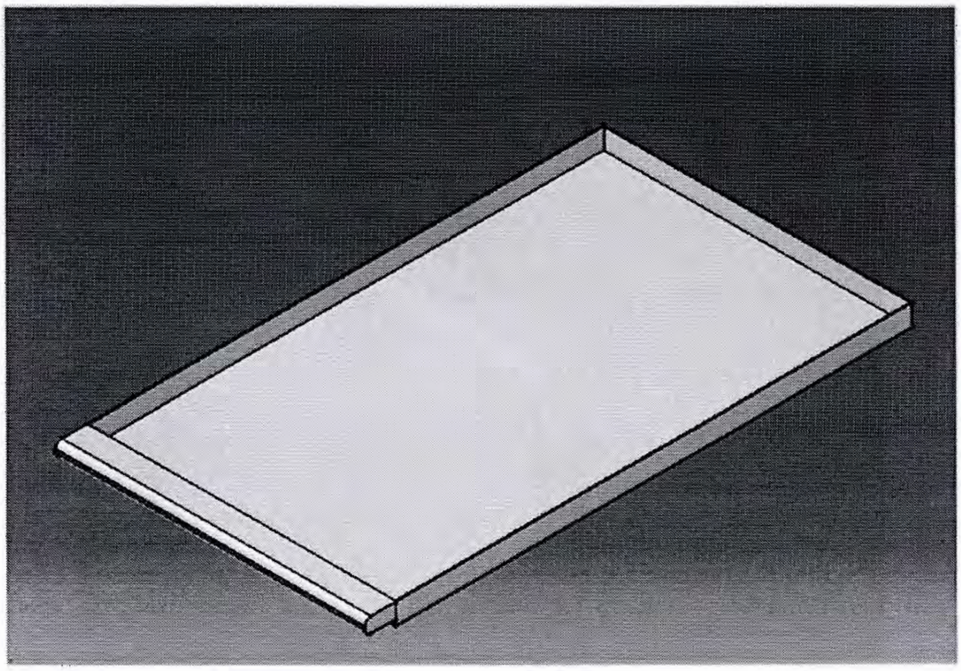


Figure 5.9: Ash Tray

General Shape Attributes for Ash Tray

1) Depress Yes
2) UniWall Yes
3) UniSect No
4) AxisRot No
5) RegXSec No
6) CaptCav No
7) Enclosed No
8) NoDraft No

Part 9: Plate Cover

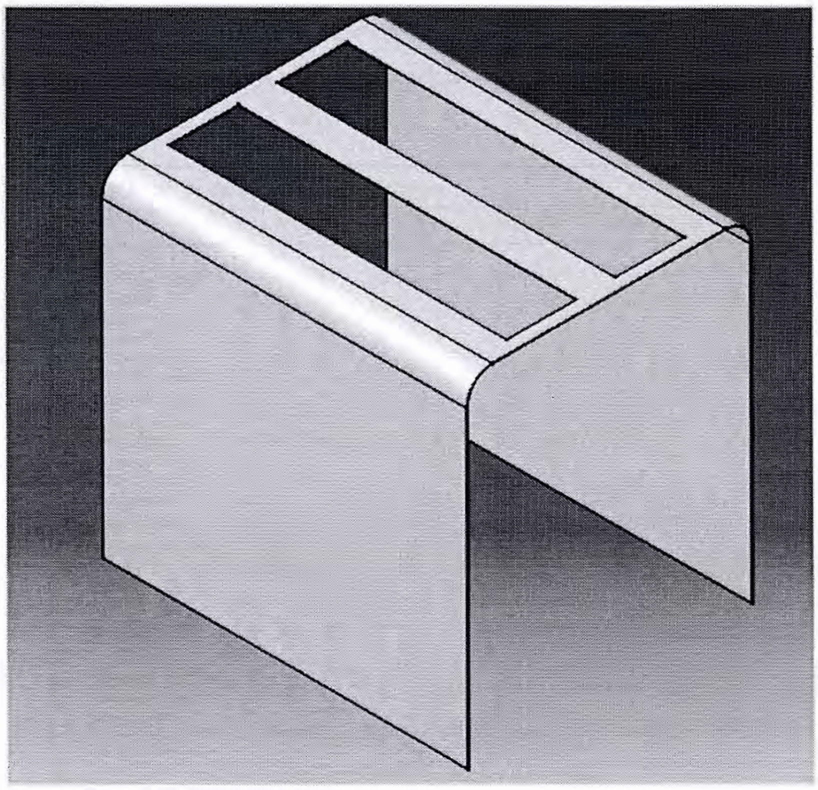


Figure 5.10: Plate Cover

General Shape Attributes for Plate Cover

1) Depress No
2) UniWall Yes
3) UniSect No
4) AxisRot No
5) RegXSec No
6) CaptCav No
7) Enclosed No
8) NoDraft No

After all of the parts attributes were listed, the shape generation capabilities of process table is used to determine which process is capable in producing the part with the appointed attributes. Figure 5.11 shows the shape generation capabilities of processes table.

TABLE 2.2 Shape Generation Capabilities of Processes

	Depress	UniWall	UniSect	AxisRot	RegXSec	CaptCav	Enclosed	NoDraft	PConsol	Alignmt	InFast	
Sand casting	Y	Y	Y	Y	Y	Y	Y	N	N	4	2	1	Solidification processes
Investment casting	Y	Y	Y	Y	Y	Y	Y	N	N	[illegible]	5	2	
Die casting	Y	Y	Y	Y	Y	Y	N	N	N	4	5	[illegible]	
Injection molding	Y	Y	Y	Y	Y	Y	N	N	N	[illegible]	[illegible]	[illegible]	
Structural foam	Y	Y	Y	Y	Y	Y	N	N	N	4	[illegible]	[illegible]	
Blow molding (extr)	Y	Y	M	N	Y	Y	M	Y	N	3	4	[illegible]	
Blow molding (inj)	Y	Y	M	N	Y	Y	M	N	N	[illegible]	1	[illegible]	
Rotational molding	Y	Y	M	N	Y	Y	N	M	N	[illegible]	[illegible]	1	
Impact extrusion	Y	N	Y	N	Y	Y	N	N	Y	1	[illegible]	1	Bulk deformation processes
Cold heading	Y	N	Y	N	Y	Y	N	N	Y	[illegible]	[illegible]	1	
Closed die forging	Y	Y	Y	Y	Y	Y	N	N	N	[illegible]	[illegible]	1	
Power metal parts	Y	N	Y	Y	Y	Y	N	N	Y	3	[illegible]	1	
Hot extrusion	Y	N	Y	M	Y	Y	N	N	Y	2	[illegible]	[illegible]	
Rotary swaging	N	N	N	N	M	Y	N	N	N	1	1	1	
Machining (from stock)	Y	Y	Y	Y	Y	Y	Y	N	Y	[illegible]	[illegible]	2	Material removal processes
ECM	Y	Y	Y	Y	Y	Y	N	N	N	3	4	1	
EDM	Y	Y	Y	Y	Y	Y	N	N	N	[illegible]	[illegible]	1	
Wire-EDM	Y	N	Y	Y	Y	Y	N	N	Y	[illegible]	2	3	Profile generating processes
Sheetmetal stamp/bend	Y	Y	M	Y	Y	Y	N	N	N	4	[illegible]	4	Sheet forming processes
Thermoforming	Y	Y	M	N	Y	Y	N	N	N	3	3	1	
Metal spinning	N	N	M	N	M	N	Y	N	N	1	1	1	

Possible at higher cost.
Shallow undercuts are possible without significant cost penalty.
Possible with more specialized machine and tooling.
[illegible]
Y, Process is capable of producing parts with this characteristic. N, Process is not capable of producing parts with this characteristic. M, Parts produced with this process must have this characteristic. [illegible]
[illegible]

Figure 5.11: Shape Generation Capabilities of Process [4]

Selection of materials and processes table is used to determine the process and material that is suitable for the part to be produced. This table is used along with the shape generation capabilities of processes table. When a process that was checked from the shape generation capabilities of process table is not capable in making the desired attributes, the process is blackened in the selection of materials and processes table that meaning the process is not capable in producing the part. Figure 5.12 show the selection of materials and processes table. All of the selection of materials and processes table is shown in appendix.

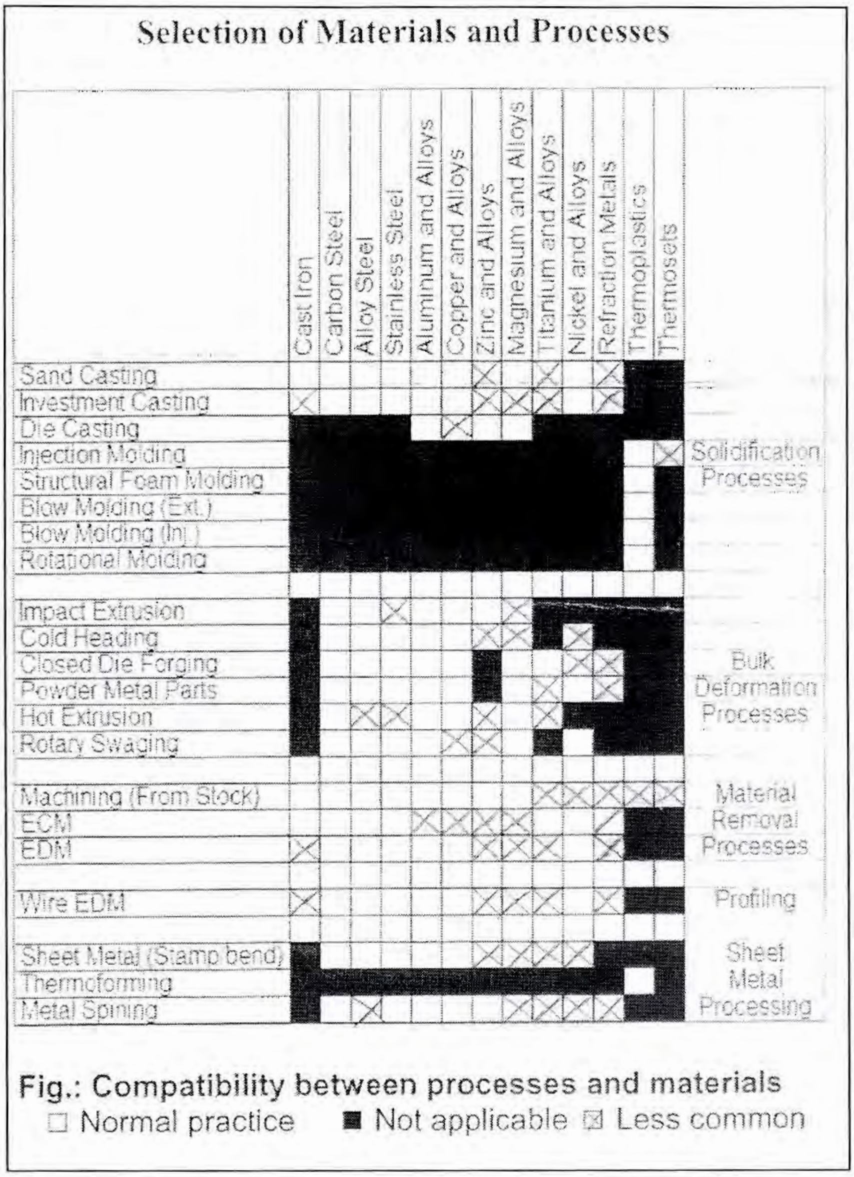


Figure 5.12: Selection of Materials and Processes Table [4]

Table 5.1 shows the processes and materials for all of the parts in the new design that was determine from the analysis above.

Table 5.1: The Selected Processes and Materials for the New Design

Part Number	Part Name	Process	Material
1	Core	Press Work	Low carbon steel
2	Heater	Press Work	Low carbon steel
3	Heat Breaker	Injection Molding	Polyster teraptalate
4	Lift Bar	Press Work	Low carbon steel
5	Main Body	Injection Molding	ABS
6	Indicator	Injection Molding	ABS
7	Lift Handle	Injection Molding	ABS
8	Ash Tray	Injection Molding	ABS
9	Plate Cover	Press Work	Aluminium

The processes and materials that were chosen are based on the cost on the quality of the desired product. Every part should be analyzed thoroughly in order to get the best result in DFM.

5.2.1 Injection Molding Analysis

For the injection molding process, firstly the projected area of the part should be calculated. The projected area is the area projected onto the surface of the mold cavity plate during the injection. Figure 5.13 shows the ashtray that was produced by injection molding process.

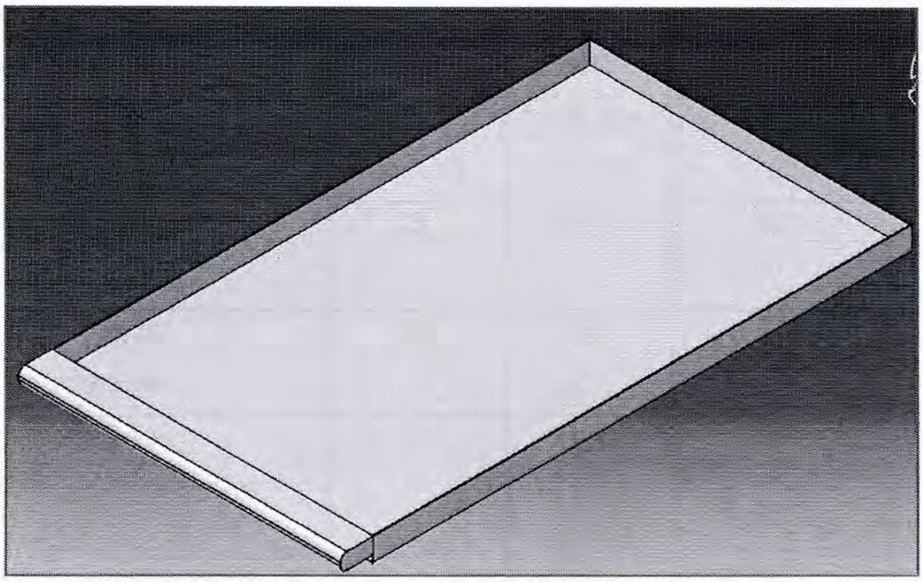


Figure 5.13: The Ashtray

From the part dimension, the projected are can be calculated by calculating the total area and minus the area within the box. This is shown in the equation below.

$$\text{Projected area} = (100 \times 16.8) - (9.2 \times 160)$$
$$= 20.80 \text{ cm}^2$$

The volume of the part is:

$$\text{Volume} = (16.8 \times 10 \times 1) - (9.2 \times 16 \times 0.6)$$
$$= 79.68 \text{ cm}^3$$

From Table 5.2, the material for the injection molding process is determined. For the ash tray, the most suitable material is the acrylonitrile-butadiene-sytrene (ABS). ABS was selected because it has a high heat deflection temperature and cost lower than any other materials with high deflection temperature.

Table 5.2: Material Selection For Injection Molding [4]

Thermoplastic	Yield Strength (MN/m^2)	Elastic modulus (MN/m^2)	Heat deflection temperature (°C)	Cost ($/kg)
High-density polyethylene	23	925	42	0.90
High-impact polystyrene	20	1900	77	1.12
Acrylonitrile-butadiene-styrene (ABS)	41	2100	99	2.93
Acetal (homopolymer)	66	2800	115	3.01
Polyamide (6/6 nylon)	70	2800	93	4.00
Polycarbonate	64	2300	130	4.36
Polycarbonate (30% glass)	90	5500	143	5.54
Modified polyphenylene oxide (PPO)	58	2200	123	2.75
Modified PPO (30% glass)	58	3800	134	4.84
Polypropylene (40%	32	3300	88	1.17

talc)				
Polyester teraphhalate (30% glass)	158	11000	227	3.74

In injection molding process, there are three main areas that will need a detail analysis. These three main areas are the molding machine size, molding cycle time and mold cost estimation.

Molding Machine Size

Firstly, in order to determine the molding machine size, the percentage of increase in area due to the runner system needs to be classified. From Table 5.3, an interpolation for volume of 79.68cm^3 must be done to get the percentage of increase in area due to the runner system.

Table 5.3: Runner Volumes [4]

Part Volume (cm³)	Shot Size (cm³)	Runner %
16	22	37
32	41	27
64	76	19
128	146	14
256	282	10
512	548	7
1024	1075	5

$$(120 - 64) / (14\text{-}19) = (79.68 - 64) / (X - 19)$$

$$-12.8 = 15.68 / (X - 19)$$

X = 17.775

So from the calculation, the percentage of increase area due to the runner system is 18 percent. In the case of the ash tray, assume the mold that was used is consisted of six cavities. The total projected shot area then calculated by:

$6 \times 1.18 \times 20.8 = 147.264\ cm^2$

The recommended injection pressure for ABS is 1000 bars. So the maximum cavity pressure is 500 bars or $500 \times 10^5\ N/m^2$.

The estimate of maximum separating force is calculated by:

F = Total projected shot area x Maximum cavity pressure

$= (147.264 \times 10^{-4}) \times (500 \times 10^5)$

= 736.320 kN

From the estimate of maximum separating force, Figure 5.14 is used to determine the best machine for the part and in the ashtray case, the machine with 800 kN clamping force is the most suitable machine to be used. Before the machine is choose, the required shot area for the part need to be calculated in order to ensure the machine can support the part.

The required shot size = 6 x 1.18 x 20.8 x x0.6

$= 88.3584\ cm^3$

The machine's maximum shot size is 201 cm^3 so the machine can be used for the injection molding process of the part.

TABLE 8.4 Injection Molding Machines

Clamping force (kN)	Shot size (cc)	Operating cost ($/h)	Dry cycle times (s)	Maximum clamp stroke (cm)	Driving power (kW)
300	34	28	1.7	20	5.5
500	85	30	1.9	23	7.5
800	201	33	3.3	32	18.5
1100	286	36	3.9	37	22.0
1600	286	41	3.6	42	22.0
5000	2290	74	6.1	70	63.0
8500	3636	108	8.6	85	90.0

Figure 5.14: The Molding Machine Size [4]

Molding Cycle Time

After the machine size was determined, the molding cycle time can now be estimated based on three separate segments that are injection time, cooling time and mold resetting time. Normally, the cycle time is spent mostly on the cooling time because the polymer needs to be cooled to ensure its quality.

Injection time is the time for the polymer to flow through runners, gates and cavity passages. It can be calculated using the equation:

$T_s = 2 V_s p_j / P_j$

Where:

V_s = Required shot size

p_j = Recommended injection pressure

P_j = Injection power

$V_s = [\, 2 \times (89 \times 10^{-6}) \times (100 \times 10^{6}) \,] / 18.5 \times 10^{3}$

$= 0.96$ seconds

Cooling time takes place almost the entirely by heat conduction. This process requires the most time in the injection molding process. The cooling time is calculated by using the equation:

$t_c = (h^2_{max} / \pi^2 \alpha) \log_e [(4 (T_i - T_m))/ \pi (T_x - T_m)]$

Where:

h_{max} = Maximum wall thickness

T_x = Recommend part ejection temperature

T_m = Recommend mold temperature

T_i = Polymer injection temperature

α = Thermal diffusivity coefficient

$t_c = [4^2 / \pi^2 (0.13)]\log_e [4 (260 - 54) / \pi (82 - 54)]$

$= 50.73$ seconds

Mold resetting time is the time required for the mold to be opened, part ejection and mold closing times and it depends on the amount of movement required for part separation from the cavity and core and on the time required for part clearance from the mold during free fall. It can be calculated as in equation:

$t_r = 1 + 1.75\, t_d [(2D + 5) / L_s]^{1/2}$

Where:

t_d = Dry cycle time

D = Depth

L_s = Maximum clamp stroke

$t_s = 1 + 1.75(3.3)[(2+5)/32]^{1/2}$

$= 1.63$ seconds

Mold Cost Estimation

The mold cost can be classified in two main categories that are the cost of the prefabricated mold base consisting of the required plates, pillars, guide bushings, etc and the cavity and core fabrication cost. However, in this case, the cavity is assumed as six cavities so the detail analysis for cavity and core fabrication cost can be neglected.

Mold base cost is a function of the surface area of the selected mold base plates and the combined thickness of the cavity and core plates. The mold base cost can be calculated by using the equation:

$C_b = 1000 + 0.45\, A_c\, h_p^{0.4}$

Where:

A_c = Area of mold base cavity plate

h_p = Combined thickness of cavity and core plates in mold base

Usually, the minimum clearance between adjacent cavities and between cavity surfaces and the edges and rear surfaces of cavity plates should be 7.5 cm. So the area of the mold cavity plate in this case is 3417 cm^2 and the combined thickness of the cavity and core plates in mold base is 16 cm. Thus the mold base cost is:

$C_b = 1000 + 0.45\,(3417)\,(16)^{0.4}$

$= RM\ 5661.28$

The number of ejector pins required for the mold is calculated by using the equation:

$N_e = A_p^{\ 0.5}$

Where:

A_p = Projected part area

N_e $= (20.8)^{0.5}$

$= 4.56$

5 ejector pins are required for the mold.

Manufacturing hours for the ejection system can be calculated using the equation:

M_e $= 2.5 \times A_p^{0.5}$

$= 11.40$ hours

Geometrical complexity is determined by counting all separate surfaces on the part inner and outer surfaces. An inner surface is the surface which is in contact with the main core or other projections during the molding process meanwhile the outer surface is the surface opposite the inner surface. For the ashtray, the appearances of the surfaces are as in Table 5.4.

Table 5.4: Surface Appearances of The Ashtray

Inner Surface	Outer Surface
Flat wall	Flat outer wall
Flat base	Flat outer base
Single depression	-

So the geometrical complexity of the surface can be calculated as:

$X = 0.01\ N_{sp} + 0.04\ N_{hd}$

Where:

N_{sp} = Number of surface patches

N_{hd} = Number of holes and depressions

The inner surface complexity:

$X_i = 0.01\ (2) + 0.04\ (1)$

$= 0.06$

The outer surface complexity:

$X_o = 0.01\ (2)$

$= 0.02$

From the inner and outer geometry complexity, the mold manufacturing hours now can be calculated using equation:

$M_x = 45\ (X_i + X_o)^{1.27}$

$= 45\ (0.06 + 0.02)^{1.27}$

$= 1.82$ hours

Finally, the manufacturing hours for one cavity and core is calculated by using equation:

$M_{po} = 5 + 0.085 \times A_p^{1.2}$

Where:

A_p = Part projected area

$M_{po} = 5 + 0.085 \times (20.8)^{1.2}$

$= 8.24$ hours

5.2.2 Sheet Metal Analysis

The operations associated with sheet metal working/ stamping are blanking, piercing, forming and drawing. These operations are doe with dedicated tooling also known as hard tooling. All these operations can be done either at a single die station or multiple die stations-performing a progression of operations, known as a progressive die.

In this new design, a stamping process will be applied to two parts that are core and plate cover. There are six main areas that will need analysis in order to identify the suitable machine and die size. These six areas are:

1) The blanking cost
2) The piercing cost
3) The bending cost
4) The progressive die cost
5) The press machine selection
6) The cycle time

Before proceeding with the DFM analysis, the material selection for the stamping process must be done. Figure 5.15 shows the material selection tables.

Alloy	Cost ($/kg)	Scrap value ($/kg)	Specific gravity	UTS (MN/m^2)	Elastic modulus (GN/m^2)	Max. tensile strain
Steel, low-carbon commercial quality	0.80	0.09	7.90	330	207	0.22
Steel, low-carbon, drawing quality	0.90	0.09	7.90	310	207	0.24
Stainless steel T304	6.60	0.40	7.90	515	200	0.40
Aluminum, 1100, soft	3.00	0.80	2.70	90	69	0.32
Aluminum, 1100, half hard	3.00	0.80	2.70	110	69	0.27
Aluminum, 3003, hard	3.00	0.80	2.70	221	69	0.02
Copper, soft	9.90	1.90	8.90	234	129	0.45
Copper, 1/4 hard	9.90	1.90	8.90	276	129	0.20
Titanium, Grade 2	19.80	2.46	4.50	345	127	0.20
Titanium, Grade 4	19.80	2.46	4.50	552	127	0.15

Figure 5.15: Material Selection Table [4]

From Figure 5.15, the material that was selected for the plate cover is the low carbon steel (commercial quality) due to its low cost. The plate cover design does not require any high tensile strain or other attributes because it is placed on the outside of the toaster and merely a cover.

After the material was selected, the gage number should be determined based on Figure 5.16 according to the material thickness. In the plate cover case, the gage that had been chosen was the gage number 13 with 2.29 mm thickness.

Steels		Aluminum alloys	Copper alloys	Titanium alloys
Gage no.	(mm)	(mm)	(mm)	(mm)
28	0.38	0.41	0.13	0.51
26	0.46	0.51	0.28	0.63
24	0.61	0.63	0.41	0.81
22	0.76	0.81	0.56	1.02
20	0.91	1.02	0.69	1.27
19	1.07	1.27	0.81	1.60
18	1.22	1.60	1.09	1.80
16	1.52	1.80	1.24	2.03
14	1.91	2.03	1.37	2.29
13	2.29	2.29	2.06	2.54
12	2.67	2.54	2.18	3.17
11	3.05	3.17	2.74	3.56
10	3.43	4.06	3.17	3.81
8	4.17	4.83	4.75	4.06
6	5.08	5.64	6.35	4.75

Figure 5.16: Gage Number Selection Table [4]

Blanking Cost

Blanking is a cutting up a large sheet of stock into smaller pieces suitable for the next operation in stamping, such as drawing and forming. Before the blanking cost analysis was done, the usable area of the part should be determined first.

Usable are, AU $= 14 \times (13+11+13)$

$= 518\ cm^2$

From the usable area, the cost of individual dies can be determined using the equation below whereas Cds is the die set purchase set and AU is the usable are.

Cds = 120 + 0.36 AU
= RM 306.48

After that, the profile complexity is determined and measured by index Xp as:

Xp = P2 / (LW)

Where

P = perimeter length to be sheared

L, W = length and the width of the smallest rectangle that surrounds the punch

Xp = (62.8)2 / (11 x 14)
= 25.61

From the profile complexity (Xp), the basic manufacturing point (Mpo) can be determined using Figure 5.17. In this case, the Mpo is 32.5. From the plan area (L x W), the correction factor can be determined using Figure 5.18. From figure 4.35, the correction factor is 1.6.

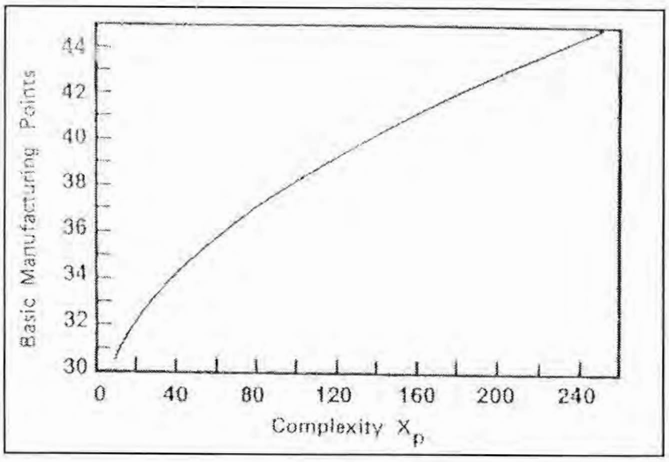


Figure 5.17: The Basic Manufacturing Point Graph [4]

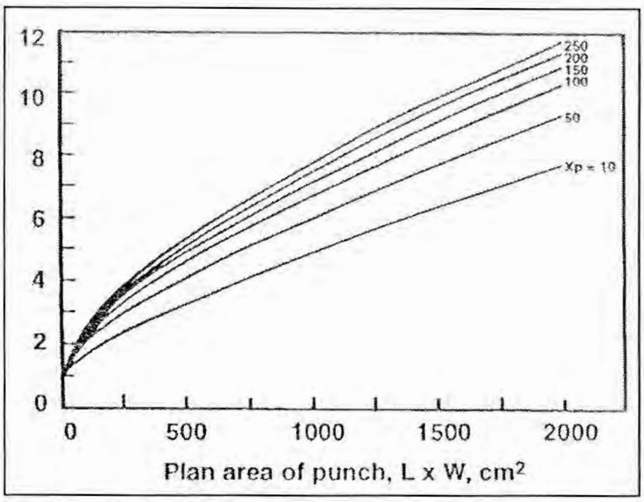


Figure 5.18: The Area Correction Factor Graph [4]

After that, the die plate thickness can be determined using equation:

$h_d \quad = 9 + 2.5 \times \log_e (U/U_{ms})\, Vh^2$

Where:

U = The ultimate tensile stress of sheet metal

U_{ms} = The ultimate tensile stress of annealed mild steel ($262MN/m^2$)

V = The required production volume (10, 000)

h = The sheet metal thickness

h_d $= 9 + 2.5 \times \log_e (330/262)(10000)(2)^2$

$= 63.70$ mm

After the die plate thickness was determine, the thickness factor will then be calculated using equation:

f_d $= 0.5 + 0.02\ h_d$

$= 0.5 + 0.02\ (63.70)$

$= 1.774$

After that, the total die manufacturing point is calculated by using equation:

M_p $= f_d\ f_{iw} M_{po}$

Where:

f_d = Thickness factor

f_{iw} = Plan area correction factor

M_{po} = Basic manufacturing cost

M_p $= 1.774\ (1.6)\ (32.5)$

$= 92.248$

From all the results above, the blanking die cost can finally be calculate by multiplying the total die manufacturing point, M_p with the cost of die making per hour (assume RM 40/hour) and added with the cost of individual dies, C_{ds}.

Blanking die cost = 306.48 + (92.248 x 40)

= RM 3996.40

Piercing Cost

Piercing is the operation of cutting internal features (holes or slot) in stock. Piercing also can be combined with other operations such as lance and form (to make small feature such as tab), pierce and extrude (to make an extruded hole).

In order to determine the piercing cost, there are three main things that need to be identified. These three important things are the base manufacturing score, M_{po}, the manufacturing time, M_{pc} and the manufacturing hours, M_{ps}. Firstly, the base manufacturing score is determined by using the equation:

$M_{po} = 23 + 0.03\ LW$

Where:

L, W = Length and width of the rectangle surrounding the parts.

$M_{po} = 23 + 0.03\ (11 \times 14)$

$= 27.62$ hours

After that the manufacturing time is determine using the equation:

$M_{pc} = 8 + 0.6\ P_p + 3\ N_p$

Where:

P_p = Total perimeter of all punches

N_p = Number of punches

$M_{pc} = 8 + 0.6\ (62.8) + 3\ (2)$

$= 51.68$ hours

After that the manufacturing hours is determine by using the equation:

$M_{ps} = K\,N_p + 0.4\,N_d$

Where:

K = 2 for round holes and 3.5 for square and rectangular

N_p = Number of punches

N_d = Number of different punch shape and size

$M_{pc} = 3.5\,(2) + 0.4\,(1)$

$= 7.4$ hours

After that, the piercing die cost is determined by adding up all the manufacturing score, hours and time and multiply with the die cost per hour and plus with the cost of the individual dies.

Piercing die cost = 306.48 + (27.62+51.68+7.4) x 40

= RM 3774.48

Bending Cost

Bending process is similar to forming. Complex parts such as U-sections, channel sections of different profiles can be produced by doing multiple bends. There is no change in thickness during the bending process. Good dimensional repeatability as well as close tolerances is possible with this process.

Before the bending cost is determine, there are two main things that need to be determine that are the base manufacturing score and the additional point for bend length and multiple bend.

Firstly the base manufacturing cost is determined by using equation:

$M_{po} = [18 + 0.023\ LW\}\ x\ [0.9 + 0.02\ D]$

Where:

L, W = Length and width of rectangle which surrounds the part

D = Final depth of the bent part

$M_{po} = [18 + 0.023\ (37)\ (14)]\ x\ [0.9 + 0.02\ (13)]$

$= 34.7002$

After that the additional point for bend length and multiple bend is calculated by using equation:

$M_{pn} = 0.68\ L_b + 5.8\ N_b$

Where:

L_b = Total length of bend lines

N_b = Number of different bends to be formed in the die

$M_{pn} = 0.68\ (14) + 5.8\ (1)$

$= 15.32$

After these two values were determined, the bending die cost can now be calculated by adding the base manufacturing score and additional point for bend length and multiple bend and multiply them with labor cost per hour and added with the cost of the individual dies.

Bending die cost = 306.48 + (34.7002 + 15.32) x 40

= RM 2307.29

Progressive Die Cost

After all of the cost for blanking, piercing and bending were determined, the progressive die cost now can be calculated. The progressive die cost is the sum of all the blanking, piercing and bending and multiply with two.

$C_{pd} \quad = 2\ C_{id}$

Where:

C_{pd} = Cost of single progressive die

C_{id} = Cost of individual dies for blanking; cut-off or part-off; piercing and forming operations for the same part

$C_{pd} \quad = 2\ (3996.40 + 3774.48 + 2307.229)$

$= \text{RM } 20156.34$

Press Selection

After all the cost had been determined, it is the time for choosing the most suitable press machine for the part. In order to identify the press machine, the required press force for the part must be calculated using the equation:

$F \quad = 0.5\ U\ h\ l_s$

Where:

U = The ultimate tensile stress of sheet metal

h = Gage thickness

l_s = Length to be sheared

F $= 0.5 \times 330 \times 10^{3} \times 628 \times 10^{-3} \times 2.29 \times 10^{-3}$

$= 237.2898$ kN

From the required press force for the part that is 237.2898 kN, it is shown that the most suitable press machine for the part is the machine with 500kn press force. Figure 5.19 was used in choosing the suitable press machine for the part.

Bed size					
Width (cm)	Depth (cm)	Press force (kN)	Operating cost (S/hr)	Maximum press stroke (cm)	Strokes (per min)
50	30	200	55	15	100
80	50	500	76	25	90
150	85	1750	105	36	35
180	120	3000	120	40	30
210	140	4500	130	46	15

Figure 5.19: Press Machine Selection Table [4]

Cycle Time

Finally, the cycle time of the press working is calculated by applying equation:

t $= 3.8 + 0.11\ (L+W)$

t $= 3.8 + 0.11\ (11+14)$

$= 6.55$ seconds

5.3 SUMMARY

From this chapter, it has been determined that by applying DFM, the manufacturing cost can be reduced because the DFM analysis will make us consider all of the available processes and materials for the analyzed part in order to get the best and most economic result.

During the DFM analysis, many factors will affect the cost of manufacturing the product such as tooling, raw materials, time for each process, the geometry complexity and the machine type. All this factors will be considered thoroughly in DFM in order to minimize the cost and waste during the manufacturing process.

CHAPTER 6

CONCLUSION

6.0 INTRODUCTION

In this chapter, the comparison between Lucas Hull DFMA and Boothroyd Dewhurst DFMA will be discussed. The comparison is made not to prove which DFMA methodology is better than the other but it is more on determining which DFMA methodology is suitable for which process. The recommendation should also be include in this chapter.

6.1 COMPARISON BETWEEN LUCAS DFMA AND BOOTHROYD-DEWHURST DFMA METHODOLOGY

From the result of the analysis done on both original and new design of the bread toaster, it is has been discovered that there are differentiation between the Lucas and Boothroyd DFMA result. Although the main purpose of DFMA is to aim at the same goal, to improve the design for the ease of assembly and manufacturing, the principles for both method is not the same.Lucas DFMA focused mostly on the assembly sequence flowchart (ASF) meanwhile Boothroyd DFMA focused on the assembly time.

In Lucas DFMA, the flow of the assembly process is visualized into an array of assembly sequence flowchart. The process flow is represented by symbols in the ASF. Each symbol is then analyzed depending on the process that occur such as work-holding process, insertion process, secondary operation and many more. In determining the design efficiency, Lucas DFMA depends entirely on the total number of essential parts and the total number of parts.

In Boothroyd DFMA, the main factor in determining the design efficiency is the time. By applying Boothroyd DFMA, the user will be capable to make estimation on the handling and insertion time. Insertion analysis in Boothroyd DFMA is almost the same as assembly process in Lucas Hull but it is not visualized in ASF. The handling and insertion analysis in Boothroyd DFMA focused more on the estimated time and the estimate assembly cost can be determined from the assembly time. This feature is not available in Lucas DFMA where it only focused on reducing the part count.

The DFM analysis for Lucas Hull in the TeamSet Software focused mostly on the materials, processes, waste, tolerance, geometry complexity and surface. In the software, the manufacturing detail analysis such as injection molding and sheet metal analysis is not included. But in the Boothroyd Dewhurst DFMA, such details are also evaluated in order to choose the most suitable machine and tools for the process.

Generally, Lucas Hull DFMA methodology was widely applied in the locomotive area where big and complicated parts are designed. Meanwhile, Boothroyd Dewhurst DFMA methodology is usually applied on product which the total part count is below than 2000.

Table 6.1: The Comparison Between Lucas DFMA and Boothroyd DFMA

Criteria	**Lucas-Hull DFMA**	**Boothroyd-Dewhurst DFMA**
Focused Area	Focused on assembly sequence flowchart	Focused on assembly time
Target	Reduce part count	Reduce assembly time and part count
Application Area	Product that have more than 2000 parts	Product that have less than 2000 parts
DFM Analysis	Only on processes and materials	Very detail including the tooling and machine types

6.2 CONCLUSION

As the conclusion of this project, it has been proved that DFMA methodology can improve the design of a product for the ease of assembly and manufacture. There are many types of DFMA methodologies available in the whole world that aims for the same target, to reduce the part count to make the assembly and manufacturing process easier and faster. Each DFMA methodology has its own strength and weakness, depends on the application area where some DFMA method is perfectly suitable when applied to the complex parts and some others in other different condition.

The main target of DFMA is to reduce the part count because by reducing the part count comes a lot of benefit such as making the assembly and manufacturing process cheaper, easier, faster and make the product more reliable.

6.3 RECOMMENDATION

From this project, I would like to give some suggestion as to improve the project. The suggestions are:

1) DFMA software should be used in doing the Boothroyd Dewhurst DFMA methodology because the analysis will become much easier and accurate when using the software.
2) The standard price for all of the materials and processes that is available should be easier to find because the price keep changing from time to time and hardto find the reliable source for the prices.

6.4 SUMMARY

As the summary of this chapter, it is proved that DFMA methodologies are very important in order to ensure the design to more reliable because all aspect in manufacturing and assembly is considered during the analysis.

REFERENCES

[1] Xiao, F. X. "Design for Manufacture and Assembly." Dept. of Mechanical Engineering, University of Utah.

[2] Redford, A. and Chai, I. (1994). "Design for Assembly-Principles and Practice." England: McGraw Hill Inc.

[3] Stone, R. B., McAdams, D. A. and Kayyalethekkel V. J. (2004). "A Product Architecture-Based Conceptual DFA Technique." Design Studies. 25. pp 301-325

[4] Boothroyd, G., Dewhurst, P. and Knight, W. (1994). "Product Design for Manufacture and Assembly." Madison Avenue, New York: Marcel Dekker Inc.

[5] Whitney, D. E. (2004). "Mechanical Assembly." New York: Oxford University Press.

[6] Greer, J. L., Wood, K. L. and Jensen, D. D. (2004). "Effort Flow Analysis: A Methodology for Directed Product Evolution." Design Studies. 25. pp 193-214

[7] Gauthier, B., Dewhurst, P. and Japikse, D. (2000). "Application of Design for Manufacture and Assembly Methodologies to Complex Aerospace Products." American Institute of Aeronautics and Astronautics.

MANUAL INSERTION – ESTIMATED TIMES (seconds)

Key:

PART ADDED but NOT SECURED

PART SECURED IMMEDIATELY

SEPARATE OPERATION

			after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
			easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
			no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	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

			no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion: plastic bending or torsion			plastic deformation immediately after insertion: rivetting or similar operation			screw tightening immediately after insertion (6)	
			easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	not easy to align or position during assembly: no resistance to insertion	not easy to align or position during assembly: resistance to insertion (5)	easy to align and position during assembly (4)	not easy to align or position during assembly: no resistance to insertion	not easy to align or position during assembly: resistance to insertion (5)	easy to align and position with no torsional resistance (4)	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

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	additional material required: soldering processes	additional material required: weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	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	3.5	7	8	12	12	9	12

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
		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
		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 required for LARGE SIZE

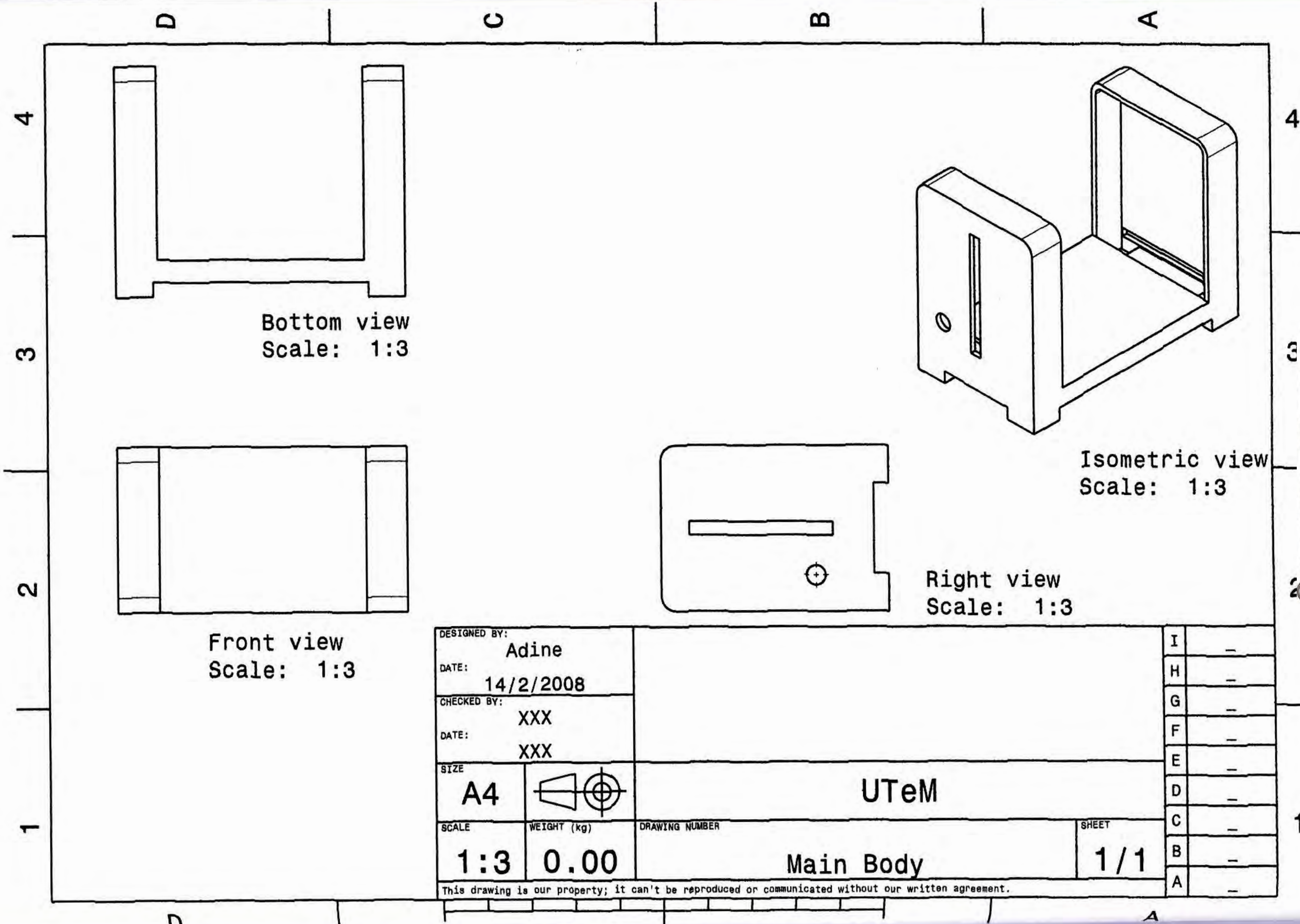
		parts can be handled by one person without mechanical assistance								parts severely nest or tangle or are flexible (2)	two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible									
		part weight < 10 lb				parts are heavy (> 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

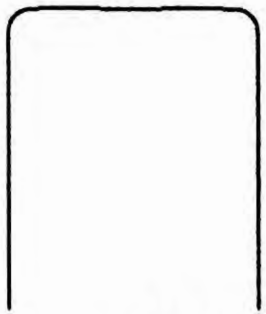
	Depress		UniWall	UniSect	AxisRot	RegXSec	CaptCav	Enclosed	NoDraft	PConsol	Alignmt	IntFast	
Sand casting	Y	Y	Y	Y	Y	Y	Y	N	N	4	3	1	Solidification processes
Investment casting	Y	Y	Y	Y	Y	Y	Y	N	N	5	5	2	
Die casting	Y	Y^{a}	Y	Y	Y	Y	N	N	N	4	5	3	
Injection molding	Y	Y^{a}	Y	Y	Y	Y	N^{b}	N	N	5	5	5	
Structural foam	Y	Y^{a}	Y	Y	Y	Y	N	N	N	4	4	3	
Blow molding (extr)	Y	Y^{a}	M	N	Y	Y	M	Y	N	3	4	3	
Blow molding (inj)	Y	Y^{a}	M	N	Y	Y	M	N	N	3	4	3	
Rotational molding	Y	Y^{a}	M	N	Y	Y	N	M	N	2	2	1	
Impact extrusion	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	Bulk deformation processes
Cold heading	Y	N	Y	N	Y	Y	N	N	Y	3	3	1	
Closed die forging	Y	Y^{a}	Y	Y	Y	Y	N	N	N	3	2	1	
Power metal parts	Y	N	Y	Y	Y	Y	N	N	Y	3	3	1	
Hot extrusion	Y^{d}	N	Y	M	Y	Y	N	N	Y	2	2	3	
Rotary swaging	N^{c}	N	N	N	M	N^{c}	N	N	N	1	1	1	
Machining (from stock)	Y	Y	Y	Y	Y	Y	Y	N	Y	2	3	2	Material removal processes
ECM	Y	Y^{c}	Y	Y	Y	Y	N	N	N	3	4	1	
EDM	Y	Y^{c}	Y	Y	Y	Y	N	N	N	3	4	1	
Wire-EDM	Y^{d}	N	Y	Y	Y	Y^{d}	N	N	Y	2	2	3	Profile generating processes
Sheetmetal stamp/bend	Y	Y	M	Y	Y	Y	N	N	N	4	3	4	Sheet forming processes
Thermoforming	Y	Y^{a}	M	N	Y	Y	N	N	N	3	3	3	
Metal spinning	N	N	M	N	M	N	Y	N	N	1	1	1	

[a] Possible at higher cost.
[b] Shallow undercuts are possible without significant cost penalty.
[c] Possible with more specialized machine and tooling.
[d] Only continuous, open-ended possible.

Y, Process is capable of producing parts with this characteristic, N, Process is not capable of producing parts with this characteristic, M, Parts produced with this process must have this characteristic. An underlined entry indicates that parts using this process are easier to form with this characteristic.

The last three columns refer to DFA guidelines and are rates on a scale of 1 to 5, with 5 assigned to processes most capable of incorporating the respective guideline.


Bottom view
Scale: 1:3
Front view
Scale: 1:3
Right view
Scale: 1:3
Isometric view
Scale: 1:3
DESIGNED BY: Adine
DATE: 14/2/2008
CHECKED BY: XXX
DATE: XXX
SIZE A4
UTeM
SCALE 1:3
WEIGHT (kg) 0.00
DRAWING NUMBER Main Body
SHEET 1/1
This drawing is our property; it can't be reproduced or communicated without our written agreement.



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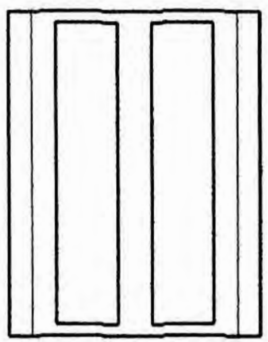

Front view
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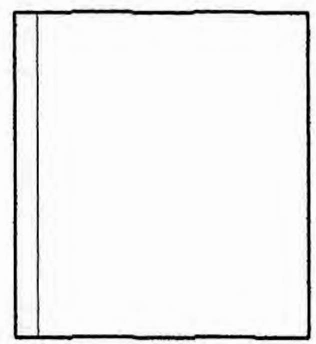
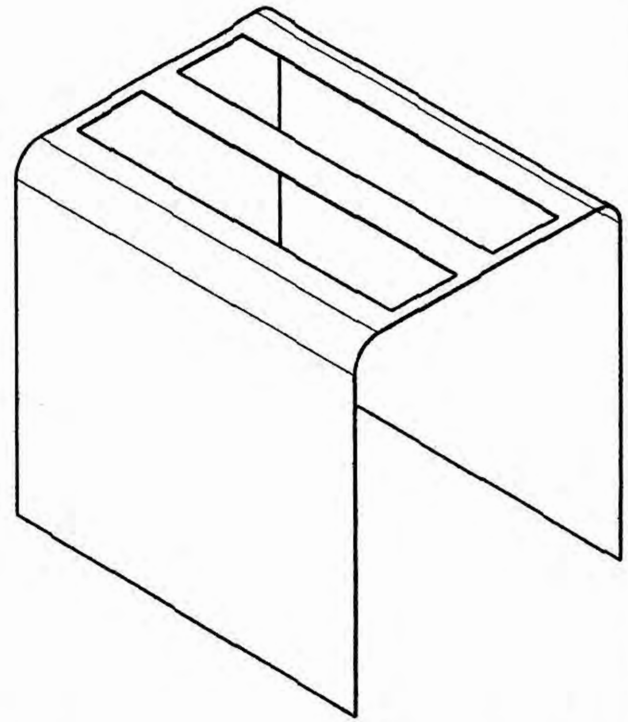


Right view
Scale: 1:3



Isometric view
Scale: 1:3

DESIGNED BY: Adine DATE: 14/2/2008			
CHECKED BY: XXX DATE: XXX			
SIZE A4		UTeM	
SCALE 1:3	WEIGHT (kg) 0.00	DRAWING NUMBER Plate Cover	SHEET 1/1

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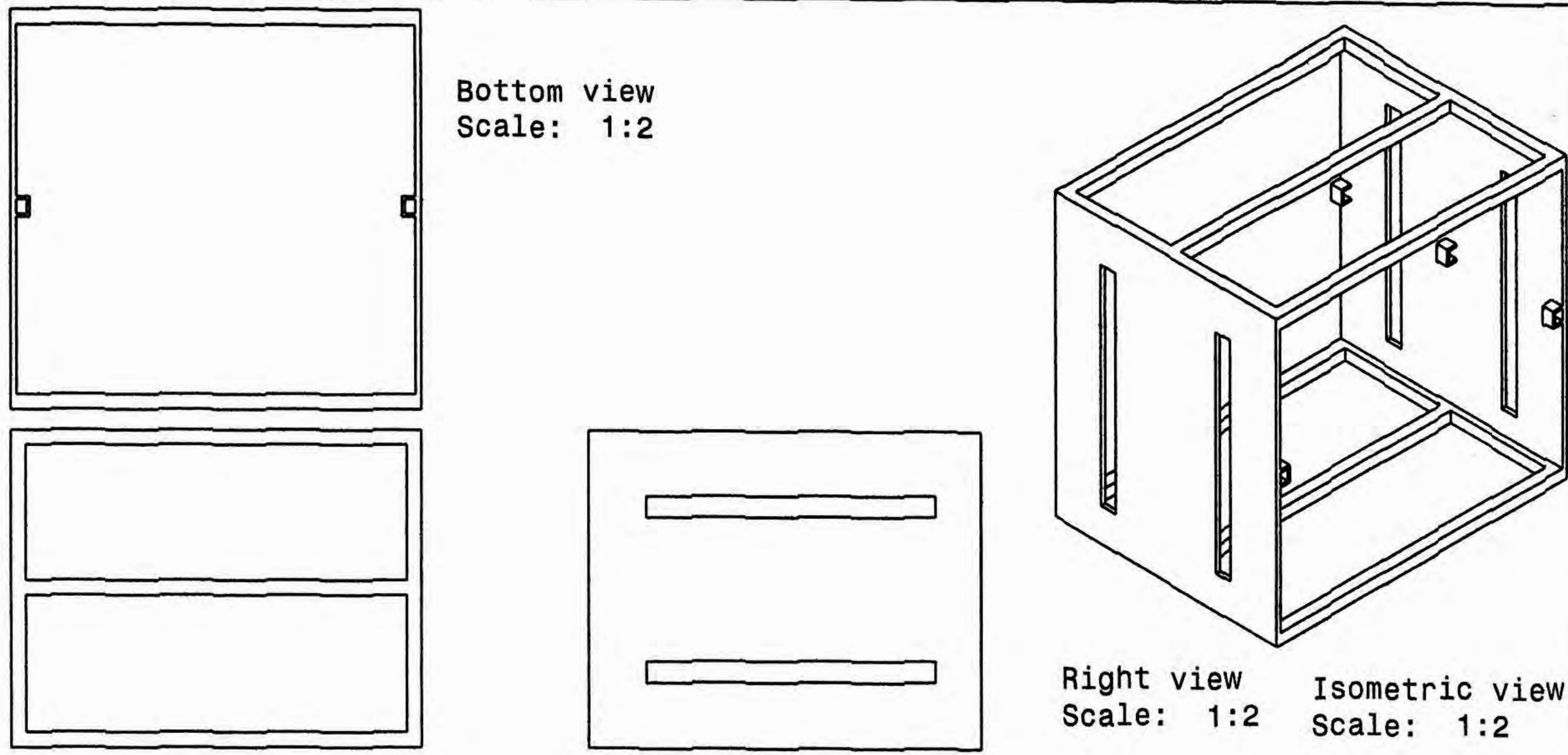

Bottom view
Scale: 1:2

Front view
Scale: 1:2

Right view
Scale: 1:2

Isometric view
Scale: 1:2

DESIGNED BY: Adine				I	_
DATE: 14/2/2008				H	_
CHECKED BY: XXX				G	_
DATE: XXX				F	_
SIZE A4		UTeM		E	_
				D	_
SCALE 1:2	WEIGHT (kg) 0.00	DRAWING NUMBER Core	SHEET 1/1	C	_
				B	_
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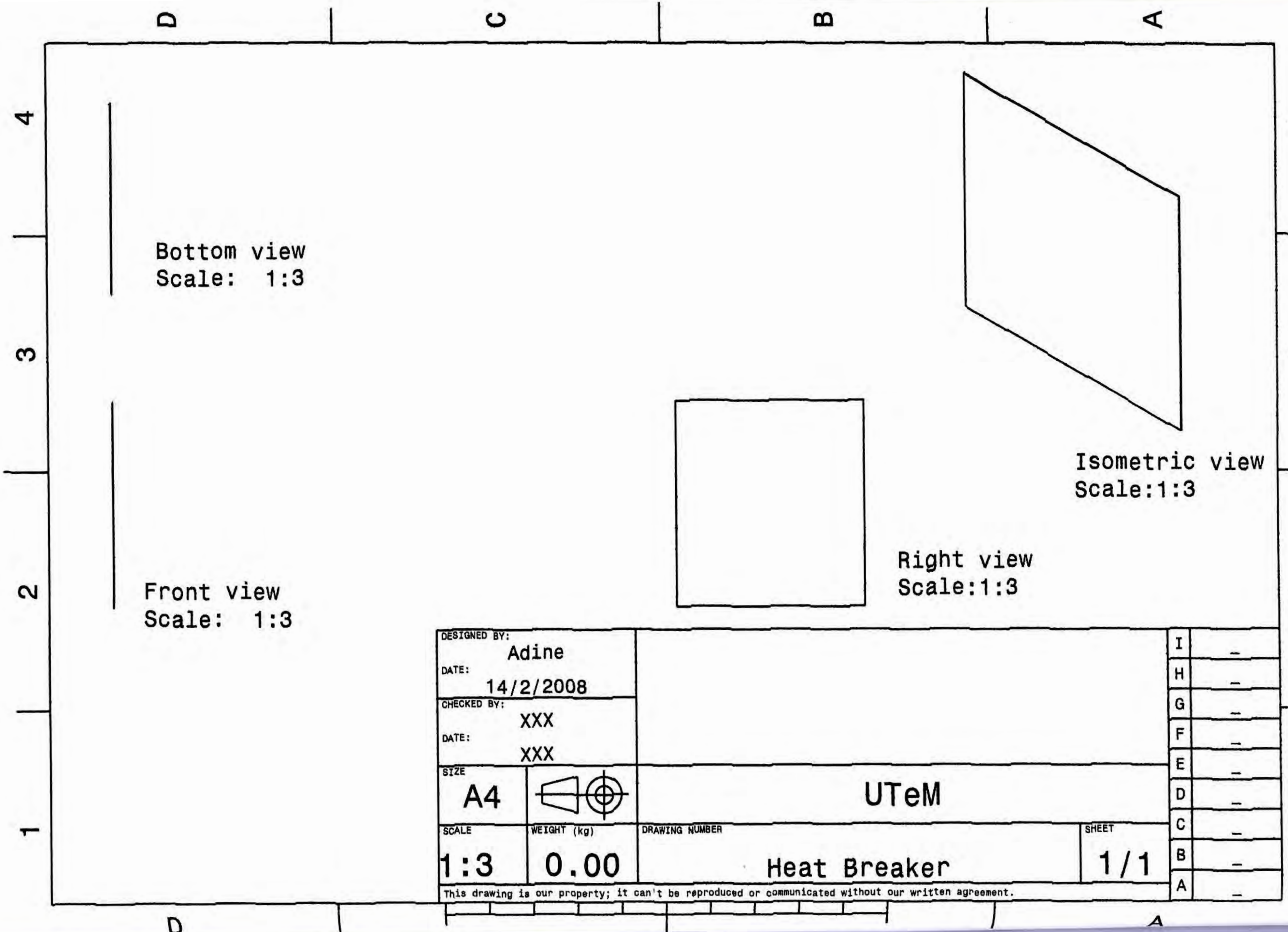

Bottom view
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Front view
Scale: 1:3
Right view
Scale:1:3
Isometric view
Scale:1:3
DESIGNED BY:
Adine
DATE:
14/2/2008
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
UTeM
SCALE
1:3
WEIGHT (kg)
0.00
DRAWING NUMBER
Heat Breaker
SHEET
1/1
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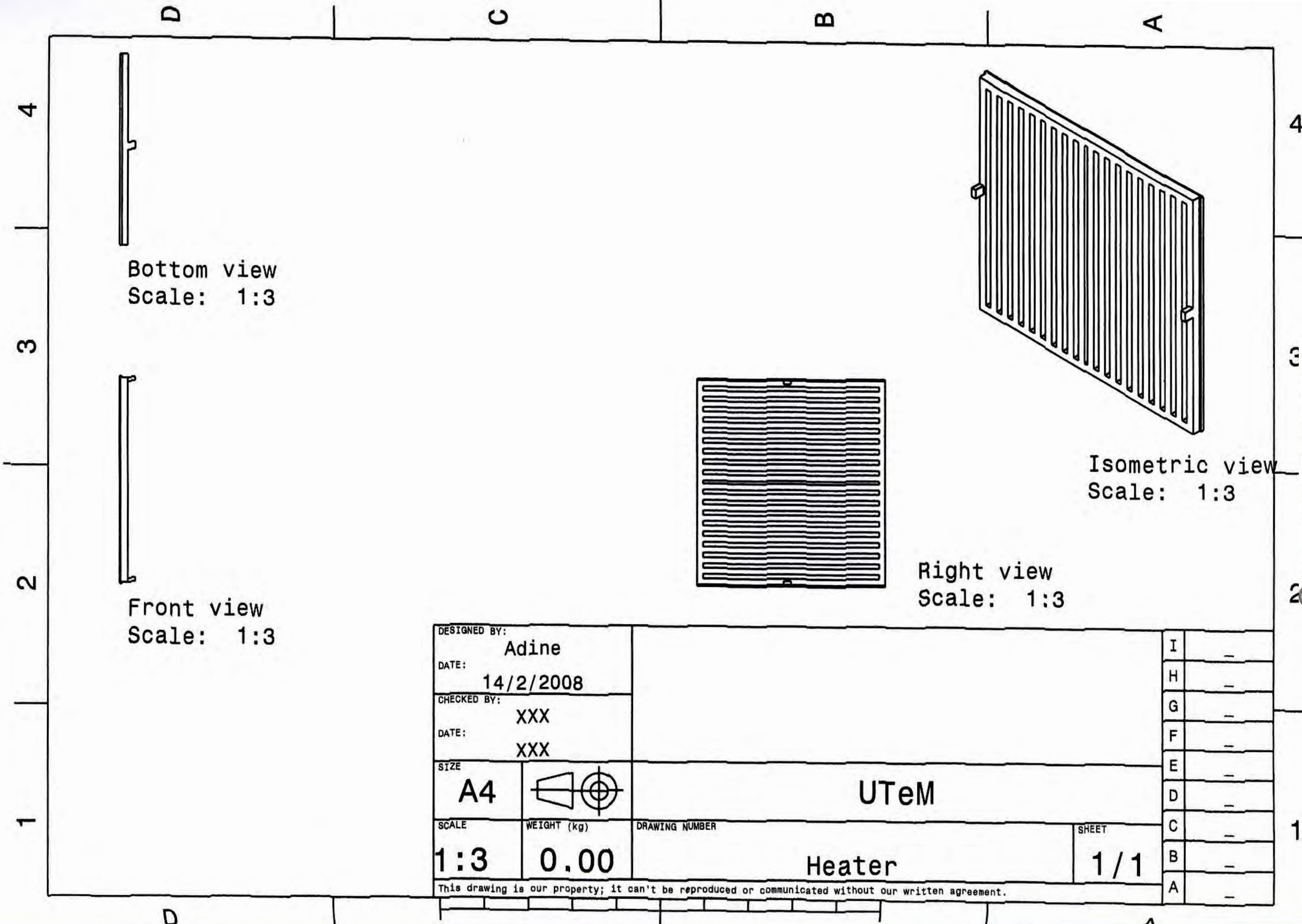
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Front view
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Right view
Scale: 1:3
Isometric view
Scale: 1:3
DESIGNED BY:
Adine
DATE:
14/2/2008
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
UTeM
SCALE
1:3
WEIGHT (kg)
0.00
DRAWING NUMBER
Heater
SHEET
1/1
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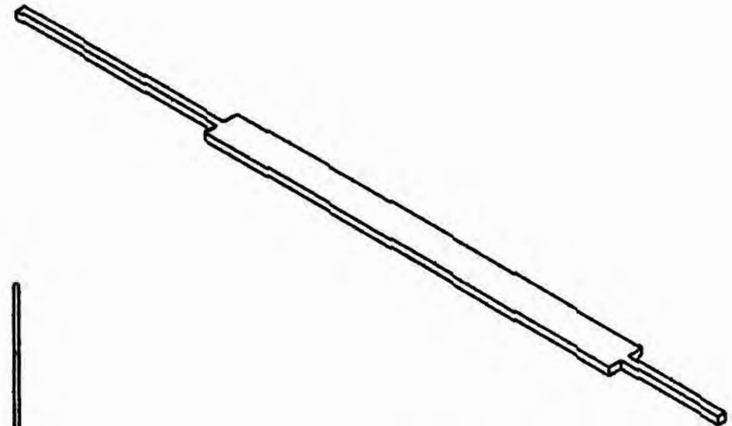
Bottom view
Scale: 1:1

Front view
Scale: 1:2

Right view
Scale: 1:2



Isometric view
Scale: 1:1

DESIGNED BY: Adine DATE: 14/2/2008			
CHECKED BY: XXX DATE: XXX			
SIZE A4		UTeM	
SCALE 1:1	WEIGHT (kg) 0.00	DRAWING NUMBER Lift Bar	SHEET 1/1

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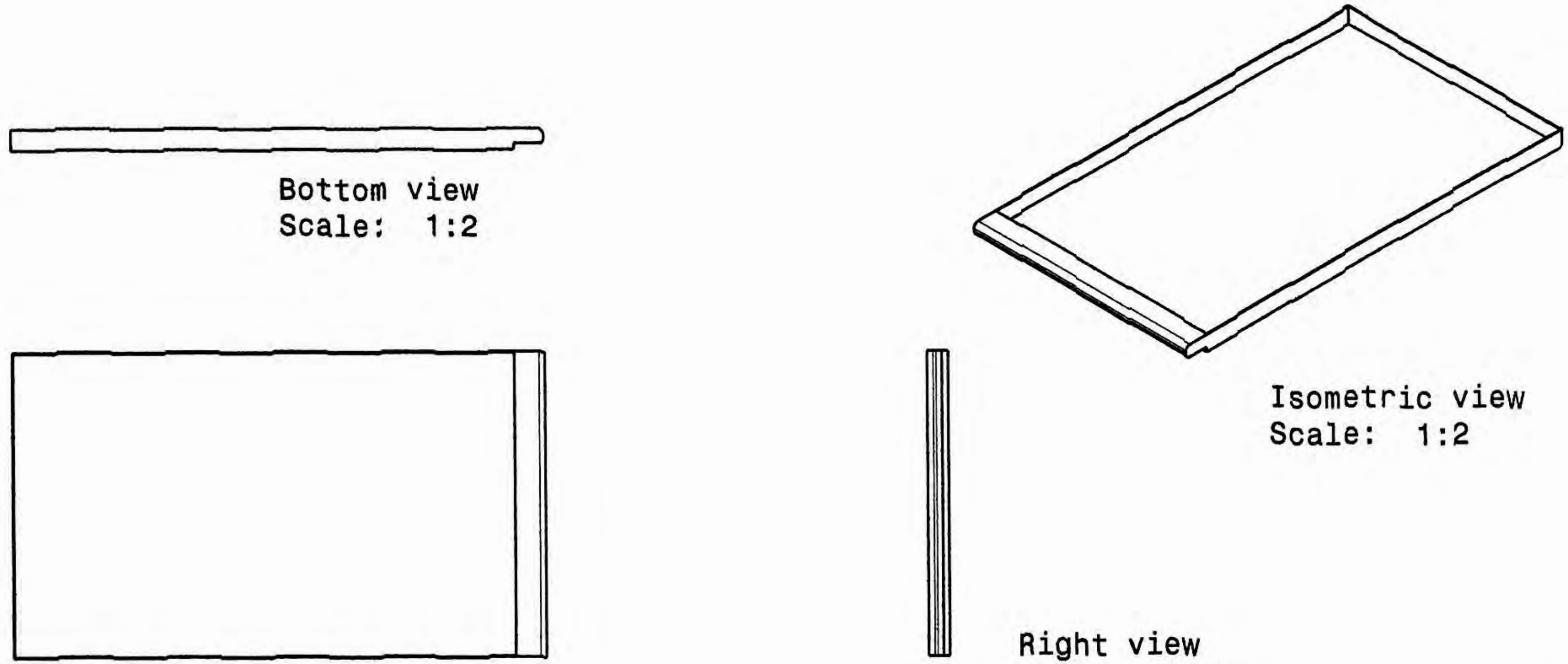

DESIGNED BY: Adine DATE: 14/2/2008 CHECKED BY: XXX DATE: XXX			
SIZE A4		UTeM	
SCALE 1:2	WEIGHT (kg) 0.00	DRAWING NUMBER Ash Tray	SHEET 1/1

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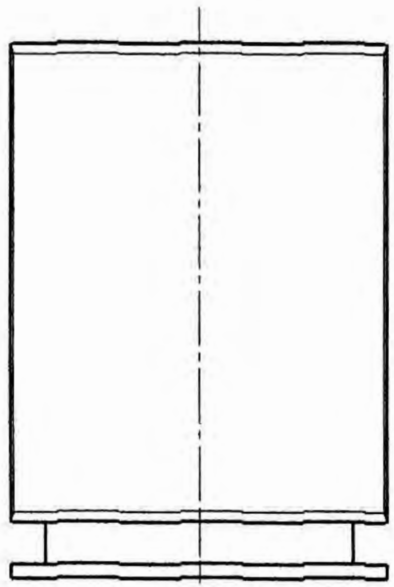
Bottom view
Scale: 1:2



Front view
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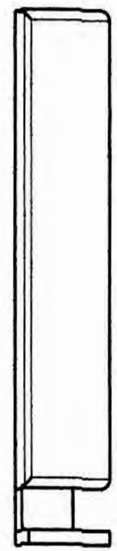

Left view
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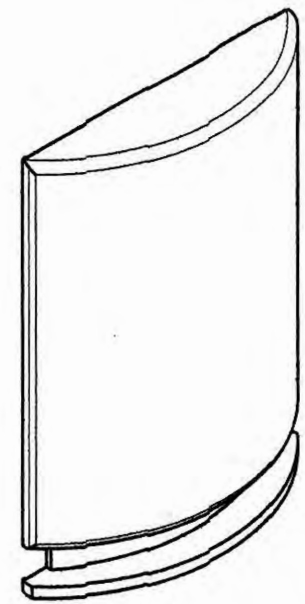

Isometric view
Scale: 1:2

DESIGNED BY: Adine DATE: 4/2/2008			I	_
CHECKED BY: XXX DATE: XXX			H	_
SIZE A4		UTeM	G	_
SCALE 1:2	WEIGHT (kg) 0.00	DRAWING NUMBER Plastic Cover	F	_
		SHEET 1/1	E	_
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			A	_

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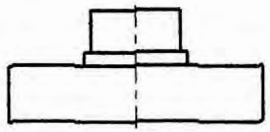

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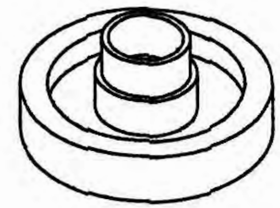

Isometric view
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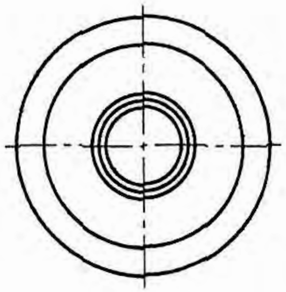
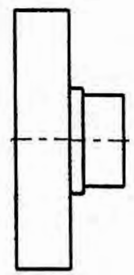


Front view
Scale: 1:1



Left view
Scale: 1:1

DESIGNED BY: Adine DATE: 4/2/2008				I	_
CHECKED BY: XXX DATE: XXX				H	_
SIZE A4		UTeM		G	_
SCALE 1:1	WEIGHT (kg) 0.00	DRAWING NUMBER Indicator	SHEET 1/1	F	_
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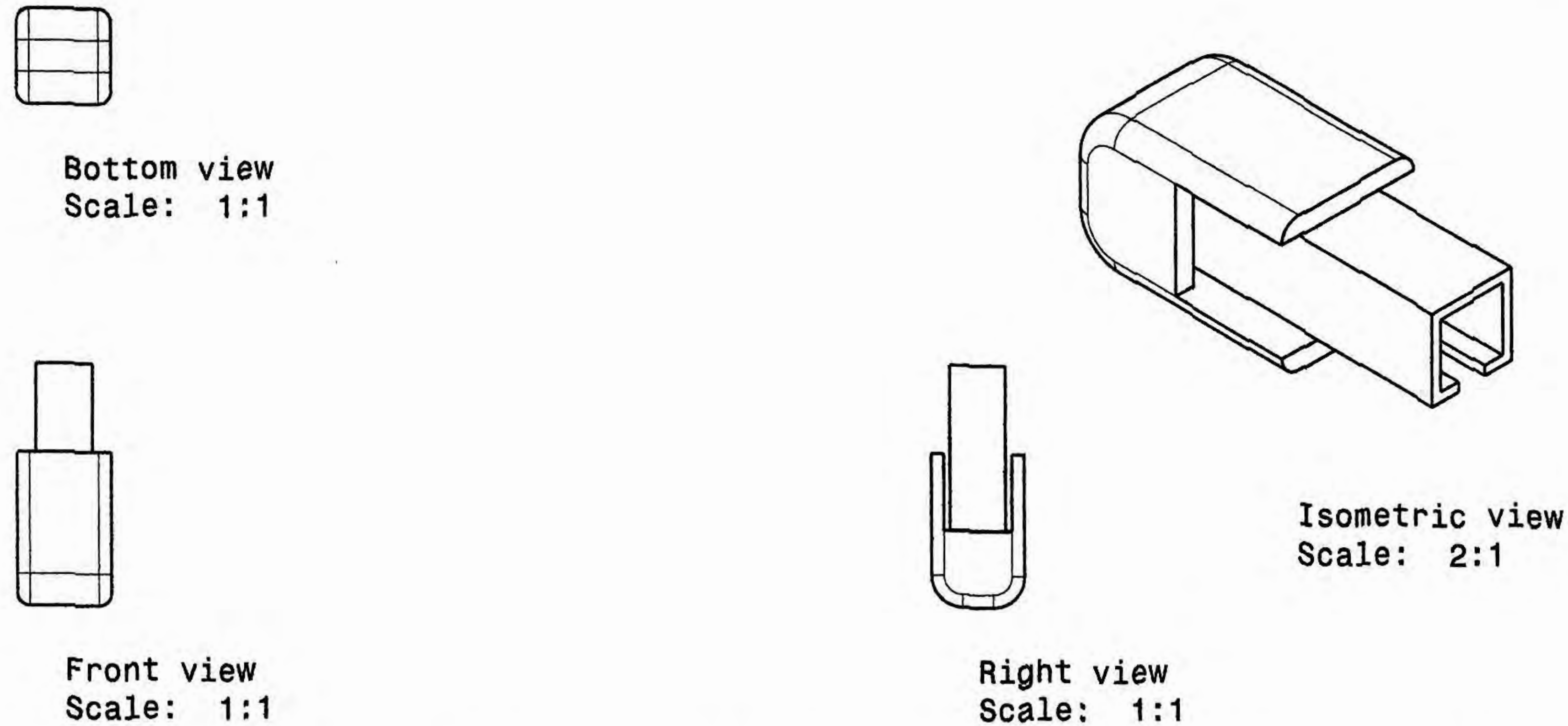
				A	_



DESIGNED BY: Adine			
DATE: 4/2/2008			
CHECKED BY: XXX			
DATE: XXX			
SIZE A4		UTeM	
SCALE 1:1	WEIGHT (kg) 0.00	DRAWING NUMBER Lift Handle	SHEET 1/1

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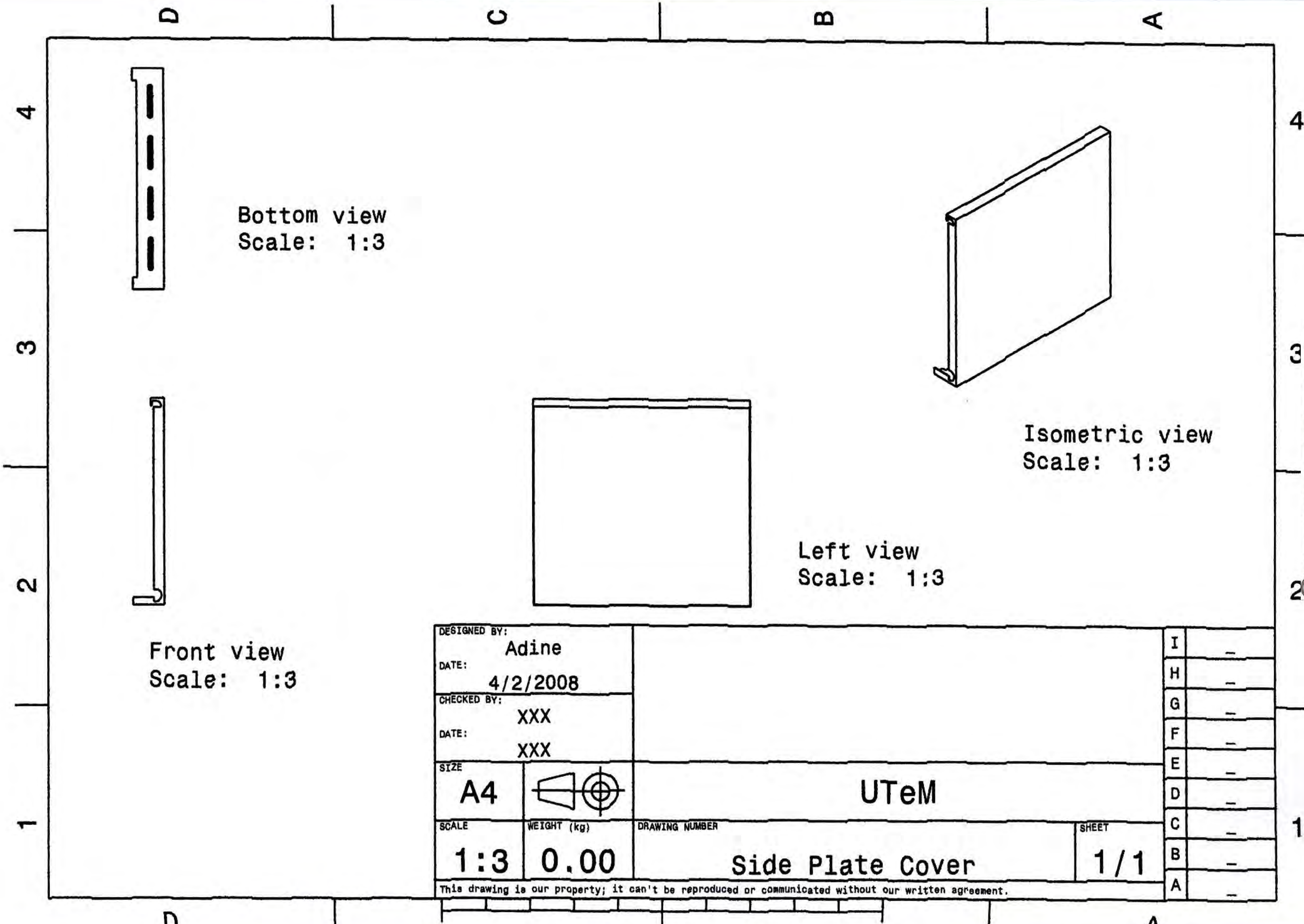

D
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Bottom view
Scale: 1:3
Front view
Scale: 1:3
Left view
Scale: 1:3
Isometric view
Scale: 1:3
DESIGNED BY:
Adine
DATE:
4/2/2008
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
UTeM
SCALE
1:3
WEIGHT (kg)
0.00
DRAWING NUMBER
Side Plate Cover
SHEET
1/1
I
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E
D
C
B
A
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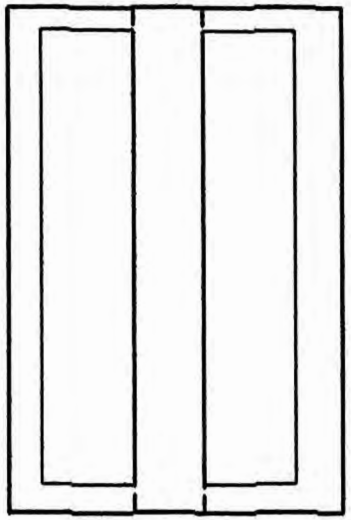

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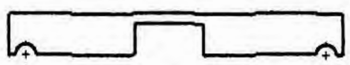

Front view
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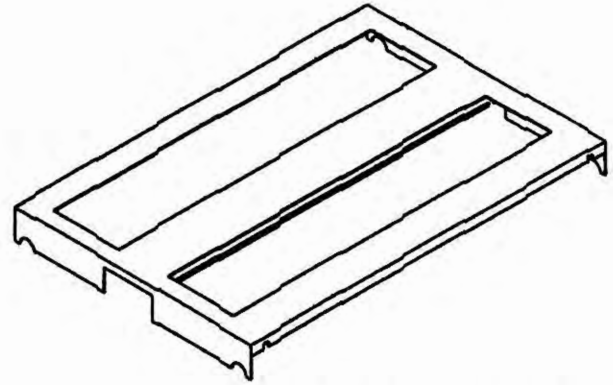

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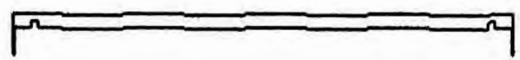

Left view
Scale: 1:2

DESIGNED BY: Adine DATE: 4/2/2008			
CHECKED BY: XXX DATE: XXX			
SIZE A4		UTeM	
SCALE 1:2	WEIGHT (kg) 0.00	DRAWING NUMBER Top Plate Cover	SHEET 1/1

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I	_
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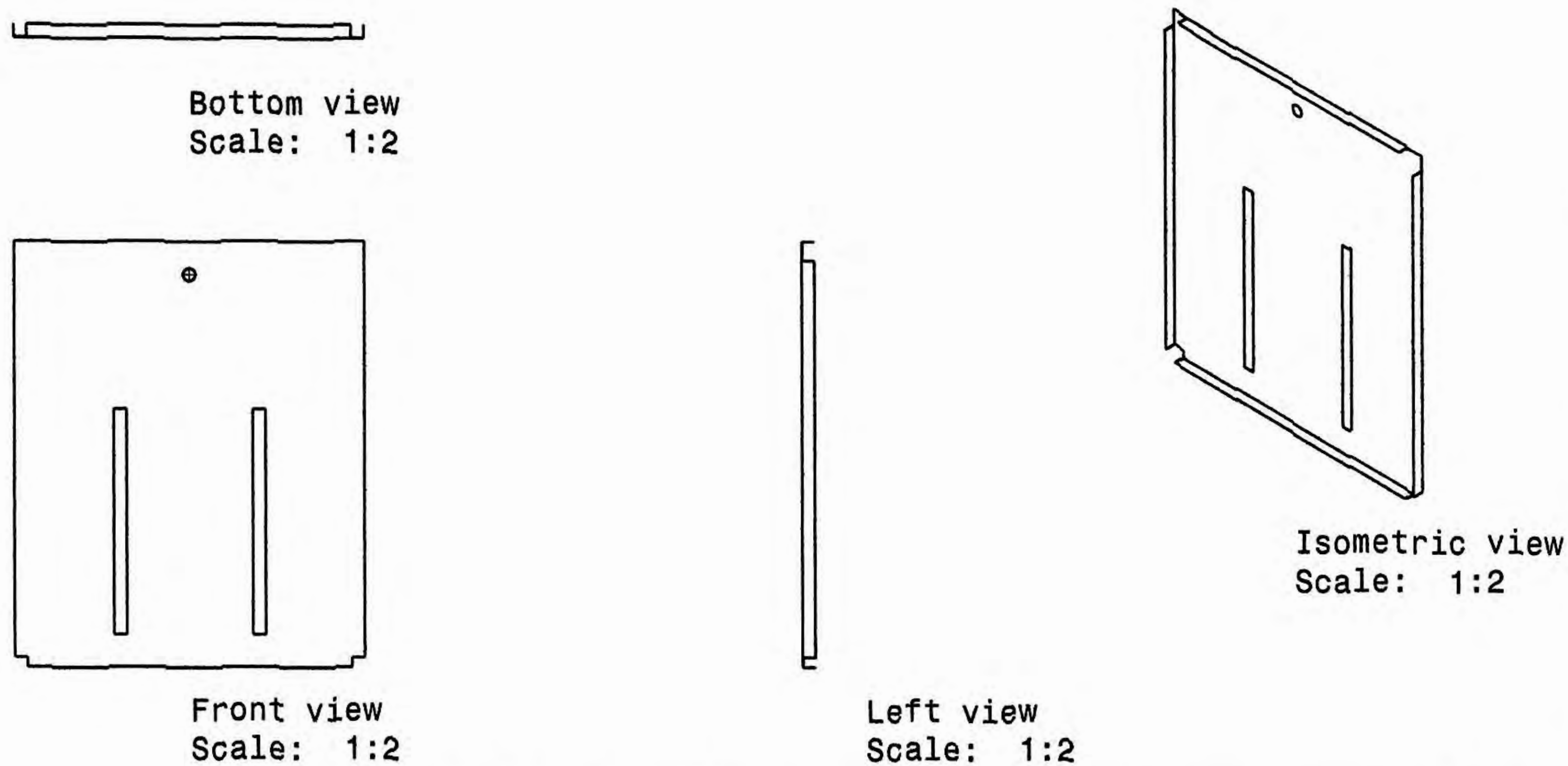

DESIGNED BY: Adine			
DATE: 4/2/2008			
CHECKED BY: XXX			
DATE: XXX			
SIZE A4		UTeM	
SCALE 1:2	WEIGHT (kg) 0.00	DRAWING NUMBER Plate Core	SHEET 1/1

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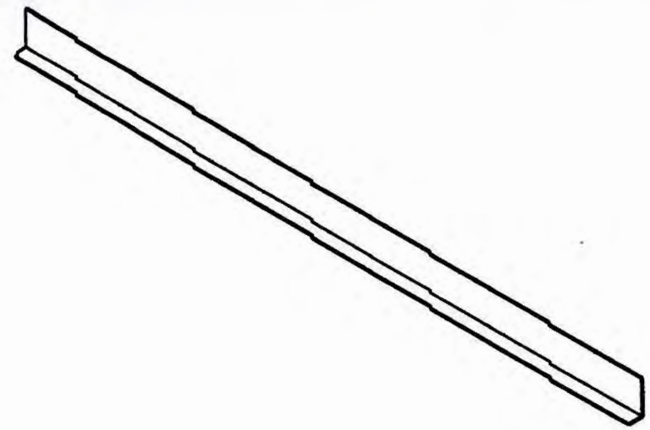
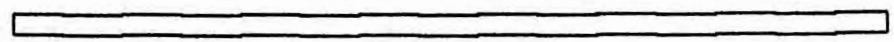
Bottom view
Scale:1:1



Isometric view
Scale: 1:1

Front view
Scale: 1:1



Left view
Scale: 1:1

DESIGNED BY: Adine DATE: 4/2/2008				I	–
				H	–
CHECKED BY: XXX DATE: XXX				G	–
				F	–
SIZE A4		UTeM		E	–
				D	–
SCALE 1:1	WEIGHT (kg)	DRAWING NUMBER Main Frame	SHEET 1/1	C	–
				B	–
				A	–

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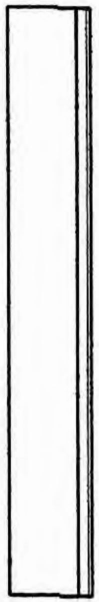

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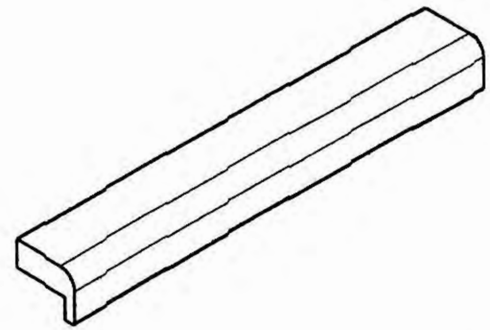

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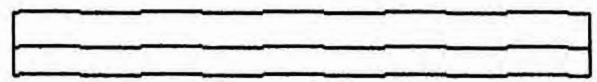
Front view
Scale: 1:1



Left view
Scale: 1:1

DESIGNED BY: Adine DATE: 4/2/2008				
CHECKED BY: XXX DATE: XXX				
SIZE A4		UTeM		
SCALE 1:1	WEIGHT (kg) 0.00	DRAWING NUMBER Handle	SHEET 1/1	

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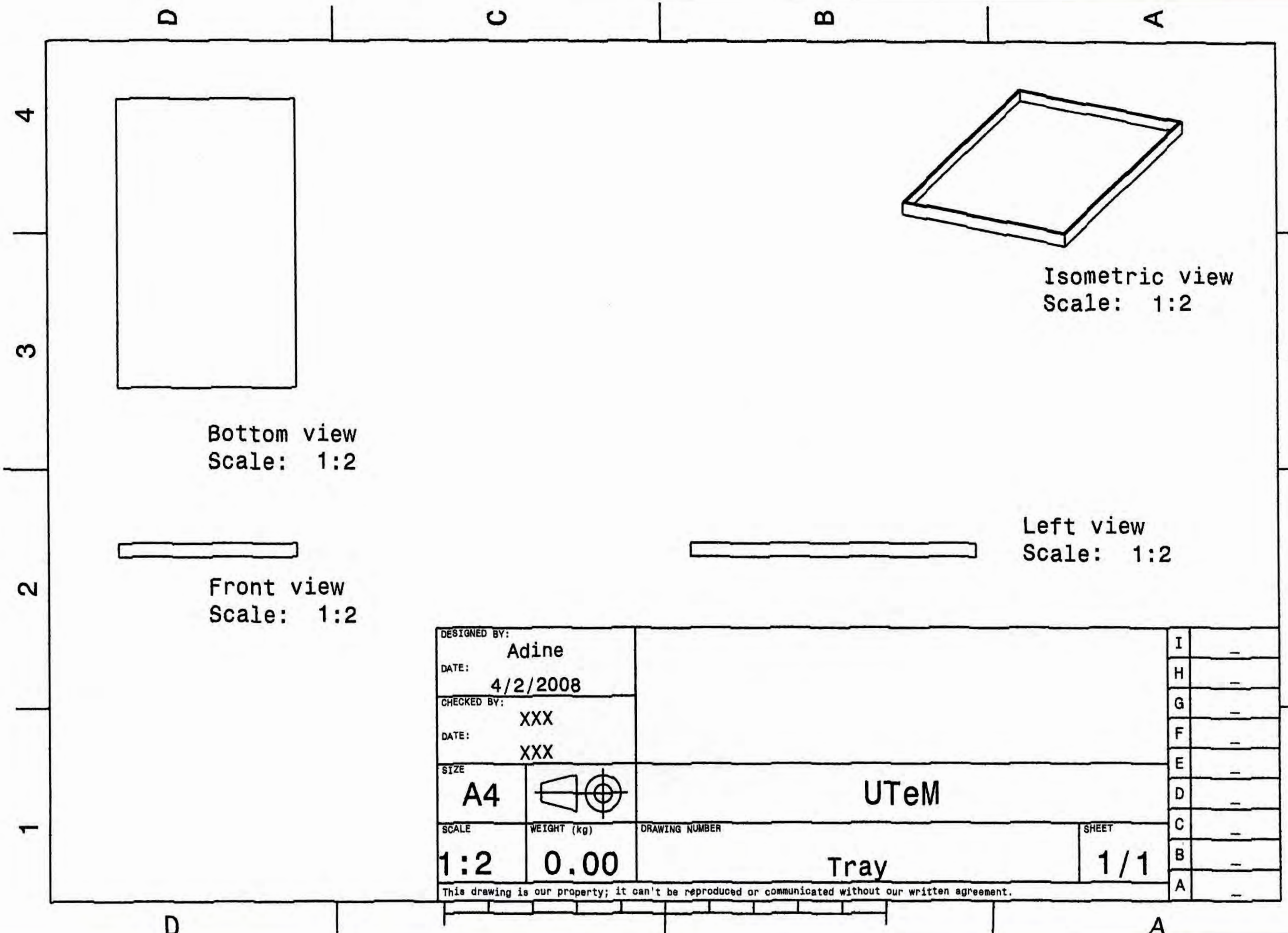
Isometric view
Scale: 1:2
Bottom view
Scale: 1:2
Left view
Scale: 1:2
Front view
Scale: 1:2
DESIGNED BY:
Adine
DATE:
4/2/2008
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
UTeM
SCALE
1:2
WEIGHT (kg)
0.00
DRAWING NUMBER
Tray
SHEET
1/1
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'art 1: Core

epress – No

niWall – Yes

niSect – No

xisRot – No

egXSec - No

aptCav - No

nclosed - No

oDraft - No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
nvestment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
3low Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
₹otational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
'owder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■		■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

☐ Normal   ■ Not Applicable

'art 2: Heater

epress	– No
niWall	– Yes
niSect	– No
xisRot	– No
egXSec	- No
aptCav	- No
nclosed	- No
oDraft	- No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■		■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

☐ Normal ■ Not Applicable

Part 3: Heat Breaker

Depress – No
UniWall – Yes
UniSect – No
AxisRot – No
RegXSec - No
CaptCav - No
Enclosed - No
NoDraft - No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■		■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■	■	■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

□ Normal ■ Not Applicable

art 4: Lift Bar

epress – No
niWall – No
niSect – Yes
xisRot – No
egXSec - No
aptCav - No
nclosed - No
oDraft - No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■		■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

□ Normal ■ Not Applicable

'art 5: Ash Tray

epress	– Yes
niWall	– Yes
niSect	– No
xisRot	– No
egXSec	- No
aptCav	- No
nclosed	- No
oDraft	- No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■		■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■	■	■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

□ Normal ■ Not Applicable

'art 6: Lift Handle

epress – Yes

niWall – Yes

niSect – No

xisRot – No

egXSec - No

aptCav - No

nclosed - No

oDraft - No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■		■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■	■	■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

□ Normal

■ Not Applicable

Part 7: Indicator

Depress	– Yes
UniWall	– No
UniSect	– Yes
AxisRot	– No
RegXSec	- No
TaptCav	- No
Enclosed	- No
NoDraft	- No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■		■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■	■	■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

□ Normal ■ Not Applicable

Part 8: Main Body

Depress	- Yes
UniWall	- No
UniSect	- No
AxisRot	- No
RegXSec	- No
CaptCav	- No
Enclosed	- No
NoDraft	- No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■		■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■	■	■	■	■	■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

□ Normal ■ Not Applicable

Part 9: Plate Cover

Depress – No

UniWall – Yes

UniSect – No

AxisRot – No

RegXSec - No

CaptCav - No

Enclosed - No

NoDraft - No

	Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminium and Alloys	Copper and Alloys	Zinc and Alloys	Magnesium and Alloys	Titanium and Alloys	Nickel and Alloys	Refraction Metal	Thermoplastics	Thermosets	
Sand Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	Solidification Processes
Investment Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Die Casting	■	■	■	■	■	■	■	■	■	■	■	■	■	
Injection Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Structure Foam Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Ext.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Blow Molding (Inj.)	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotational Molding	■	■	■	■	■	■	■	■	■	■	■	■	■	
Impact Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	Bulk Deformation Processes
Cold Heading	■	■	■	■	■	■	■	■	■	■	■	■	■	
Closed Die Forging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Powder Metal Parts	■	■	■	■	■	■	■	■	■	■	■	■	■	
Hot Extrusion	■	■	■	■	■	■	■	■	■	■	■	■	■	
Rotary Swaging	■	■	■	■	■	■	■	■	■	■	■	■	■	
Machining (From Stock)	■	■	■	■	■	■	■	■	■	■	■	■	■	Material Removal Processes
ECM	■	■	■	■	■	■	■	■	■	■	■	■	■	
EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	
Wire EDM	■	■	■	■	■	■	■	■	■	■	■	■	■	Profiling
Sheet Metal (Stamp/bend)	■	■	■	■		■	■	■	■	■	■	■	■	Sheet Metal Processing
Thermoforming	■	■	■	■	■	■	■	■	■	■	■	■	■	
Metal Spining	■	■	■	■	■	■	■	■	■	■	■	■	■	

□ Normal ■ Not Applicable