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APPLICATION OF DESIGN FOR MANUFACTURING AND ASSEMBLY (DFMA) METHOD TO VEHICLE DOOR DESIGN

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ABSTRACT

Design for manufacturing and assembly (DFMA) guidelines aim to reduce part count, number of welds and number of operations. By doing so, production advantages such as shorter production time, higher management efficiency and greater customer satisfaction are achieved. In this paper, the effectiveness of the DFMA method was shown in vehicle door design. Two vehicle door designs were taken apart to investigate the feasibility of better designs using the Boothroyd and Dewhurst analysis. It employed quantitative analysis of various parts of the design, such as door frame, door board and screws. Each part of the design was rated with a numerical value depending on its assembly requirements. The product was then redesigned, using the numerical values as a goal to be minimised. Various factors concerning assembly were considered, such as symmetry and size of part. The outcome was designs that have shorter assembly time and assembly efficiency higher than 15%.

Keywords: *Assembly efficiency; automotive; design for manufacturing and assembly (DFMA); DFMA index; vehicle door design.*

1. INTRODUCTION

Ground automotive vehicles have been in use in many areas of our lives. In defence applications, vehicles are used to either transport troops to strategic locations or, with the ones equipped with weapons, for combat. They are designed in a variety of constructions and the lightweight ones are known by names such as military vehicle, utility vehicle, fighting vehicle, etc., and historically, originated from commercial civilian vehicles (Military-Today, 2021). Their modifications can still be found today, especially for fixing weapons and grafting armour. It is not unusual to note Toyota Hilux pickup trucks or Chevrolet Camaro cars to have been redesigned as military vehicles (Petrány, 2014).

When it comes to modifying a vehicle's design, one has to consider the body to be the biggest concern in terms of impact, time, cost and customer satisfaction. In terms of impact, the body is the part of a vehicle that has the most outstanding feature throughout a vehicle (Genta *et al*., 2014). Many vehicle designs begin with a layout of the vehicle's body. Models are often redesigned with completely new bodies. The vehicle body manufacturing always demand much time and stays on the critical vehicle development path. This is true as installing other parts to the body require much systematic approach to ensure efficient production. Related tooling needs to be developed to ensure production runs according to market demand. Alongside the power train, the cost for the body is one of the most costly vehicle system (Genta *et al.*, 2014). It is always important to consider the increase in cost when new changes are made to the body.

Many companies have turned to design for manufacturing and assembly (DFMA) to improve the design of their products and achieve competitive advantage. The data collected by McDonnell Douglas, an aerospace manufacturing company at St Louis on over 50 case studies revealed that many companies have achieved good results using the DFMA methodology (Herrera, 1997). Some of the results are reduction in manufacturing cycle time, part count reduction, part cost reduction, time-to-market improvements, quality and reliability improvements and reduction in assembly time. The practice, known as the combination of design for assembly (DFA) and design for manufacturing (DFM), had their starts in the late 1970's at the University of Massachusetts (Boothroyd, 1994; Herrera, 1997). Between the two, companies are mostly interested in DFA.

Many have pointed out the advantages of using DFMA. Some recent applications include the application of DFA and DMA in washing machine design, where the authors concluded that the study as achieved an acceptable cost estimation (Annamalai, 2013). Da Silva *et al*. (2013) mentioned that DFMA enabled finding opportunities for improvement as they are applied for electronic voting machine printers. Barbosa & Carvalho (2013), who applied DFMA on aircraft electrical system design, listed the advantages as allowing low cost, high quality and best optimised condition. Yuan *et al*. (2018) mentioned good manufacturability and assemblability when applied in the construction industry. Tasallato *et al*. (2016) demonstrated DFMA application with welding as an independent design module, while Kim *et al*. (2016) applied it in bridge design. In the automotive industry, Suresh *et al*. (2015) studied the environmental impact of a charge alternator pulley designed using DFMA, while Ardayfio *et al*. (1998) applied DFMA in automotive electrical and electronic systems.

This paper focuses the applicability of DFMA to the design of vehicle doors. It begins with a reverse engineering approach to chosen vehicle models and followed by design analysis. The aim is to further simplify the design so that newly recommended designs allow better efficiency in its production, particularly in terms of assembly time and cost reduction.

2. BACKGROUND

2.1 Design for Assembly (DFA)

According to Kuo *et al*., (2001), DFA was pioneered by Boothroyd and Dewhurst. It began with the aim of reducing assembly cost by having the easiest method of assembly. This in turn is achieved by redesigning the parts. They classified the assembly system into three basic types, namely, manual, special-purpose machine and programmable machine assembly. Later on, they wrote a book called *Product Design for Assembly Handbook* that helped designers assign parts of an assembly with ratings based on the part's ease of handling and insertion.

The handbook described how design features may have constraints that slow down assembly, and hence increase production cost. Following this, Kuo *et al*. (2001) reported that other researchers introduced similar methods in rating parts or components to the extent of how easy (or difficult) they are to assemble. Some recent innovative ideas regarding this may be found in Harik & Sahmrani (2010) and Ahmad *et al*. (2018). Their works proved to provide cost reductions in product assembly.

2.2 Design for Manufacturing (DFM)

DFM is related to the process of selecting the appropriate processes for the manufacture of a particular part. This is based on the match between the part attributed to process capabilities. Among the considerations are raw material selection, process selection, modular design, standard component usage, multi-use part development, separate fasteners usage and assembly minimisation (Kirkland ,1988; Kuo *et al*..2001).

DFM has been proven to be able to help companies achieve cost reduction estimation from the early stage of design. The method is known to be applicable in machining parts, injection molds, sheet metal stamping, die cast parts, construction and powder parts (Bogue, 2012; Gao *et al.*, 2020)

2.3 Similar Methods

There are a number of methods those are associated with DFMA. This includes the Lucas DFA methodology, which was adopted in Ahmad *et al*. (2018). In the Lucas DFA methodology, the processes are separated into three stages: (1) Function analysis, (2) Handling analysis, and (3) Fitting analysis. All the processes are carried out throughout the design process in order to identify the most cost-effective approach of the design.

Other well-known methods are the Cyber Cut and the Nippondenso methods (Whitney, 1993; Harik & Sahmrani, 2010). The Cyber Cut method simplifies the design by removing non-essential features of a product. The simplified design then is run through computer numerical control (CNC) machining processes. The Nippondenso method is better known for having sets of designs that are interchangeable. This reduces the need to have extra jigs and fixtures for new products.

3. METHODOLOGY

The study was carried out using a DFMA software based on the Boothroyd and Dewhurst analysis. The software can quickly calculate the costs involved for different materials and manufacturing processes as well as identify areas where the number of parts can be reduced.

Several important rules when evaluating part manual assembly are to:

- Reduce part count and type
- Eliminate necessity for adjustments
- Allow parts to be self-aligned and self-locating
- Ensure adequate access and vision
- Ensure ease of handling when parts are in bulk
- Minimise re-orientation
- Design parts that cannot be incorrectly installed
- Maximise part symmetry or make parts clearly asymmetrical

Several stages are carried out when implementing DFMA and the implementation is represented as in Figure 1 (Boothroyd *et al.*, 2010).

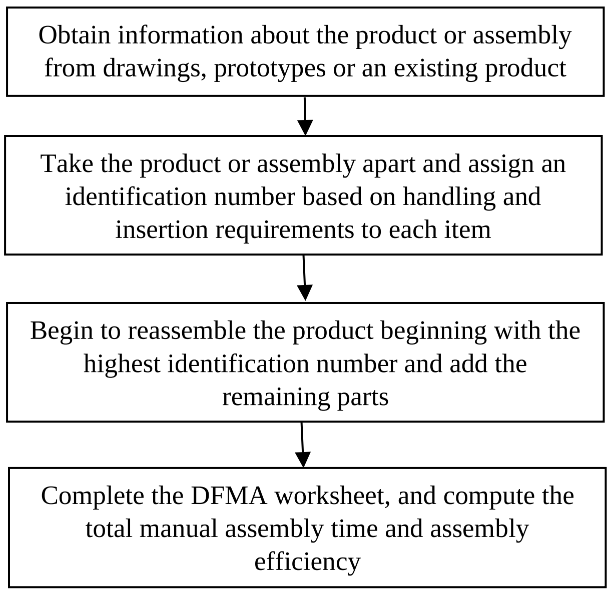

Figure 1: Stages of DFMA application.

In the third stage, when beginning to reassemble the product, at each stage of assembly:

- Rows of the DFMA worksheet is filled for each part respectively.
- Never assume that parts are grasped one in each hand and then assembled together first before placing them in a partially-completed assembly.

The study was focused on manual assembly where, based on Boothroyd *et al*. (2010), it can be divided naturally into two separate areas: (1) Handling (acquiring, orienting and moving the parts), and (2) Insertion and fastening (mating a part to another part or group of parts).

The assembly efficiency, which is known as the DFMA index (E_{ma}), is calculated based on:

$$E_{ma} = 3 \times N_{min} / t_{ma} \quad (1)$$

where:

N_{min} : theoretical minimum number of parts
t_{ma} : total assembly time

4. RESULTS

4.1 Vehicle Door 1

Shown in Figure 2 are two among many components of the first vehicle door that was disassembled and given identification numbers.

Figure 2: Component and one of the screw types of Vehicle Door 1.

Following the disassembly exercise, the components were then counted, given their handling and insertion codes. From their handling and insertion codes, handling and insertion times were calculated and hence, from the sum, assembly time for the parts was obtained. Analysis was done to identify strategies to simplify the design according to the rules provided and so, some parts were able to be eliminated. Table 1 shows the results before and after simplification (part elimination) of the design.

Table 2 shows the overall results of a new design developed after implementation of DFMA. Based on the criteria provided in the Boothroyd and Dewhurst analysis, the theoretical minimum number of parts is set as nine.

Table 1: Before and after simplification of Vehicle Door Design 1.

		Before part elimination		After part elimination	
No.	**Name of Part**	**Quantity**	**Assembly Time (s)**	**Quantity**	**Assembly Time (s)**
1	Door Frame	1	12	1	12
2	Door Board	1	10.10	1	10.10
3	External Door Handle	1	3	1	3
4	Internal Door Handle	1	2.63	1	2.63
5	Automatic Door Lock	1	15.6	1	15.6
6	Window Bar	1	5.34	1	5.34
7	Glass Window	1	11.50	1	11.50
8	Power Window	1	14.60	1	14.60
9	Side Mirror	1	2.63	1	2.63
10	Flat Head Screw	3	21.30	2	14.20
11	Pan Head Screw	3	21.30	2	14.20
12	Round Head Screw 1	6	42.60	4	28.40
13	Round Head Screw 2	6	42.60	4	28.40
14	Round Head Screw 3	1	7.10	1	7.10
15	Oval Head Screw	2	14.20	2	14.20
16	Indented Hexagon Washer Head Screw 1	2	14.20	2	14.20
17	Indented Hexagon Washer Head Screw 2	6	42.60	4	28.40
18	Indented Hexagon Washer Head Screw 3	2	14.20	2	14.20
19	Indented Hexagon Washer Head Screw 4	1	7.10	1	7.10
	Total	41	304.6	33	247.80

Table 2: Comparison of before and after DFMA application on Vehicle Door Design 1.

	Old design	**New design**	**% Change**
Number of parts	41	33	19.50 % reduction
Assembly time (second)	304.60	247.80	18.65 % reduction
Assembly efficiency (%)	9	11	22.2 % increment

By using DFMA, as many as eight parts were identified as suitable to be taken out from the assembly. No component was completely removed but the quantity was reduced. The reductions were as follows:

- Flat head screw from three to two parts
- Pan head screw from three to two parts
- Round head screw 1 from six to four parts
- Round head screw 2 from six to four parts
- Indented hexagon washer head screw 2 from six to four parts.

4.2 Vehicle Door 2

Shown in Figure 3 are two of the components of the second vehicle door that has been disassembled and given identification number.

Figure 3: Component and one of the screw types of Vehicle Door 2.

For this design, 15 different components were identified. Aside from six types of fasteners, the components were the same as Design 1. Table 3 shows the results before and after simplification (part elimination) of the design.

Table 3: Before and after simplification of Vehicle Door Design 2.

		Before part elimination		After part elimination	
No.	**Name of Part**	**Quantity**	**Assembly Time (s)**	**Quantity**	**Assembly Time (s)**
1	Door Frame	1	12	1	12
2	Door Board	1	10.10	1	10.10
3	External Door Handle	1	3	1	3
4	Internal Door Handle	1	2.63	1	2.63
5	Automatic Door Lock Device and Component	1	15.60	1	15.60
6	Window Bar	1	5.34	1	5.34
7	Glass Window	1	11.50	1	11.50
8	Power Window Component	1	14.60	1	14.60
9	Side Mirror	1	2.63	1	2.63
10	Round Head Screw	2	14.20	2	14.20
11	Flat Head Screw	3	21.30	2	14.20
12	Washer Head Screw	3	21.30	2	14.20
13	Indented Hexagon Washer Head Screw 1	8	56.80	5	35.50
14	Indented Hexagon Washer Head Screw 2	2	14.20	2	14.20
15	Indented Hexagon Washer Head Screw 3	1	7.10	1	7.10
	Total	28	194.30	23	176.80

Table 4 shows the result of a new design developed after implementation of DFMA for Vehicle Door 2. The theoretical minimum number of part is set as nine. For this design, only five parts were eliminated. Again, no component was completely removed but the quantity was reduced. The reductions were as follows:

- Flat head screw from three to two parts
- Washer head screw from three to two parts
- Indented hexagon washer head screw 1 from eight to five parts.

Table 4: Comparison of before and after DFMA application on Vehicle Door Design 2.

	Old design	New design	% Change
Number of parts	28	23	17.90 % reduction
Assembly time (second)	194.30	176.80	9 % reduction
Assembly efficiency (%)	13	15	15.4 % increment

5. DISCUSSION

The original assembly time is fairly large. This is because many parts in these case studies require two hands for manipulation. Some are heavy (door frame), some need very precise and careful handling (window glass), while some are large and flexible (door board). These were the initial considerations as assembly time was estimated.

An important factor that affects assembly time in one of the principal geometrical design feature is its symmetry. According to Boothroyd *et al.* (2010), the symmetry factor contributes much to the time required to grasp and orient a part. Assembly usually involves two parts – the part to insert, and the part or assembly to be inserted, also known as receptacle. In discussing symmetry as an important factor, one has to consider the need for orienting the part to the correct position. Orientation may be defined as the alignment of part, e.g., screw relative to the corresponding receptacle. It involves aligning the part to the axis of insertion and rotating it about the axis before insertion may begin. In the cases presented, the factor has been shown to be highly significant, hence fasteners became the primary focus on reduction of assembly time. For Vehicle Door 1, as many as eight fasteners (symmetrical screws) were eliminated, while for Vehicle Door 2, five fasteners were eliminated.

In agreement with Balasubramanian (2002), who discussed the development of a drug-delivery device, and also mentioned in Boothroyd *et al.* (2010), two other major factors in the current study that affect the time in manual assembly are the thickness and size of the part. The two cases presented involve a variety of fastener sizes. Time was reduced as some of these were able to be removed, especially some big ones. In bulk production, minor savings like this will greatly improve production efficiency. Even though the margin of assembly time difference between the old and new design is not much, simplifying the product by combining and eliminating parts is known to have great impact on reducing assembly time. From the case studies, the analysis has proven that these approaches are feasible and may improve the assembly processes. The quantity of fasteners may be considered to be reduced.

6. CONCLUSION

The study showed that, by applying DFMA, further improvement may be made to vehicle door designs. Fundamentally, areas that permit further improvement are parts that are symmetrical and small, such as fasteners. A calculated, increments of 22.2 and 15.4 % efficiency may be achieved if the new designs are adopted the two vehicle doors. DFMA has been shown to have another area for design improvement towards concurrent engineering, particularly in automotive industry, for a wide range of transportation requirements in many fields.

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