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Design of a Portable Carrier System for Transporting Basic Household Utilities in Hatchback Family Cars

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ABSTRACT

The passenger seat in hatchback vehicles is sometimes adjusted to create more space for cargo and passengers oftentimes stretch uncomfortably in attempt to load and offload heavy cargo. This paper is focused on designing a portable carrier system to minimise passenger's efforts while conveying heavy loads to desired destinations. Quality Function Design (QFD) method was used to analyse four conceptual designs in terms of safety, function, interaction, cost and ergonomics and the second concept was selected as the final design due to its potentials compared to the third and fourth concepts which were used in the design analysis. CATIA software was used to carry out stress analysis using a force of 10KN equivalent to about 1000Kg and the maximum stress was about 80MPa, with stress concentrations around the edges where the framework is vertically attached to the surface plate. Also, the final design efficiency was about 80% which therefore implies that the design is optimal. Incorporated in the final design is also a roller at the base of the carrier for ease of mobility and manoeuvrability.

Keywords: Design, Hatchback, Carrier, Cargo space, Minimal effort, Transportation

INTRODUCTION

Hatchback cars are defined generally as cars having passenger cabin with an integrated cargo space. The vehicles are commonly provided with two rows of seating space. The rear seat space however, can be folded away in a bid to increase cargo space. The car is provided with a rear door to provide easy access to the cargo compartment. Figure 1 shows pictorial views of hatchback family cars, while Fig 2 represents carrier designs anchored unto rear axle of hatchback family cars. The limited space in hatchback family cars however prevents some basic facilities like Electric Mobility Scooters, Bicycles, trollies etc. of intending long distance travellers from being conveyed to their destination, as this inconveniences passengers and can as well incur additional cost. Considering the limited cargo space in hatchback family cars as shown in Fig 3, this necessitated the need for alternative means of transporting basic household utilities to cushion the effects on passengers seated on the passenger's space of the hatchback. This paper will therefore focus on developing a carrier system that can ensure little or no effort from passenger while conveying basic household utilities such as electric mobility scooters in hatchback passenger cars to various destinations.

Fig. 1 A Typical Hatch back Vehicles [8]

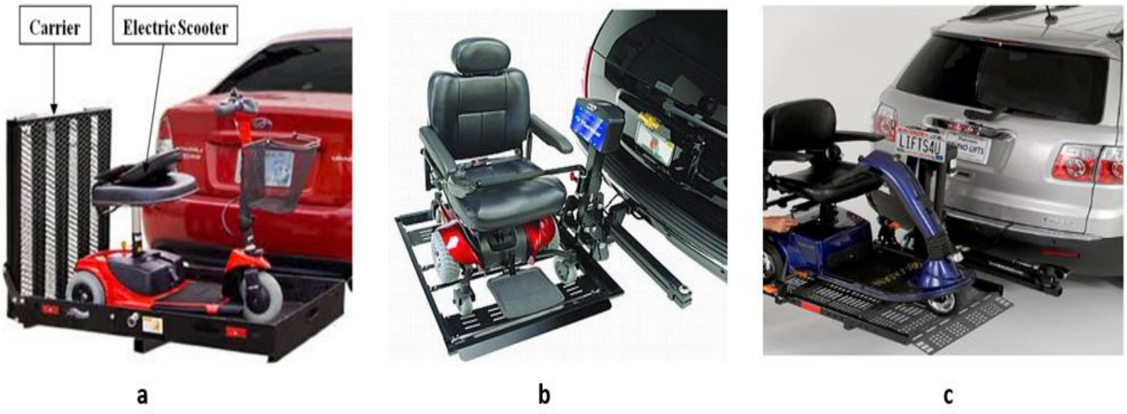


Fig. 2 Existing carrier Designs for Hatchback Passenger vehicle

Fig. 3 Typical Hatchback Passenger vehicle with Limited Storage Space [2]

Over the years, electric mobility scooters have found their ways into the market as a means of helping people minimize stress in their daily activities. The electric mobility products have been used widely for differing needs, and they are built to the highest standards in some of the world's leading specialist manufacturing facilities. Due to the weight of the scooters, many users have developed trouble with the transportation of basic utilities such as electric mobility products in the boot of hatchback passenger vehicles [1, 3, 10, 11].

To solve the problem of storage and removal of an unoccupied electric mobility scooter into the boot of a hatchback passenger vehicle which is oftentimes very narrow with limited storage space as shown in Fig 3, an innovative system that will require minimal physical interaction of the user with the process and the storage system.

METHODOLOGY

A Function Analysis System Technique (FAST) diagram was created to help in identifying the functional design requirements as well as to ensure that design criteria are met as much as possible. Figure 4 shows a FAST diagram used to analyse the design of an innovative system to facilitate storage and removal of an unoccupied electric mobility scooter into the boot of a hatchback passenger vehicle. The important function of the design is to ensure that the scooter is moved in and out of the hatch back with minimum involvement by the operator. With this design, it is expected that families will be able to load and offload their electric mobility scooter without stress. To determine the various customer requirements, a Quality Function Deployment (QFD) analysis of the innovative system to facilitate storage and removal of an unoccupied electric mobility scooter into the boot of a hatchback passenger vehicle was carried out as shown in Fig 5. The diagram was created to enable a better understanding of the basic requirements of the design from the customer's perspective. The important customer requirement as well as the functional design requirements are researched and compared in the diagram shown in Fig 5. The QFD Analysis showed the major functional requirement of the design to be its ability to move the unoccupied electric mobility scooter into and from the boot of a hatchback passenger vehicle with minimal human involvement. With this design, it is expected that families will be able to load and offload their electric mobility scooter without stress.

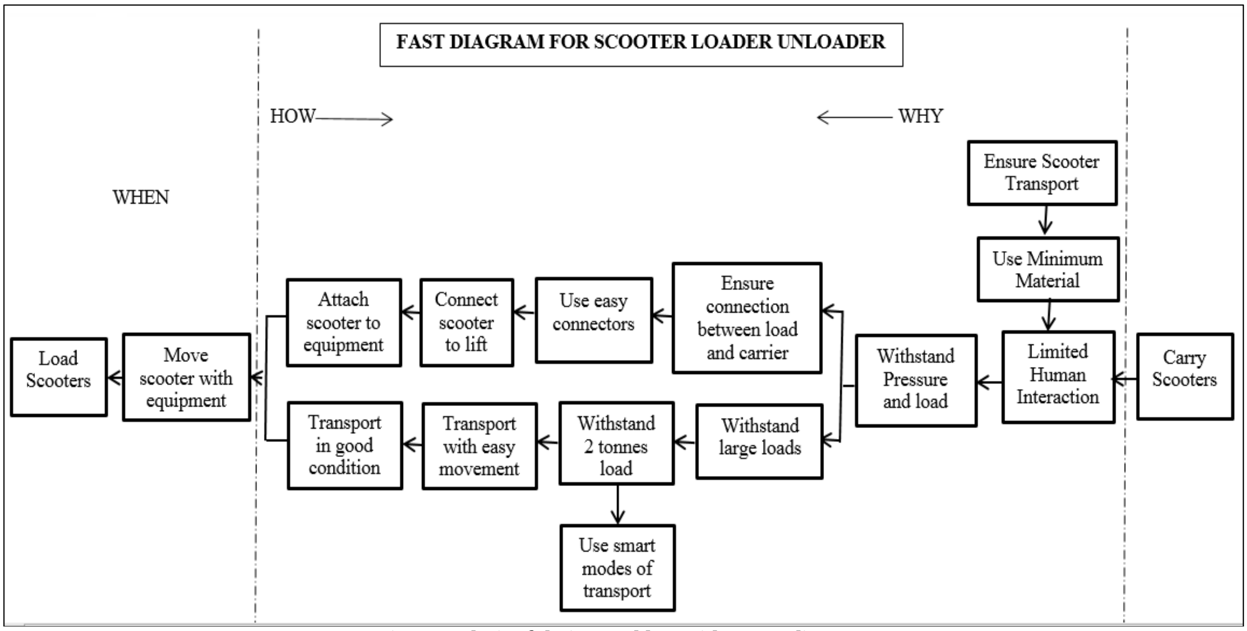
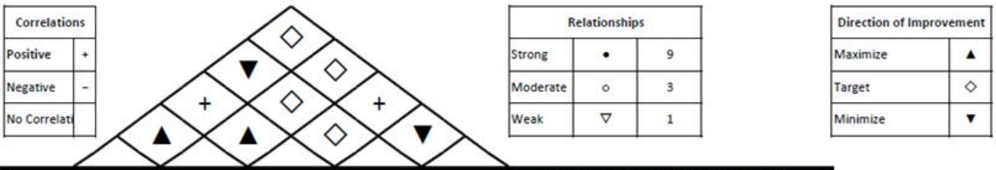


Fig. 4 Analysis of design problem with FAST diagram

QFD Analysis



Direction of Improvement							Customer Competitive Assesment				
Functional Requirements / Customer Requirements	Weighting (1-5)	Ergonomics	Safety	Function	Cost	Interaction	Our Product 'X' 1	2	Comp A 'A' 3	4	Comp B 'B' 5
Cheap Material	2	1	1	1	9	1					
Weight	1	1	3	9	9	3					
Design Load	5	1	3	9	1	3					
Fit Car Hatch back	4	1	1	9	1	1					
Moveable	3	1	1	9	1	9					
Target											
Unit		15	27	##	39	51					
Absolute Importance rating		15	27	119	39	51					
Relative Importance rating		6	10.8	47.4	20.3	15.5					

Fig. 5 QFD Analysis of the functional requirements of the unoccupied electric mobility scooter

Functional Requirement

There are varied international standards that relate to the design of equipment for load carriage. International Standard ISO 8686-4:2005 'Cranes Design principles for loads and load Combinations-Part 4: Jib cranes' relates design concepts as declared in ISO 8686-1 to jib crane designs. The jib cranes in this regard are those cranes other than those contained in ISO 8686-1 [9]. This includes gantry cranes, offshore cranes, mobile cranes, tower cranes as well as overhead cranes as described in ISO 4306-1. ISO 8686-4:2005 however described to detail the loads and load combinations desirable in proof-of-competence calculations for the steel structures of jib cranes. ISO 12482:2014 is another standard that relates to the design of carriage and it majorly has to do with the detailed presentation of the monitoring mechanism for accommodating basic utilities over long working hours [4, 9]. The standard also compares the performance of the crane during long operating period to the original design specification which is often provided after relevant and appropriate classification procedure has been carried out on the product. This standard may be highly unnecessary for consideration in this exercise because the design is not expected to work over a long range of hours as the major function of the product in this report is to assist users in loading and offloading family hatchback cars. Another related standard is 4301-1 [4, 9]. If the design limit of a carriage is reached or approached, there may be increased possibility of unforeseen failure of the component [5, 6]. It is therefore, a standard practice that the allowable load for any carriage device be 75% of its maximum capacity. Since the equipment is expected to carry 150kg of load it is then expected that the actual capacity of the product be around 200kg. This will ensure that the 75% criterion is met. Depending on the style of the design, the product may experience any of tensile, shear or longitudinal stresses. The bending load in any of the design ideas may produce bending moment in the members of the product, therefore, resistance to shear strength must be very high [7]. To ascertain the level of stress that the product may undergo in its service condition, static analysis of the worst case scenario will be considered. A design that can withstand the total weight must be produced to avoid failure under loading. The major source of stress is the weight of the unoccupied electric mobility scooter. The weight of the members of the design may also add to the stress level as the case may be. The design must ensure that the product remains within its elastic limit under the weight of the unoccupied electric mobility scooter. The various deflections of the members of the design must be minimal. Stiffness of the members must be ensured to resist the lateral load that the weight of the unoccupied electric mobility scooter will produce.

Product Design Specification

Client:	Low Budget Family
Designers:	Ikpe, Owunna & Satope

Design Requirement

- It is required that a weight handling device that can help in transporting basic house utilities such as unoccupied electric mobility scooter in hatchback vehicle be designed.
- The design should allow for the safety of the user throughout the duration of the process.
- The design should be innovative and borne out of the need for a solution that requires little or no interaction by the operator throughout the whole process.
- The level of physical interaction of the user is an important design factor.

Design Statement

Designing a weight handling device that can manage the loading and offloading of an unoccupied electric mobility scooter into a cargo space with minimal interaction by human operator for use in a modest income family.

Design Constraints

- The cost of the product is of high importance as the family is of low budget.
- The capacity of the weight handling device must be 200kg minimum.
- The final design must be made from a readily available material with relatively cheap handling cost.
- Efficiency of the final design must not be less than 70%.
- Maximum stress for the final design must not be above 85MPa if a force of 10KN (1000Kg) is applied on it.

INNOVATIONS

There are many routes to solving the problem at hand. The easiest will be a carrier that can allow the unoccupied electric mobility scooter to roll over it comfortably. This is represented in the first concept shown in Fig 6. The design in Fig 6, can be made of aluminium or steel. It consists of a steel plate of 3mm thickness and hollow pipes that can be welded and braced to improve rigidity. The 3mm plate serves as the path that carries the unoccupied electric mobility scooter from the floor to the cargo space level, with a landing that allows the unoccupied electric mobility scooter to roll into the car. To improve the ability and ease of movement of the wedge, rollers are provided at its base such that the movement of the wedge is made comfortably possible unlike existing carrier designs as shown earlier in Fig 2. This is shown in Fig 7, as the second concept. A completely different approach is the light weight crane that can be used to carry the unoccupied electric mobility scooter by using a hook. A rough sketch is shown in Fig 8 as the third idea. The tires of the crane can be made completely of metal. The fourth concept is a different form of crane that has its carriage axis adjustable. This implies that the carrier teeth can be lowered or raised to give a clearance between the car body and the unoccupied electric mobility scooter for easy movement without causing a drag along the cargo body seat. The first design concept takes on an evenly distributed load which is equal to the weight of the unoccupied electric mobility scooter. The second design also takes an evenly distributed load on the face of the metallic plate that is equivalent to the weight of the unoccupied electric mobility scooter. A simple finite element analysis was used to determine the maximum capacity of the various designs selecting the highest load upon which the material will exceed its yield point as the maximum load of the designs.

Conceptual Designs

The following design concepts as shown in Fig. 6, 7. 8, 9 and 10 have been considered in relation to the inconveniences undergone by passengers dealing with carrying heavy cargos into hatchback vehicles and offloading them at dispatch points. Also, Table 1, 2, 3 and 4 represents the Decision Matrices, Design Constrains, Selection Concepts and Concepts Selection Chart respectively.

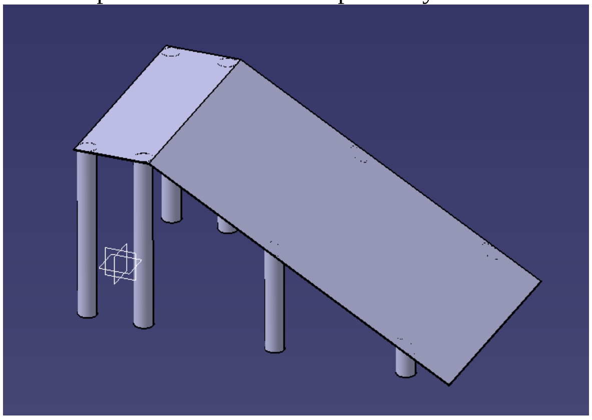


Fig. 6 First Innovation

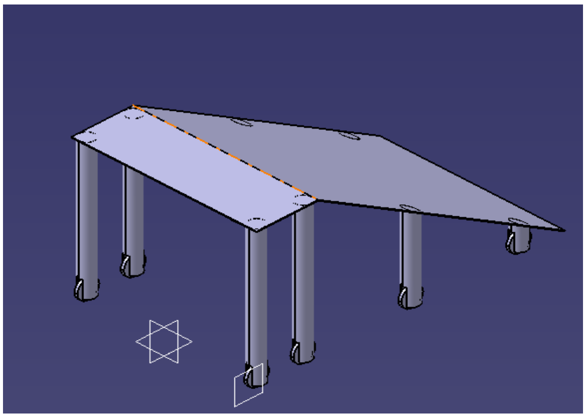


Fig. 7 Second Innovation

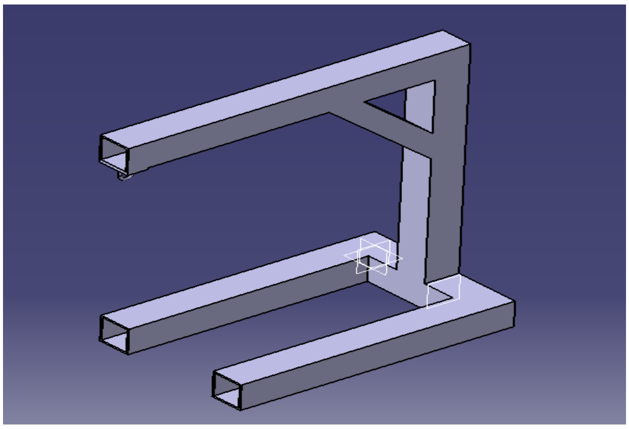


Fig. 8 Third Innovation

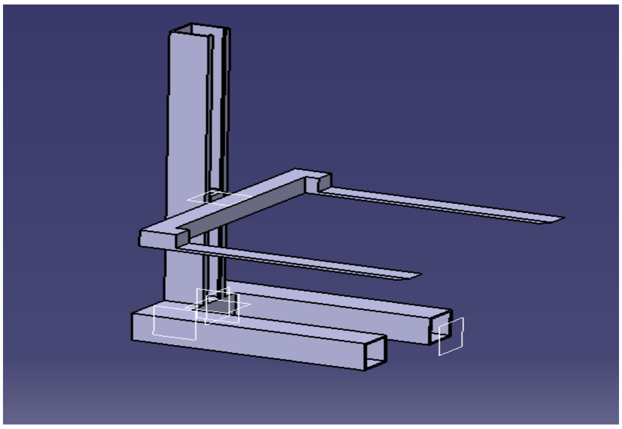


Fig. 9 Fourth Innovation

Fig. 10 Fifth Innovation

Table -1 Selection Concepts

Concept	Material	Estimated Weight	Total Capacity	Mobility
Idea 1	Steel	25kg	9 tonnes	No Wheels
	Aluminium	9 kg	4 tonnes	
Idea 2	Steel	29 kg	13 tonnes	Wheeled
	Aluminium	10 kg	10 tonnes	
Idea 3	Steel	9 kg	0.6 tonnes	No Wheeled
	Aluminium	4 kg	0.2 tonnes	
Idea 4	Steel	8 kg	0.2 tonnes	No Wheeled
	Aluminium	3 kg	0.1 tonne	

Table -2 Design Constrains

Constrains	Fit Car Hatch back	Cheap Material	Moveable	Cost	Design Load	Judgement
Idea 1	Yes	Yes	No	Yes	Yes	Not good
Idea 2	Yes	Yes	Yes	Yes	Yes	Ok
Idea 3	Yes	Yes	Yes	Yes	Yes	Ok
Idea 4	Yes	Yes	Yes	Yes	Yes	Ok

Table -3 Decision Matrices

Functional Requirement											
Scale	1:2	1:3	1:4	1:5	2:3	2:4	2:5	3:4	3:5	4:5	Score
Ergonomics	0	0	1	0							1
Safety	1				1	1	0				3
Function		1			0			1	1		3
Cost			0			0		0		1	1
Interaction				1			1		0	0	2

Table -4 Concepts Selection Chart

Functional Requirement		Concept 2		Concept 3		Concept 4	
	Wt.	Rate	Weighted	Rate	Weighted	Rate	Weighted
Safety	5	8	40	7	35	8	40
Function	5	9	45	10	50	9	35
Interaction	4	8	40	5	40	6	24
Cost	2	8	16	4	8	3	6
Ergonomics	2	5	10	8	16	7	14
Total		151		149		119	

From the concept selection chart present in Table 4, the second design concept is therefore selected due to the ratings and impact it has over the third and fourth design concept.

FORCE AND STRESS ANALYSIS

By running a finite element analysis, the stress condition of the design can be ascertained to ensure that the design will not pass its yield point under loading. To estimate this, the design is constrained at the wheel and a 10kN force is positioned on the top plate as shown in Fig 11. The material used for the analysis is aluminium which means the stress in the plate should not exceed 95MPa which is the yield stress of aluminium.

Using CATIA software for the stress analysis, it can be observed that the maximum stress in the design after applying a load of 10kN (1000kg) is about 80MPa as shown in Fig 12. It can therefore be concluded that the design is fit for use in the unoccupied electric mobility scooter. Moreover, Fig 13, 14 and 15 present parts design for the rollers, stand and the top plate respectively.

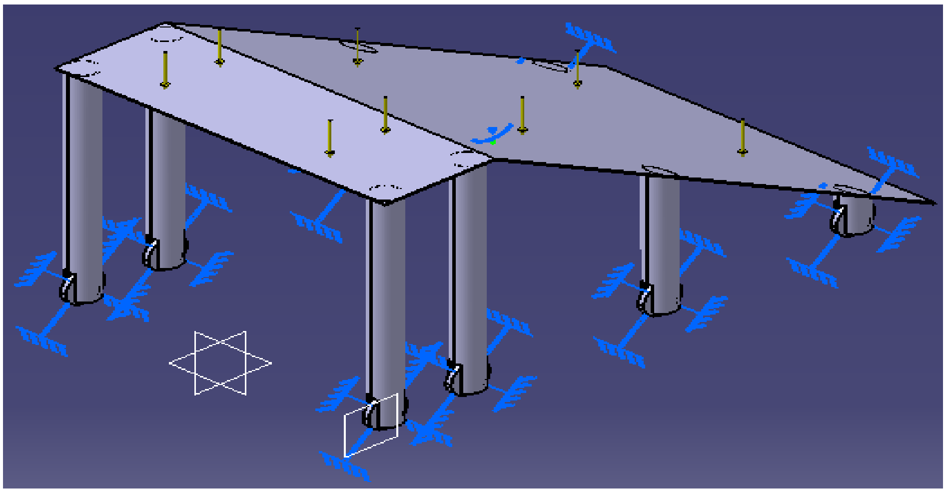


Fig. 11 Finite element setup for the final design

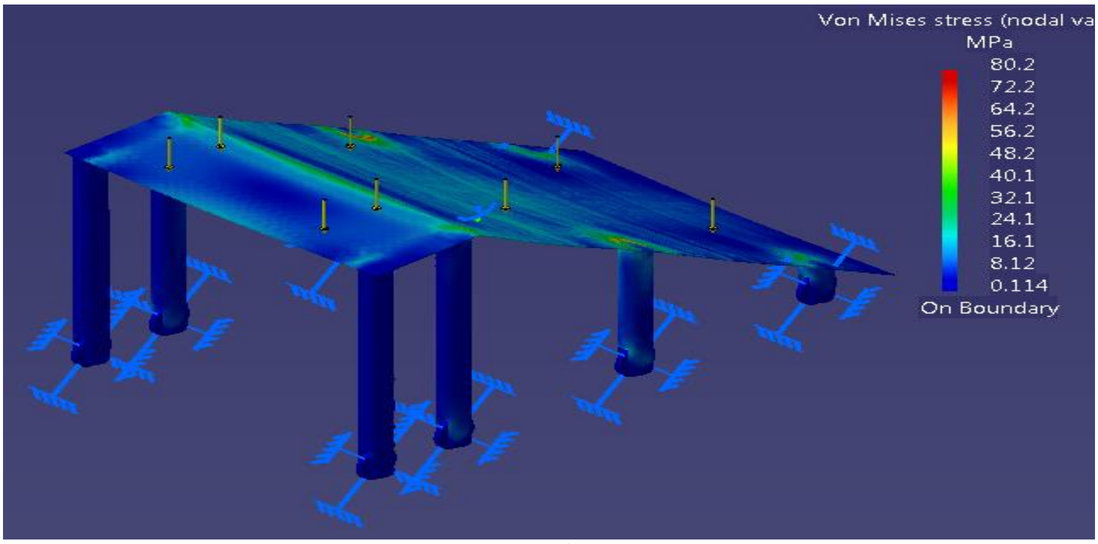


Fig. 12 Stress Analysis for the Final Design

DESIGN FOR MANUFACTURABILITY (DFM)

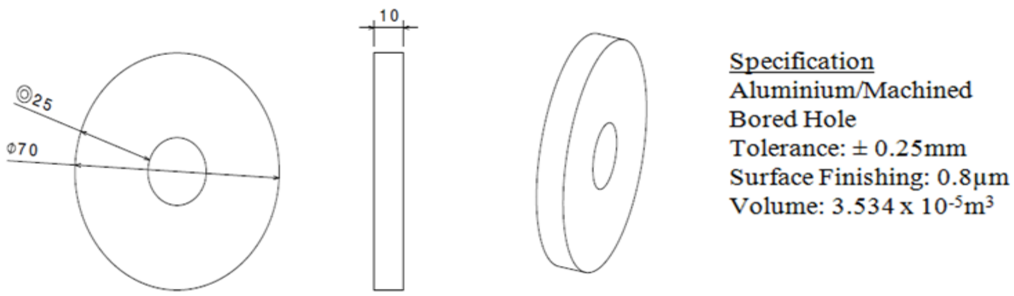


Fig. 13 Design Specification for the Rollers

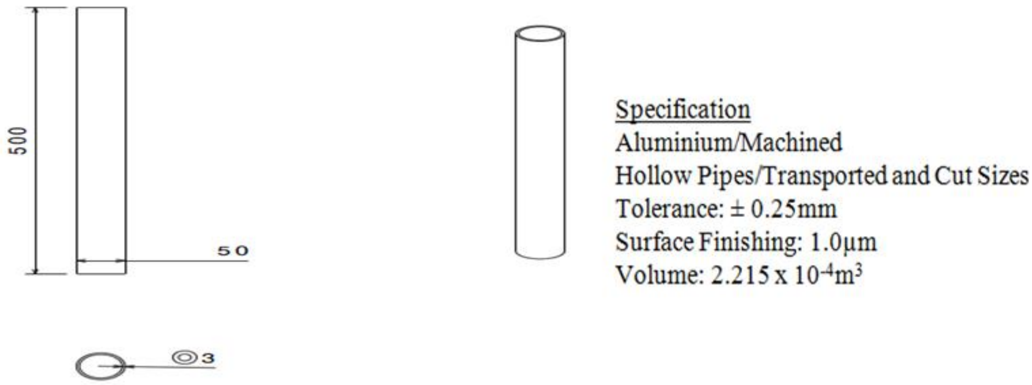


Fig. 14 Design Specification for the Stand

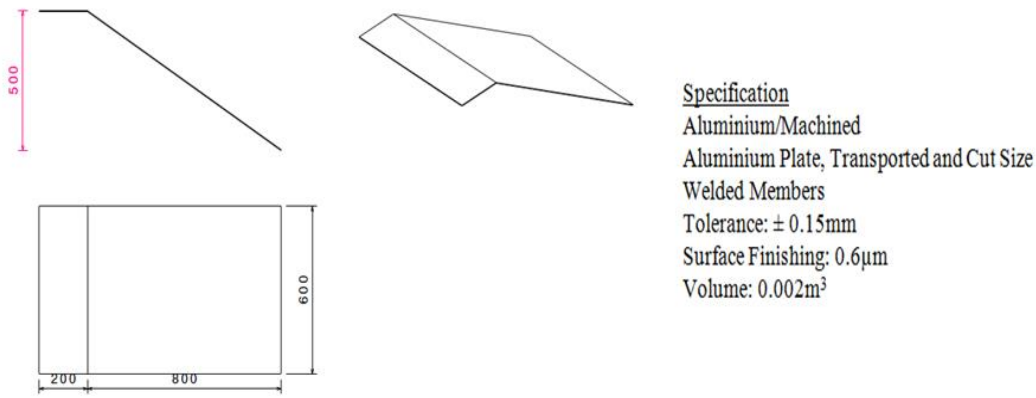


Fig. 15 Design Specification for the Top Plate

Design for Assembly (DFA)

The assembly of this product is relatively easy. There are 5 major parts namely:

(1) The top plate (2) The stands (3) The wheels (4) The braces and (5) and the wheel shafts

The assembly is basically welded. After manufacturing all the parts as shown in Table 5, the stand braces are connected to the stands at its edge and welded to the stands. The braces carry the top plate hence the top plate can then be welded to the braces. The wheel shaft is inserted into the wheels and then welded to the stands to ensure rigidity. The major disadvantage of this design is the issue of permanent joints which limit the ability to repair spoilt parts in the design. Since the parts are made of aluminium, TIG welding can be employed in completing the welding procedures. This is however quite costly compared to the common welding types that are relatively cheaper to perform.

Table -5 List of Parts Assembly

Handling Component	A/B	Size and weight A	Handling difficulties B	End to end Orientation C	Rotational orientation D	Manual Handling Index A+B+C+D
Top plate	A	1	0.1	0	0	1.1
Stands	A	1	0.1	0.3	0	1.4
Wheels	A	1	0	0	0.1	1.1
Braces	B	1	0	0	0	1
Wheel shafts	A	1	0	0.1	0.2	1.3

Fitting Component	A/B	A	B	C	D	E	Fitting index A+B+C+D+E	Non – Assy Process	Total
Top plate	A	1	0	0	0	0	1	0	1
Stands	A	1	0.2	1.2	0	1	3.4	0	3.4
Wheels	A	1	0.2	1.2	1.5	1	4.9	0	4.9
Braces	B	1	0.2	0	0	0	1.2	0	1.2
Wheel shafts	A	1	0.2	1.2	1.5	0	3.4	0	3.4

$$\text{Design Efficiency} = \frac{\text{Number of}'\text{A}'\text{Parts}}{\text{Total part count}} = \frac{4}{5} = 0.8 = 80\%$$

CONCLUSION

Different innovative ideas to help load and offload an unoccupied electric mobility scooter into the boot of a hatchback passenger vehicle has been critically analysed. The QFD Analysis showed the major functional requirement of the design to be its ability to move the unoccupied electric mobility scooter in and out of the boot of a hatchback passenger vehicle with minimal human effort. Unlike existing designs, rollers were incorporated into the carrier design to enable its movement to the anchor point located at the rear axle of the hatchback family cars, as well as its mobility alongside the hatchback family car while being driven. The important function of the design was to ensure that basic household utilities is moved in and out of the hatch back with minimum effort by the operator. The selection process showed the second concept to be the most optimal of all the conceptual designs presented in the study. The final design has a design efficiency of 80% and all the design constrains were met.

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