

## **OPTIMIZATION OF PRODUCT ARCHITECTURE BY USING DESIGN FOR MANUFACTURE AND ASSEMBLY**



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## DECLARATION

I hereby, declared this report entitled "Optimization of Product Architecture by using Design for Manufacture and Assembly" is the results of my own research except cited in

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## APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as partial fulfillment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:





## ABSTRACT

Product architecture choice deserves careful consideration, which would be facilitated by the ability to represent and assess alternatives at an early stage. To optimize the manufacturing cost and product development throughout time, manufacturers have to increase commonality among products and eliminate redundant components from their product ranges, without losing functionality and quality. This study investigates a product architecture through a case study of an existing furniture caster wheel by using Design for Manufacture and Assembly. The aims is to proposed a new caster wheel design. Bill of Materials, Analytical Hierarchy Process and Boothroyd and Dewhurst Software were used as a tool to analyze the design. The new design is then develop by using Solidwork CAD and validate through Solidworks Simulations feature. The results of this study is the data comparison between the existing product design and new design in terms of mechanical perspective such as number of components, assembly time and assembly cost used. As a conclusion, the performance in terms of mechanical perspective the new design is improved.



## ABSTRAK

Pilihan seni bina produk patut dipertimbangkan dengan teliti, yang akan difasilitasi oleh keupayaan untuk mewakili dan menilai alternatif pada peringkat awal. Untuk mengoptimumkan kos pengeluaran dan pembangunan produk sepanjang masa, pengeluar perlu meningkatkan kesamaan antara produk dan menghapuskan komponen yang berlebihan daripada rangkaian produk mereka, tanpa kehilangan fungsi dan kualiti. Kajian ini menyiasat senibina produk melalui kajian kes roda perabot sedia ada dengan menggunakan Reka Bentuk untuk Pembuatan dan Perhimpunan. Tujuannya adalah untuk mencipta reka bentuk roda kastor baru. *Bill of Materials*, Proses Hierarki Analisis dan Perisian Boothroyd dan Dewhurst digunakan sebagai alat untuk menganalisis reka bentuk. Reka bentuk baru kemudiannya dibangunkan dengan menggunakan Solidwork CAD dan disahkan melalui ciri Soliwork Simulasi. Hasil dari kajian ini adalah perbandingan data antara reka bentuk produk yang ada dan reka bentuk baru dari segi perspektif mekanikal seperti jumlah bilangan komponen, masa perhimpunan dan kos perhimpunan yang digunakan. Sebagai kesimpulan, prestasi dari segi perspektif mekanikal, reka bentuk baru dapat diperbaiki.

## DEDICATION

To my hero father, Abu Zarin bin Jalaluddin My supportive mother, Yuhainis binti Mohd Yusop My siblings, Helpful friends For giving me moral support, time, encouragement and also understandings.

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## LIST OF ABBREVIATIONS

Design for Assembly DFA Design for Manufacture DFM \_ DFMA Design for Manufacture and Assembly \_ FYP Final Year Project \_ Analytical Hierarchy Process AHP Finite Element Analysis FEA TEKM **TEKNIKAL MALAYSIA MELAKA** UNIVERSITI



## **CHAPTER 1**

## INTRODUCTION

This chapter describes the background of study, problem statement, objectives of study and scope of study. The background of study focuses on modifying of product architecture design by using Design for Design for Manufacture and Assembly based on previous research. The problem statement reveals the issues are happen in recent years where. The scope of study emphasizes in the detail design of product development.

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#### 1.1 Background of study

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A product's architecture can influence many aspects from the design phase to the recycling of a product and the reuse of fragments of its design. Therefore, the selection of product architecture surely deserves careful consideration, which would be facilitated by the ability to represent and evaluate alternatives early on. To optimize the manufacturing cost and product development throughput time, manufacturers have to increase commonality among products and eliminate redundant modules and components from their product ranges, without losing functionality and quality. At the same time, product differentiation should not be sacrificed by excessive commonality.

The arrangement of functional element, the mapping from functional elements to physical elements, and the specification of the interfaces among interacting physical components is defined as product architecture (Ulrich, 1995). In this context, product architecture refers to the conceptual structure of a design. (Otto and Wood, 2001) extend the definition to include the division of a product into relationships between components and functional modules in the product family.

Using the product modeling language, product architecture can be represented. There are many such languages that vary in their types of information and how they do so. Models of the architecture of a product constructed in such languages may be used for different purposes, including communication between the customer and a design team or within a design team. The focus in this study are optimizing of product assembly time and cost development and quality of the product. Design for Manufacturing and Assembly is chose to prove either the investigation is suitable or not in this study.

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## UNIVERSITI TEKNIKAL MALAYSIA MELAKA 1.2 Problem Statement

Product architecture design could be a challenge in conceptual design that affects a wide range of development goals such as cost, time, quality and satisfaction of consumer. However, existing methods of product architecture design often have a limited number of such effects. The range of design capability are often not been exploited to the full and the existing methods are highlighted to represent a limited view on product architecture. Without losing functionality and quality, manufacturers also have to increase commonality among products and eliminate redundant modules and components from their product ranges to optimize the manufacturing cost and product development throughput time. To optimize the product architecture of product, a study of DFMA widen the view on product

architecture design, thus a design will be proposed. A caster wheel for furniture is selected as a product of the case study for this report.

Although casters are one of the smaller parts that make up a material handling cart, they play an integral role in how that product will move efficiently and safely. Also, premature caster failure can impact the company's bottom line. There are many reasons a caster can fail but the some that comes up most often are: choosing the wrong component replacement for maintenance. Many times, casters are selected based on upfront cost. What is not taken into account is that an inexpensive caster purchase can cost you much more in the long run.



- 2) To develop new design by using Design for Manufacture and Assembly
- 3) To validate the proposed design by comparing the old design and new design.

### 1.4 Scope of Study

This study focuses on modifying product architecture of an industrial product through a case study of furniture caster wheel. The existing top plate furniture caster wheel is chose as a case study for this report. Design for Manufacture and Assembly will be involved in these studies. The study is in detail design of design process. 3-D CAD modelling of the caster wheel will be designed using SolidWorks software.

## **1.5 Significant of Study**

This study is intended to optimize the existing product by using Design for Manufacture and Assembly in product architecture either by combining or modify them. The new product of a case study is validated by comparing the old design and new design through Finite Element Analysis. Due to the scope is in industrial product, the industry also get benefits from the outcome of this study. The study then can be used as reference in developing their products. Other industry can also relate the outcome to their product.



## CHAPTER 2

## LITERATURE REVIEW

This chapter discusses on previous project or studies on Design for Manufacture and Assembly application in product architecture as well as method to investigate the feasibility of the framework to achieve the objectives. This chapter also provides the basic knowledge for report finding by other researcher and the methodology used was summarized. The project information can be obtained from the online-journals, articles, relevant project paper, books and electronic publication.

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## 2.1 Product Architecture

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In 1995. Ulrich and Eppinger has stated that the physical units and the way the unit interacted that were configured from the functional elements defined as Product architecture. Architecting consist of building a system and designing (Rechtin, 2000). Chen and Liu (2005) described Architecture as a method where the function of a product is allocated to its physical component. For any real product of architecture, it varies from modular to integral. In subsets product's functional model that have a one-to-one correspondence from the existing multiple physical substructures is called modular architecture. An integral architecture occurs when achieving multiple functions by a physical substructure.

In the conceptual phase, Pahl et al.(2007) suggested a functional basis for product architecture. At this stage, no form details are required for the design. The inputs and outputs of the subsystem which associated with the environment are divided from the system or a product. The intended input/output relationship of a system whose purpose is to perform a task represents the function. Usually functions are represented in a verb-noun (function flow format). There are three types of flow which based from a function namely energy, material and signals. Branch, channel, connect, control magnitude, covert, provision, signal and support are the eight classes from which a function can be divided to.

Pahl et al. (2007) said by following the steps, product architecture in a functional model can be obtained. The case where black box diagram ignored the initial processes and sub-system given in the block are the overall function of the product which later are divided into sub-function of lower complexity. Overall function is then can be satisfied when the sub-functions able to produce an integrated function structure.

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A functional basis that were developed from product architecture can be utilized for developing a modular architecture. In identifying modules for product architecture, Stone et al. (2000) suggested three heuristics where one function can be related to one module.

Dominant flow heuristics: A modules that define as a non-branching flow that passes through from the group of sub-functions with the initiation of the flow in the system to exit from the system without transformation.

Branching flow heuristic: A module which branched from a flow constitute of a parallel function chain. A module at the branch location that interfaced with the other modules. Conversion-transmission heuristics: A module which represents a conversion sub-function or a conversion-transmission pair or a chain of conversion-transmission chains. In the case of conversion-transmission chains, only operate on the converted flow for the intermediate sub-functions between the convert and transmit sub-functions.

A method has been proposed where it can identify variety in product portfolios based on product function and customer needs to reduce the system impact of variety. It describes the entire set of products used by monolith function structure which merged from the individual product functions. Stone et al. (2000) then said the monolith later partitioned into modules according to function and product variety heuristics. A core platform module is then formed when the variety heuristics clusters functions across the portfolio by isolating the variety of the module and reducing the variety by grouping the remaining function. Different characteristic is achieved through optional modules for varying performance.

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Diverse customer needs can be meet if platform-based design helps an industry to benefit by sharing the technology platform. In the case of mass-produced goods, the benefit product platform can be significant. A set of subsystem and interfaces that are shared among a group of products is called product platform where it develops derivative products. Target market segments that satisfied by common product platform that are shared from a group of products are defined as product family. Thus, the need of multiple product lines in the market is served by product platform. A product variant consists of individual product within a product family. Jiao et al. (2007) have provided a literature review on product family design and platform-based product development.

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Companies can increase the flexibility, differentiated products developed efficiently and responsiveness of their manufacturing processes by sharing components and production processes across a platform of products . Companies can also gain market share away from competitors who develop only one product at a time. Further, it also improves ability to upgrade products, development cost, products and product development time. Commonality among product ranges will increase from the efficiencies of supply chain resulting in better negotiating terms with suppliers and reductions in direct and indirect manufacturing costs enhanced. Platform-based design helps to reap the benefits of mass customization at mass production efficiency by meeting the needs of diversified market segments.

Each product in the family that were compared with functional structure from shared interchangeable modules is one of the approached to architecting a product family suggested by Dahmus et al. (2001). Zhang et al. (2006) have suggested a function-based modularity approach for development of product families. Guidelines for improving commonality among product platforms in custom products have been specified by Farrell and Simpson (2003).

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Optimization and product for family design approaches have been discussed by Simpson et al. (2006). Module-based method and/or scale-based method can be used to achieve the platform-based product design. For deriving individual products in a family in the module-based method, one or more functional modules are added, substituted and/or removed from the platform. In the case of scaled-based method, the platforms are scaled in one or more dimensions to meet the requirements. Top-down and bottom-up approaches can be used to achieve the product family design. In the top-down approach, a platform for a group of products are developed strategically by a company and in the bottom up approach, the technology shared were based from a platform developed from a company that groups its products. Marinelli et al. (2009) have introduced a mathematical programming-based modelling framework for the combined module-based and scale-based platform designs using the top-down approach.

#### 2.2 Product Design and Development Process

The product design scope extends beyond industrial design. Industrial design focuses more on the "art" of a product such as esthetics, shape, color, texture and feeling. Product design is considered a mix of marketing, managing products, industrial design and engineering. (Sapuan, 2017).

Product development defined by Mazumdar (2002) as a process for translating customer requirements into product design and manufacturing involving the management of mutual dependency between all phases of the product life cycle, including design, manufacturing, distribution, technical support and disposal or recycling phases.

Sapuan and Maleque (2005) used total design model in the development of a household appliance, that is, a telephone stand from woven banana pseudo-stem fiber reinforced epoxy composites. The overall design as coined by Pugh (1991) is considered a key activity in the development of products. The overall design model is shown in Figure 2.1. It begins with market research, product design requirements (PDSs), conceptual design, detailed design, manufacturing and sales. This model can be easily used for engineering and consumer products, even in composite applications.





The model developed by Pugh (1991) has become increasingly popular with product designers, among others, due to the strong emphasis on product design specifications, the combination of conceptual and embodiment designs only as conceptual design and the introduction of a well- respected Pugh concept assessment method. Pahl et al. (2007) have developed a model that sometimes referred to as the German method. In 1984, their work was originally translated and published in English. It is well accepted that this work is the pioneering work in design engineering. It is because, they have written a very comprehensive and detailed book and this work is sometimes considered so much beyond what is normally needed.

#### 2.3 Design for Manufacture and Assembly

DFMA is combinations between Design for Manufacture and Design for Assemble which stands for Design for Manufacture and Assembly. At the early stage, design engineers analyze the manufacturing and assembly problems by applying the DFMA paradigm or software and act as a basic concept of it. By this means, the factors that affect the final output will all considered as early as possible in the design cycle. The time spent at the early stage will be less than the time to redesign repeatedly. Meanwhile, the cost will also be reduced. The Figure 2.2 shows the framework of DFMA by Boothroyd (1994):



Figure 2.2: The framework of DFMA by Boothroyd (1994).

Design for manufacture (DFM) and design for assembly (DFA) developed from the recognition that the cost of producing a product is largely determined by its design. Failing to consider manufacture and assembly in design can result in products that are either

fundamentally impossible to make, or more expensive (and hence less profitable) than they could be.

Design for manufacture and assembly (DFMA) is a design procedure and guideline that supports product simplification, integration of economic materials and processes into the design with the goal of achieving optimal manufacturing and assembly (Boothroyd et al., 2004). DFMA has been successfully applied for various optimisation processes such as; enhancing early stage design specification by Vliet and Luttervelt (2004), Marinelli et al. (2007) evaluated the ease of sourcing materials and manufacturing components, Howard and Lewis (2003) recommending manufacturing options for concurrent engineering to designs.

#### 2.3.1 Design for Assembly

DFA is considering and resolving the possible problems in the assembly process at the early stage of the design which can make sure the part will be assembled with high speed, low cost and productivity. DFA is a kind of design paradigm with which, the engineer use all kinds of methods such as analyze, estimating, planning and simulating to consider all the factors that will affect the assembly process during the whole design process; revise the assembly constructions to satisfied the characteristics and functions of the final products; and meanwhile, lower the cost as most as possible.

DFA is a kind of design method that can be used in two ways. First, as tool for assembly analysis and as guide for assembly design. The former usage is that at the time after the beginning of the product design, the engineer makes estimation of assembly possibility by analyzing all the factors that can affect the assembly process, and give suggestions. The second one is that collecting the knowledge and experience from the assembly experts and recording them as design guides. By the help of these guides, the engineer can choose the design plan; determine the product construction such as under the guidance of those experts.

If the product design and process design are chose simultaneously in the early design the optimal method of design for assembly can be achieved. The systems of assembly are including manual assembly, semi-automatic assembly, adaptive assembly, automatic assembly, and flexible assembly.

In designing for manual assembly, judgment, dexterity and skill can be use by human assemblers. However, the consistency is doubted and will affect the quality. Therefore, to minimize the chance and error consequences, parts and assembly should be designed. Parts symmetrical are some of the example includes in minimizing errors so that they do not need to be oriented

### 2.3.2 Design for Manufacture

DFM is that by considering the limitations related to the manufacturing at the early stage of the design; the design engineer can make selection among the deferent materials, different technologies, estimate the manufacturing time the product cost quantitatively and rapidly among the different schemes. They compare all kinds of the design plans and technology plans, and then the design team will make revises as soon as possible at the early stage of the design period according these feedback information and determine the most satisfied design and technology plan as stated by Xie (2006).

There are three goals in DFM:

1. Increase the quality of new produces during the developing period, including design, technology, manufacturing, service and so on.

- 2. Decrease the cost, including the cost of design, technology, manufacturing, delivery, technical support, discarding and so on.
- 3. Shorten the developing cycle time, including the time of design, manufacturing preparing, and repeatedly calculation.

### 2.3.3 DFMA Methodologies

Although the concept of DFMA can be very simple, Schwarz (2015) said creating a quantitative method and implement in different companies is very complex and each case has its own unique challenges. However, each situation has the same objective, to reduce to the minimum the number of components and manufacturing steps. Reducing the number of parts is reducing work design, document update, inventory, bill of materials (BOM) and assembly error probability. The decrease in the number of manufacturing steps leads to reduced machining costs and reduces the chance of machining errors. The combination of these two steps can lead to higher profit margins and faster the delivery of the product.

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DFMA analysis can be used in three main ways:

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- As a basis for the study of concurrent engineering to provide guidance to the design team in simplifying the product structure, reduce manufacturing / assembly costs, and to measure improvements
- 2. As a benchmarking tool for study of competitor products and manufacturing measuring and assembly difficulties; and
- 3. As the supposed cost of tools to help control costs and to help negotiate supplier contracts.

DFMA analysis conducted for this study fall under the first category.

#### 2.4 Benefits of Design for Manufacture and Assembly

The existence and involvement of DFM is mainly for designing that will help to ease the manufacturing of product parts. DFM is focused on selecting materials that are very cost effective including the suitable processes that will be used later in production. Other than that, complexity of manufacturing operations can be minimized with the used of DFM. While DFA on the other hand, is focused more on to ease the product's assembly. It is concerned with the product's assembly cost that can be reduced and also will reduce the number of assembly operations. Thus, reducing the products cost and time taken for the product to be made can be reduced by using DFMA (Barbosa, 2013).

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Mary et al. (2018) said DFMA also have other advantages that can be included such as speed. Speed of operation especially on site can be reduced significantly by using prefabricated element. Next, lower assembly cost, when the products have less parts or components the work labor also can be reduced to make the assembly and managed to reduce the cost of assembly, while reducing the assembly cost, the time taken to make the assembly also decreased hence improved the time taken to complete a product as stated by Bayoumi (2000). Moreover, is higher quality and sustainability, when the parts are decreased or reduced, means less materials are used to make the products and parts hence sustainability is conserve. Quality is improved because operators' productivity has improved as well (Zhenmin Yuana, 2018). DFMA reduced number of parts hence increased the reliability that will cause the chances of parts to fail is increase significantly.

## 2.5 Summary

This Chapter cover the understanding of Product Architecture, Product Development process and the methodology and benefits of Design for Manufacture and Assembly. It has been clear that product architecture deserves a careful consideration in the early design and Design for manufacturing and Assembly is happen to be the suitable process in finding the solution. Optimizing the product architecture through DFMA indeed reduce the number of parts of a product. Hence, the time development, manufacturing cost, quality of a product can be optimize.



## **CHAPTER 3**

## **METHODOLOGY**

This chapter explains the methodologies and procedures to achieve the objectives of the report. This includes method and procedures in the process of the studies of design for x framework in product architecture. A new framework is proposed and will be validated through a case study.

## UNIVERSITI TEKNIKAL MALAYSIA MELAKA 3.1 Flowchart of Final Year Report

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hunds,

The study has two phases FYP 1 and FYP 2. FYP 1 focuses on the introduction, literature review, methodology. This step includes the problem statement, objectives, scope and information or knowledge relating to the study through various resources. The literature of this study referred to product architecture as well as Design for Manufacture and Assembly application, benefits and methodologies. For the next step, it will be done in the FYP 2. It consists of data collection for the study and the results are documented. Figure 3.1 illustrates the flowchart of the study.



Figure 3.1: The Flowchart of Study

### **3.2 Gantt Chart of Final Year Report**

The purpose of a Gantt chart is to illustrate a project schedule. It illustrates the individual tasks or activities in a project. Table 3.1 shows the Gantt chart for the whole duration of Final Year Project (FYP) 2 from week 1 to week 14. The Gantt chart includes the planning schedule from the making of introduction, searching for related researches, writing the reports, poster presentation as well as the submission. for FYP 2 as shown in Table, the planning schedule includes the conceptualization and CAD of the case study of caster wheel using SolidWorks, Bill of Material (BOM), DFMA software, discussion of the result and making conclusions.

Gantt Chart for FYP 2																
No	🔮 Task 💈	Week														
•		1	2	3	4	5	6	7	8	9	1	1	1	1	1	1
	No.	_					5				0	1	2	3	4	5
1	Discussion with SV on method use															
2	Analyzing and correction on previous		<		ú	1		J.	-	à	0					
	data in FYP 1	-			-1	Ċ.	2 44	6	-	7	2					
3	Select a case study SITI TEKNIKA	L	M	AL	.A`	<b>rs</b>	IA	M	EL	Ał	(A					
4	Questionnaire distribution															
5	Building Bill of Materials									natio	reak					
6	Material Selection process by using									xami	ter B					
	AHP									erm E	Semes					
7	DFMA Process									lid-Te	Mid-S					
8	3-D cad modelling of result and									Σ						
	validate the product															
9	Making conclusions															
10	FYP Final presentation															
11	Report Submission															

Table 3.1 : Gantt Chart for FYP 2

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#### 3.3 Investigation of a Product Architecture of a Caster Wheel

The investigation of a caster wheel product architecture is conducted through questionnaire, bill of materials, Boothroyd & Dewhurst Software, Analytical Hierarchy Process and Solidworks CAD. The questionnaire is used to gain the data from the consumer to support the existence of the problem. Bill of Material is used to understand the product architecture such as the number of part and material use from the selected caster wheel. Analytical Hierarchy Process then is used to select the most suitable or the most preferred material to be used in the study. Boothroyd & Dewhurst Software is a tool used in Design for Manufacture and Assembly to complete the study. For proving part of the study, Solidworks Cad and Simulation is then used.

#### 3.3.1 Questionnaire

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A questionnaire is a research instrument consisting of a series of questions to gather information from respondents. The questionnaires can be considered as a kind of written interview. They can be conducted face-to-face, telephone, computer or mail. In this case study, a questionnaire is performed by the form of Google for more data and information products problems. The questionnaire that been used for this study are proved in appendix.

#### **3.3.2 Bill of Materials**

The bill of materials (also known as a BOM) is a complete list of documents, articles, assemblies and other materials necessary for the production of a product, and instructions for collection and use of necessary materials. The bill of materials can be understood as the recipe and shopping list for the development of a final product. The bill says what, how and where to buy the necessary materials and includes instructions on how

to assemble the product different parts ordered. All manufacturers making products, whatever their sector, starting with a BOM.

In this case study, bill of material was used to determine the number of parts in the original caster wheel because the bill of materials collects all kinds of product information, it is common for a number of disciplines to use data contained in the BOM record to get the job done correctly.

#### 3.3.3 Analytical Hierarchy Process

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Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method. In short, it is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as price, weight etc., or from subjective opinion such as satisfaction feelings and preference. AHP allow some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value. AHP is used for material selection in this case study. Below are the steps for AHP :

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- 1. Define criteria
- 2. Develop hierarchy framework
- 3. Construct pairwise comparison matrix
- 4. Perform judgement for pairwise comparison
- 5. Synthesize pairwise comparisons
- 6. Check for consistency
- 7. Perform steps (3-6) for all levels or criteria in the hierarchy
- 8. Develop the overall priority ranking
- 9. Select the best alternative.

Figure 3.2 shows the hierarchy framework of this study. The goal of this AHP is to find a new material that suit the most for the new caster wheel. The criterion used in to performed the AHP are specific heat, mass density and tensile strength. The alternatives of the AHP of the new caster wheel are cast iron, nylon and rubber.



3.3.4 Design for Assembly

The Boothroyd Dewhurst Method is systematically examined the geometry of the part and how they are attached to estimate the time to the different parts together. Then, by adding and comparing it to a theoretical minimum partial number

#### 3.3.5 Design for Manufacture

In this part, DFM concurrent costing is used to determine the suitable process in manufacture the new design of a product to achieve the aim of reducing cost piece of part of the product.

#### 3.3.6 Development of 3-D Modelling

3-D CAD modelling is used to compare the old design and new design using Solidworks Software. Solidworks Simulation will also be used to generate Finite Element Analysis to test the solution in forms of detail design

## **3.4 Expected Result**

The reduction of part assemblies will help in achieving the aim of study which to reduce the cost and assembly time of a product and indirectly enhance the quality and satisfaction of consumer.

#### **3.5 Result and Discussion Phase**

In this phase, all the results that were obtained from analysis will be discuss in chapter 4 which is result and discussion. 3D CAD modelling drawing of caster wheel will be presented in chapter 4. The result of BOM, questionnaire, AHP and DFMA are discussed in this chapter. In addition, all the steps for each phase are explained more clearly and briefly.
### **CHAPTER 4**

## **RESULTS AND DISCUSSION**

This chapter discussed the result from the Bill of Material, Questionnaire conducted, Design for Assembly, Analytical Heuristics Process, Design for Manufacture Concurrent costing, 3-D CAD Modelling and Finite Element Analysis of newly developed caster wheel.

#### 4.1 Bill of Materials

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From the original caster wheel design specification obtained, the bill of material are develop to analyze the assembly part level consist as shown in table 4.1. Part level is a detail number of each part or component or assembly where it fits in the hierarchy of BOM. Part name is the name of each part or components. Quantity is number of parts that have been recorded. Unit of measure is the measurement unit that been use to each part. Millimeter is selected as the measurement unit. Description provides the description of each part such as material used. Thumb is a picture of each part in the caster wheel.

Part	Part	Quantity	Unit of	Description	Thumb
Level	Name		Measure		
1	Caster	1	Millimetre	Light Duty	
	wheel		(mm)	Caster	
2	bracket	1	Millimetre	Top Plate,	
			(mm)	Swivel fork	
3	wheel	1	Millimetre	Black and	
	MALAY	S14	(mm)	white,	
2	bolt	1	Millimetre		
TEKL		AKA	(mm)		
2	o nut	1	Millimetre		
	VAINN .		(mm)		
-	سيا ملاك	کل ملیہ	يڪيد	ۆر سىتى ت	٩اون
3 U	spacer S	$TI T_2KNI$	Millimetre	YSIA MEL	KA
			(mm)		11 11
3	Outer	1	Millimetre	Polyurethane	
	wheel		(mm)		Q
3	Inner	1	Millimetre	Solid rubber	
	wheel		(mm)		Ø
3	bearing	2	Millimetre	Roller types	8
			(mm)		

Table 4.1: Bill of Materials (BOM)

#### 4.1.1 Description of Top Plate

A horizontal plate for a fix wheel to a device. The plates distribute the load over a larger area, and often require a large flat surface for attachment. This is one of many types of attachment for smaller wheels, but the main type of attachment to larger wheels.. The top plate material made of Stainless Steel with the width of 51mm and length of 71mm. The dimension of the mounting hole is 8.5 x 11.5 mm.

#### 4.1.2 Description of Fork

Fork or rig consisting of the legs over a base (base holder caster swivel mounting plate or rigid). The fork is also made of Stainless Steel with the height of 71mm.

# 4.1.3 Description of Outer Wheel

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The outer of the caster wheel are made of rubber. The diameter of the other wheel is 38mm and width of 23mm

#### 4.1.4 Description of Inner Wheel

The inner wheel part is made of solid rubber with the diameter of 32mm and 24mm width.

#### 4.1.5 **Description of Bearings**

Objects used to reduce friction and improve movement. While the race does have bearing casters, bearings description usually refers to the caster wheel bearings. The bearing type used for the original caster wheel is roller type. The bearing are made of stainless steel.

#### 4.1.6 Description of Spacers

A non-rotating sleeve of a steel tube which is placed on the shaft or axle in several wheels. Serves as dual purpose of providing a smooth inner raceway for the wheel bearings, and strengthening the casting machine by allowing the legs to be clamped against it. The spacers are made of stainless steel.

#### 4.1.7 Description of Fasteners

Consist of 10mm nut and 10mm bolt used as shaft on the leg side holding thrust washers, bushings. The bolt and nut are made of zinc alloy.

#### 4.2 Data Analysis For Questionnaire

The first question that considered important in the questionnaire that has been conducted before is the frequency of the problem that came from for the caster wheel. The Figure 4.1 shows the result from respondents, 40.5% agree that most of the problems are caused from the component itself, such as spacers and bearing.



Figure 4.1: The rates of the wheel component problem

From the conducted survey that is largely focus on consumer, the requirement to develop of new design of the product is obtain by the problem existing. The questions that are considered to be critical is the part where the frequency of the customer in purchasing the component that need to be replaced. Figure 4.2 below show the bar chart for the questions,



Figure 4.2: The frequency of buying the wrong size of component

The Figure 4.2 shows that 31% of the respondents give the scale to 4. This means that frequency of buying a component of the caster wheel to be replaced is often happen.

Another question that considered important is the difficulty in finding the component to be replaced in their nearby hardware shops. Figure 4.3 below show the statistics of the answer



Based on the Figure 4.3, 38.1% agree that to find the replacement part of the caster wheel from hardware store in there are hard to find. This survey data reinforce the study in in order to achieve the aim of Design for Manufacture and Assembly.

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**4.3 Design For Assembly** 



Figure 4.4: Boothroyd and Dewhurst Analysis result for DFA

Figure 4.4 shows the comparison number of part assemblies between the original design, after redesign and the redesign caster wheel with new material. The original product in the analysis indicate the old product. Through the candidates for elimination more than

half of the part can be reduced. Thus, he number of the total entries can be seen from 10 part successfully reduced to 5.

Due to the total number of part from the original design has been reduced. The total time taken to assemble the product also reduced. This can be seen from the difference in the total assembly labor time in Figure 4.4, from 178.72s of the original design to assemble one product to 133.78s. The changed of material used for new design enhanced the time to reduce from the redesign caster wheel to 130.15s. In overall, result of the design efficiency can be increased to 7.92 from 5.77 the original design.



#### DFMA<sup>®</sup> - Boothroyd Dewhurst, Inc. Analysis Totals for Design for Manufacture and Assembly (DFMA)



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Monday, 16 December, 2019



Figure 4.5: Boothroyd and Dewhurst analysis with cost result for DFA

Figure 4.5 shows the total cost per product between original product, the redesign product and the redesign product with new material. From the analysis result, the total cost per product for the wheel is decreased by RM 27.42 from original design which is RM 54.19 to redesign wheel with new material that is RM26.77.

#### **4.4 Analytical Hierarchy Process**

The aim of analytical process of this study is to select the best material for the new design caster will and ease the manufacture process selection of DFM concurrent later. The Criterion and material is selected based on the existing Caster wheel specification on the

market

#### 4.4.1 Wheel

The Table 4.2 below is the materials and criterions specification of the wheel obtained from the market and Boothroyd & Dewhurst Software material library for Cast Iron, Nylon and Rubber.

	Cast Iron	Nylon	Rubber
Specific Heat (J/Kg.K)	510	1500	1120
Mass Density	7200	1400	1292
(Kg/mm^2)			
Tensile Strength	151.658	142.559	13.7871
(N/mm^2)			

Table 4.2: The AHP Materials and Criterion for Wheel

Criterion	Specific	Mass	Tensile
	Heat	Density	Strength
Specific Heat	1	5	3
Mass Density	0.2	1	0.25
Tensile	0.333333333	4	1
Strength			
Check	1.533333333	10	4.25

Table 4.3: The Pairwise Comparison Matrix of Criterion

	MALA	1SIA			Normalize	
	Ser.	Mary			Matrix	
Criterion	🔮 Heat	Mass	Tensile			
	F.	Density	Strength			
Heat	0.6521739	0.5	0.70588235	1.8580562	0.61935208	62%
	13/40		3	66	9	
Mass	0.1304347	0.1	0.05882352	0.2892583	0.09641943	10%
Density	83		9	12	T	
Tensile	0.2173913	SITI0.4EK	0.23529411	0.8526854	0.28422847	28%
Strength	04		8	22	4	
Total	1	1	1			

Table 4.3 shows the result of pairwise comparison matrix of criterion. From the Table, the criterion considered to be the most important of wheel design is specific heat with 62%. Next criterion for the design property is tensile strength with 28%. The mass density came in last with just 10%.

Specific Heat	Cast Iron	Nylon	Rubber
Cast Iron	1	0.2	0.333333333
Nylon	5	1	3
Rubber	3	0.333333333	1
Total	9	1.533333333	4.333333333

Table 4.4: Pairwise comparison matrix and judgement of Specific Heat

Specific	Cast Iron	Nylon	Rubber			
Heat						
Cast Iron	0.111111	0.130434783	0.076923	0.318468	0.106156	11
	111 MALA	YSIA	077	971	324	%
Nylon	0.555555	0.652173913	0.692307	1.900037	0.633345	63
	556	KA	692	161	72	%
Rubber	0.333333	0.217391304	0.230769	0.781493	0.260497	26
	333		231	868	956	%
Check	1 ''Wn	1	1			
اونيوم سيتي تيكنيكل مليسيا ملاك						

Table 4.5: Pairwise comparison matrix and judgement of Mass Density

Mass Density	Cast Iron	Nylon	Rubber
Cast Iron	1	0.2	0.166666667
Nylon	5	1	0.5
Rubber	6	2	1
Total	12	3.2	1.666666667

Mass	Cast Iron	Nylon	Rubber			
Density						
Cast Iron	0.0833333	0.0625	0.1	0.2458333	0.0819444	8%
	33			33	44	

Nylon	0.4166666	0.3125	0.3	1.0291666	0.3430555	34
	67			67	56	%
Rubber	0.5	0.625	0.6	1.725	0.575	58
						%
Check	1	1	1			

Table 4.6: Pairwise comparison matrix and judgement of Tensile strength

Tensile	Cast Iron	Nylon	Rubber
Strength			
Cast Iron	1	2	5
Nylon	0.5	1	5
Rubber	0.142857143	0.166666667	1
Total	1.642857143	3.1666666667	11
" Anno			

Tensile	Cast Iron	Nylon	Rubber	in ma	a	
Strength			. 9	2. 07.	2	
Cast Iron	0.608695	0.631578947	0.454545	1.694820	0.564940	56
	652		455	054	018	%
Nylon	0.304347	0.315789474	0.454545	1.074682	0.358227	36
	826		455	754	585	%
Rubber	0.086956	0.052631579	0.090909	0.230497	0.076832	8%
	522		091	192	397	
Check	1	1	1			

As shown in Table 4.3 until Table 4.6, the result of the table shows that every of each criteria on wheel gave some total percentage by simple calculation which then the highest value among the values are chose as the best criteria in decision making for the new

caster wheel. All the calculation for overall table shown, had the same steps by using few simple formulas. Firstly, each of the criteria were been determined their judgement of preference based on the comparison scale within the scale 1 to 9. Numerical rating started with 1 (equally preferred), 2 (equally to moderately), 3 (moderately preferred), 4 (moderate to strongly), 5 (strongly preferred), 6 (strongly to very strongly), 7 (very strongly preferred), 8 (very strong to extremely), and 9 (extremely preferred).

Next Table 4.7 shows the overall and final priority ranking for material selection of new wheel design. The final Analytical Hierarchy Process ranking shows that the most suitable material for the next wheel design is Nylon with 53%.

100	p. L.	AΥ	SI.	1	
16				н.	
Section					

Table 4.7: The Overall and Final Priority Ranking for Wheel

		1			
	0.61935208	0.09641943	0.284228474		
	9	7		7 V	
	Heat	Mass	Tensile		
	Molin	Density	Strength	in the star	0
Cast Iron	0.10615632	0.08194444	0.564940018	0.23422121	23%
U	INIVERSIT	I TERNIK/	AL MALAYS		(A
Nylon	0.63334572	0.34305555	0.358227585	0.52715969	53%
		6		8	
Rubber	0.26049795	0.575	0.076832397	0.23861908	24%
	6			5	

#### **4.5 DFM Concurrent Costing**

The Design for Manufacture Concurrent Costing is used in this study to determine the total cost of manufacture each part of the new caster wheel design. The product life volume and the batch size is set to 100,000 and 125 unit to match the current price of piece part cost in the market. Figure 4.6 shows the summary of DFM Concurrent Costing for top plate. The plasma cutting process is selected based on the suggestion provided from the software.



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Similarly to top plate manufacture process, the manufacturing process of the caster wheel fork is also using the same process and the summary is shown in Figure 4.7.

DFM Concurrent Costing Executive Summary Boothroyd Dewhurst, Inc.



Monday, 16 December, 2019 2:49 PM Part name: fork Material: Generic zinc alloy Process: Sheet metal plasma cutting



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fork.dfm

zinc alloy

Part number:

Figure 4.7: DFM Concurrent Costing for Fork

Next Figure 4.8 shows the DFM Concurrent Costing summary of wheel. Structural foam molding is selected as the most suitable process among other options of process in the DFM Concurrent Costing Software such as Thermoforming, Blow molding and Plastic Extrusion due to have the least total cost that shows in Figure 4.8



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Figure 4.8: DFM concurrent Costing for Wheel



Figure 4.9: DFM Concurrent Costing for Wheel Design Process

As shown in figure 4.9, the blue colour in the bar chart indicates the material cost for wheel design a new caster wheel which is nylon. The red colour indicates the setup cost for each process which are structural foam molding, plastic extrusion, blow molded and thermoforming process. Next, the process cost of the wheel are indicated as in green colour in the bar chart. Lastly, the orange colour indicates the tooling cost for each processes. From the figure, structural foam molding process is the most suitable process to be carried on to produce the new wheel design due to the overall cost is the least among other processes.

#### 4.6 CAD Modelling

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The Figure 4.10 shows the assembly part of the original furniture caster wheel design by using Solidworks Software. The original caster wheel design before going through Design for Manufacture and Assembly are consist of 10 assembly part.



Figure 4.10: Original Furniture Caster Wheel Design

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The next Figure 4.11 shows the assembly part of redesign wheel with new material. from the figure and figure, we can see the improvement of the caster wheel design by using Boothroyd and Dewhurst Software for Design for Assembly.



Figure 4.11: New Design Furniture Caster Wheel

#### 4.7 Finite Element Analysis Comparison

Finite Element Analysis is used in this study as a guarantee of the product safety in detail design before going through the manufacture process and market. The Finite Element Analysis is conducted through Solidworks Simulation. Static analysis, additionally called static code investigation, is a strategy for PC program troubleshooting that is finished by looking at the code without executing the program. The procedure gives a comprehension of the structure and can guarantee that the code holds fast to manufacturer models. In this study, a few investigations have been done to dissect the ability of the new wheel as appeared in figure and show how much the optimization of progress from old wheel to the new design wheel. Programming examination, for example, static, displacement and strain are created by utilizing Solidworks application with some of legitimate advances.

#### 4.7.1 FEA of Wheel Comparison

Figure 4.12 show the comparison of stress analysis comparison between nylon, cast iron and rubber material for the new wheel design. Stress is force per unit area or force divided by area. The force applied for the wheel is 196.24N which is 20 Kg. The yield strength of each material hold of 1.390e+08(N/m^2), 1.988e+08(N/m^2) and 9.237e+06(N/m^2). The maximum and minimum value yield strength of nylon are 1.357e+06(N/m^2) and1.824e+03(N/m^2). For cast iron material, the maximum of yield strength is 1.540e+06(N/m^2) and the minimum 1.988e+03(N/m^2). Rubber hold the maximum yield strength of 6.734e+05(N/m^2) and minimum of 2.631e+3(N/m^2). The applied force for each material is same which is 196.24N.



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the at 1.000e-30mm. 2.646e-04mm and 1.123e+00mm. The minimum displacement for each materials are same maximum static Figure 4.13 shows the result from the displacement for Nylon, Cast Iron and comparison of displacement analysis where Rubber are 2.089e-03mm,



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material are1.598e-072, 2.159e-08 and 1.078e-03. Cast Iron and Rubber are 1.492e-04, 1.859e-05 and 1.070e-1. The minimum strain of each Figure 4.14 shows the strain analysis result where the maximum strain for Nylon,



#### 4.8 Wheel Design Comparison

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This study is basically want to optimize the caster wheel product architecture and solve the problem of consumers. The original caster wheel used to have a bigger number of parts and gave some difficulty to the consumer in terms of changing part that have problem. However, after all the analyzing have been done, new design approach of caster wheel pursues to have a better specification that the old design of the caster wheel. The table 4.8 shows the difference between the old design and the new design when it goes into comparison with several specification which could be best to differentiate between both designs.

Table 4.8: Wh	eel design cor	nparison	
i G			

Old Design	Specification	New Design
10	Number of part	5
178.72 dun	Assembly time (s)	130.16
مار <u>9</u> 54.19	Assembly per product cost (RM)	26.77
15.58IVERSIT	Manufacture per product	IA MELA 5:02
	cost(RM)	
17.67	Total manufacture cost	6.86
	(RM)	

From the table 4.8, it is shown that the number of part have been decreased from the old design which is 10 parts to 5 parts. Thus, the assembly time is reduced 178.72 seconds to 130.16 seconds which make the assembly time faster. Next, the assembly per cost product is also able to decreased by RM 27.42 from RM 54.19 to RM 26.77. Then, the manufacture cost per product is also decreased by changing the material and process from RM 15.58 to RM 5.02. RM 15.58 is the sum up price of bearing, inner wheel, outer wheel and spacer part from the old design of DFM Concurrent Costing analysis that a shown in

appendices. Lastly, the total manufacture cost is also able to be reduced by RM 10.81 from RM 17.67 of old design to RM 6.86 of the new design of caster wheel.



## **CHAPTER 5**

### CONCLUSION

#### 5.1 Conclusion

There are three objectives that have been set up for this case study. First, to investigate the product architecture of a caster wheel. Second, to develop a new design by using Design for Manufacturing and Assemble. Lastly, to validate the proposed design by comparing old design with new design

- The investigations of case study conducted by using Bill of Materials and Questionnaire.
- To develop and optimize the new design of case study, Boothroyd & Dewhurst Software is used as a tool in Design for Manufacture and Assembly.
- The validation of the proposed design is done by comparing the old design and the new design through Solidwork CAD and Solidwork Simulation.

### **5.2 Recommendation**

The recommendation for this case study is to further the study for the end of life of the product. Design for Manufacture and Assembly may reduce the time development, assembly cost and increased the quality but the end of life of the product is need to be study further so that the environment for the next future to be safe.

#### 5.3 Sustainability

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In this era of globalization, sustainability became one of important aspect in order to preserve the environment to safe and green. Waste is one of the big major problem that the world had to deal with. By minimizing the number of component used in a product, the waste problem focus can be narrowed down to just deal with the material disposal at the end of life of the product.

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# **APPENDICES**

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Hi, sun ans	am a student of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka is conducting a ey of a product architecture on caster wheel for my final year project. I kindly request you to help wer the questions. Thank you for your time.
Re	quired
1	Gender *
	Mark only one oval.
	C Male
	Female MALAYSIA
2	Age
	Mark only one oval.
	20 - 29 years old
	40 - 49 years old
	O 50 and above
3	Employment Status
	Mark only one oval.
	اويىۋىرسىتى تىكنىكل ملىسىاتەتلەن
	Working
	UNIVERSITI TEKNIKAL MALAYSIA MELAKA
4	Marital Status Mark only one oval.
	Single
	Married
	Divorced
Th	e product feedback section
т.	a annuananta annaist in a anatan mhaal ana tan mlata. faula
1 n	e components consist in a caster wheel are top plate, fork,

MALAYSIA
<ul> <li>S. Do you know Caster Wheel and its Use?</li> <li>Mark only one oval.</li> <li>Yes</li> <li>No</li> <li>B. No</li> <li>B. No</li> <li>B. No</li> <li>B. No</li> <li>B. No</li> <li>J. J. J</li></ul>
Office use
Other
8. When the product goes wrong, what would you do? Mark only one oval.  Replace the component Throw away Other:
9. If you replace the product, was it hard for you to fix it?
Yes
No
Maybe

	1	2	3	4	5	
Strongly disagree	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Strongly agree
11. Buy a wrong size t Mark only one oval.	o replac	e the c	ompon	ent is u	sually o	coured *
ALAY	1	2	3	4	5	
Strongly disagree	0	$\odot$	$\bigcirc$	$\bigcirc$	$\bigcirc$	Strongly agree
Strongly disagree	1	2	3	4	5	Ströngly agree
13. Some component	are quit	e exper	sive *	4	5	اونيۇم سىتى تى
Strongly disagree	Ю	B	NIR.	6	16	Astrongly agree/ELAKA
14. Reducing the com Mark only one oval.	ponent	number	r would	be bett	er *	
		2	2	4	5	

#### DFM Concurrent Costing Executive Summary Boothroyd Dewhurst, Inc.



Monday, 16 December, 2019 3:26 PM Part name: bearing Material: FC-0200-K20 powdered iron-copper Process: Powder metallurgy bearing.dfm powder metallurgy Part number:



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#### DFM Concurrent Costing Executive Summary Boothroyd Dewhurst, Inc.



Monday, 16 December, 2019 3:13 PM Part name: inner Material: Nylon 6/6 (Polyamide) Process: Structural foam molding inner.dfm Original Part number:



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## DFM Concurrent Costing Executive Summary Boothroyd Dewhurst, Inc.



Monday, 16 December, 2019 3:10 PM Part name: Outer Wheel Material: Polypropylene Process: Injection molding outer.dfm Original Part number:



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## DFM Concurrent Costing Executive Summary Boothroyd Dewhurst, Inc.



Monday, 16 December, 2019 3:07 PM Part name: spacer Material: Ferritic stainless steel Process: Investment casting spacer.dfm investment Part number:



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