An Integrated Design, Manufacturing and Maintenance Approach to Product Development: A Case Study

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Abstract: Research trends in product development involve integrated approaches taking account of design, manufacturing, assembly, maintenance, and recycling aspects. This paper presents one such approach through a case study involving the design of a battery operated passenger cart. The design of the cart aims to reduce problems associated with carrying heavy luggage and reducing travel time between airport terminals. The use of recyclable and environmentally friendly materials was investigated to ensure that the criterion of Design for Environment was met. Engineering software applications such as AutoCAD® and SolidWorks® were used for both drafting and analysis. Product features, strengths and stability were analysed for compliance with the design specifications, giving the cart the opportunity to be used in similar locations such as hospitals, factories and schools.

Keywords: Maintenance, airport facility, matrix analysis, parametric plot

Introduction

International airport facilities have grown in size as the prevalence of air transport has increased. This has lead to an increased awareness of the needs of travelers for safety,

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convenience and comfort. Small vehicles are used to facilitate the travelers' comfort when moving through the airport. The cost of maintaining a vehicle is a direct function of the maintenance frequency and failure interval for the machine and major components, the time and labor required to complete routine, as well as unscheduled maintenance tasks. According to Buchanan (2002), maintenance cost can be over 60 percent of product related cost.

In order to reduce problems associated with carrying heavy luggage and reducing travel time between terminals, this paper describes an integrated approach to design the battery-operated carts. Product research of the cart included assessing the necessary standards to which the cart must adhere. These standards include operational standards and running conditions, safety codes and licensing agreements, as well as the noise regulations that the cart must adhere to. Similar carts were examined and a matrix analysis was used to determine the necessary features of the cart. This provided insights to new features that could be added to the cart. Parametric plots were also used to help correlate key features and to rate the importance of these features.

The issues of design for ease of maintenance (DFEM) are considered with minimum manufacturing and operating costs. General preventative maintenance of the cart should be done periodically (say, at least every six months) to ensure the comfort and safety of the passengers. The components and subassemblies can be easily accessed and replaced, since the passenger cart was designed using a modular approach. Poke-Yoke "mistake proofing" techniques were used wherever possible, to ensure ease of assembly and disassembly of assemblies. Specific component maintenance includes maintenance of the battery, brakes, seats, motor, differential and any electrical system found on the cart.

Limiting the use of mechanical fasteners to two standard sizes increases the maintainability of the entire cart. Moreover, according to Chen (1999), it is more efficient to reduce waste at the source than to create waste and have to remove it. The use of recyclable and environmentally friendly materials is investigated to ensure that the criterion of Design for Environment is met.

An Integrated Product Design and Development Approach

Research trends in product development involve integrated approaches taking account of design, manufacturing, assembly, maintenance, and recycling aspects. Numerous product design and development tools are cited in the literature to incorporate the needs of customers. Figure 1 depicts an integrated approach in the design and development of the battery-operated cart. The integrated approach primarily stresses the DFEM, in which research on appropriate products, materials and markets is done and analysis is made on generating and evaluating alternative designs. A final design would then be determined with respect to the design criteria, the customers' needs and the ease of maintenance of the cart.

(Insert Figure 1 about here)

Figure 1. An integrated product design and development approach

Design of Battery-Operated Cart

A comprehensive research on materials, products and markets was done to identify the general needs of the customers and the general scope of the cart. This information was useful in determining specific functions of the cart and the range of users. Materials research gave proper insight into both existing and developing materials that could have been used in the designs. Six models of carts products (i.e. EZ TXT and FREEDOM) manufactured by two leading manufacturers, EZ-GO® and Club Car® respectively, were compared with respect to a list of product features and functions (e.g. wheel drive, battery, fender, seatbelts, speed control, brakes, etc). Table 1 shows a summary of findings from a matrix analysis of these models. This analysis allowed specific assemblies and components to be identified and rated according to their importance. A high importance rating would imply that the component or function of the component should be incorporated in all designs.

(Insert Table 1 about here)

Table 1. A matrix analysis of cart products

Parametric plots were used to identify whether a relationship exists between key features within the design of the cart. These relationships can help to evaluate the limits of particular features. It will ensure that the design parameters do not exceed the requirements of the cart. Figure 2 shows an example of a parametric plot that was drawn between load capacity and price. Moreover, quality function deployment (QFD) was used to determine the specific needs of the customers and translate these needs into designs of the product. Figure 3 depicts a house of quality that portrays the needs and the design graphically. Relationships can be determined between different stages of the design and competitors' ratings. These importance ratings were established through the QFD process accordingly.

(Insert Figures 2and 3 about here)

Figure 2. A parametric plot of price versus load capacity

Figure 3. A house of quality for design of battery-operated cart

A failure mode and effect analysis (FMEA) was then done to determine the critical components of the cart. With this analysis each part is given a risk priority number. This number was determined by ranking the part according to risk of failure rating, probability factor, effect of failure rating, and detection rating. With the FMEA specific modes and effects of failure as well as control factors can be easily distinguished. Check lists were also prepared to ensure there was some degree of ease of maintenance.

Development of Design Alternatives

Designs of several relevant assemblies, sub-assemblies and components were examined from related studies (e.g. see Baumeister and Allalone, 1978; Juvinal and Marshek, 2000; Raplee, 1999) during the course of development of the design alternatives for the cart. Engineering software applications such as AutoCAD® and SolidWorks® were used for both drafting and analysis. Alternative designs were considered before selecting the final design. This ensured that the selected design would best meet the requirements of the product design specifications, since the designs would have to be compared to each other.

The comparison also allows for morphing and combining of unique traits from each design, by using tools such as the morphological box.

Alternative Design1

One of the alternative designs will be able to hold four persons including the driver of the passenger cart. Three passengers will be seated in a single, long seat. Safety side rails will be found on either side of the seat and will be allowed to slide backwards to allow the passengers to initially gain access to the seat. The rails will then be locked into a sturdy position when required. The passengers' luggage will be placed to the back of the passengers' seat. Individual sections for each piece of luggage are formed by utilising square section tubing placed horizontally along the depth of the luggage compartment of the cart. These tubings and belts will function to secure the luggage and ensure that they do not topple during motion of the cart. An overhead is incorporated within the design to protect the passengers from environmental elements. This canopy will be made of tarpaulin and can be removed if users desire.

One reason for not choosing this cart was because of the placement of the luggage. This design holds all luggage to the back of the cart and may increase the bending stress and deflection of a simple frame. A more complex frame will therefore be required, increasing the starting cost of the cart. Another reason for not choosing this cart was because of the limited seating arrangement as all three passengers will have to sit on the single, long passengers' seat.

Alternative Design2

The second design of the cart can hold a maximum of five persons including the driver of the cart. The individual driver's seat is made of high-density foam while the two passengers' seats are made of low-density polyethylene. The seats are positioned in such a way to allow the users to have an 18-inch clearance for legroom. All seats are ergonomically designed to ensure that the passengers' ride is comfortable. The back passenger seat however was designed so that it can be used as a luggage carrier if so desired. Maintenance of both seats involves cleaning and oiling and is relatively easy. Figure 4 shows the alternative design that is eventually the preferred design of the battery-operated cart.

(Insert Figure 4 about here)

Figure 4. Preferred design of battery-operated cart

There are a series of locations in which to place the luggage. They can be placed at the back of the cart as well as on the sturdy canopy. This canopy is more like a tray and is made from 1 ½ inch and 1 inch Aluminum (i.e. Al 1060) tubing. This tray can hold a maximum of two large suitcases. A weight of 200 pounds was used in the analysis of the tray with a factor of safety of 4. A high factor of safety is needed as passengers are directly below this tray. Any risk of the tray failing should be avoided to prevent injury to passengers.

The frame of this design can be made of Aluminum I-section beam (Al 1060). This will offer some torsional stability associated with bending stresses and strain. The frame and any other aluminum components (the flooring of the cart) should be coated with a zinc rich paint for protection from corrosion. It must be maintained to ensure a maximum life of the components. The paint can be applied by high performance, air-spraying techniques, which was particularly designed to reduce corrosion attack.

Standard safety components are also incorporated into the design of the passenger cart. Some of these featured include nylon fabric seatbelts for all passengers, mirrors placed at the front-side of the cart and all necessary lights according to International Airport Requirements for airport vehicles. These lights include two headlights and two taillights. Other safety components include gauges found on the dashboard of the cart. A speedometer, odometer and a battery charge gauge is available to allow the driver to be easily and constantly aware of the running conditions of the cart. A pricing meter is also included, as a standard usage cost will not be used. This meter will measure the distance traveled by the passenger and allow rates to be calculated according to the distance traveled. Besides, the motor will be between 30 to 40 HP, having an rpm of 3000. This is used because of the slow speeds that are required for driving regulations. The speed of the cart will range from 15 to 25 miles per hour.

Conclusions

Product design and development tools (such as matrix analysis, parametric plots. FMEA and QFD) have helped to differentiate and prioritise key features of the product. Customary traveling habits were analysed to determine the product design specifications of the cart. These specifications were in relation to the passengers' safety and comfort. The proposed integrated approach provides a practical means to generate a series of alternative designs incorporating each of these specifications. Strength and stability along with other features were analysed for compliance with the product design specifications. Both the ease and cost of maintenance were considered in relation to the life span of each design. Ease of production of the cart was accorded a high priority, giving the cart the opportunity to be used in similar locations such as hospitals, factories and schools. Nevertheless, the preferred design of the battery-operated cart is subject to further test and modifications. Future research would evaluate the applicability of the integrated approach on product design and development.

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References:

Baumeister, T. and Allalone, E. (1978), *Marks' Standard Handbook for Mechanical Engineers,* New York, McGraw-Hill Book Company

Buchanan, J. (2002), "Life cycle management for design and maintenance", *Logtech Monograph Series*, Monograph 1, Version A, pp.1-12.

Chen, K.Z. (1999), "Development of integrated design for disassembly and recycling in concurrent engineering", *Integrated Manufacturing Systems*, Vol.12, No.1, pp.67-79

Juvinal, R.C. and Marshek, K. (2000), *Fundamentals of Machine Component Design*, New York, John Wiley and Sons, Inc.

Raplee, J. (1999), “DFMA to RP, ASAP”; available at: http://www.memagazine.org/backissues/september99/features/dfma/

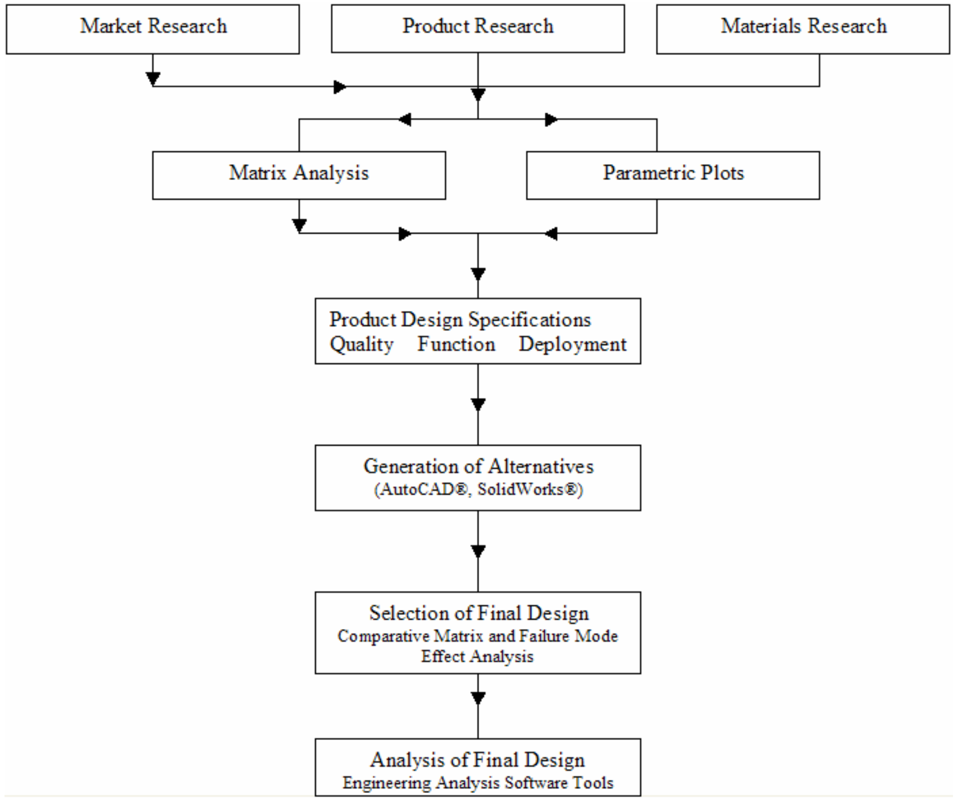

Figure 1. An integrated product design and development approach

Table 1. A matrix analysis of cart products

FEATURES & FUNCTIONS	MANUFACTURERS/MODELS						Percentage Representation
	EZ TXT 2+2	EZ TXT 4	EZ TXT 6	EZ TXT 952	FREEDOM SE	FREEDOM PDS	
Rear Wheel Drive	X	X	X	X	X	X	100
Front Wheel Drive							0
36V Battery	X			X	X		50
48 V Battery		X	X			X	50
Fender	X	X	X	X	X	X	100
Headlight/Taillights	X	X	X	X	X	X	100
Mirrors					X	X	30
Flip Flop Seats							0
Seatbelts	X	X	X	X	X	X	100
Speedometer	X	X	X	X	X	X	100
Speed Control	X	X	X	X	X	X	100
Battery Gauge	X	X	X	X	X	X	100
Pricing Meter							0
Rack/ Pinion Steering	X	X	X	X	X	X	100
Front Suspension							0
H-Shock Absorbers			X		X	X	50
Leaf Springs	X	X	X	X	X	X	100
Rear Suspensions							0
Heavy Duty Leaf Springs					X	X	30
Mechanical Brakes	X				X	X	50
Hydraulic Brakes		X	X	X			50
Automatic Park Brake	X				X	X	50

Keys: EZ TXT are models of EZ-GO® Golf Cart and FREEDOM are models of Club Car® Golf Cart

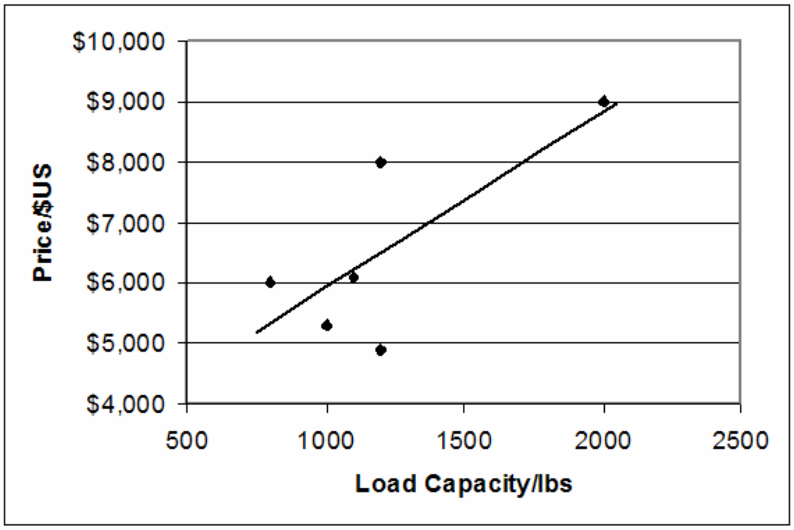

Figure 2. A parametric plot of price versus load capacity

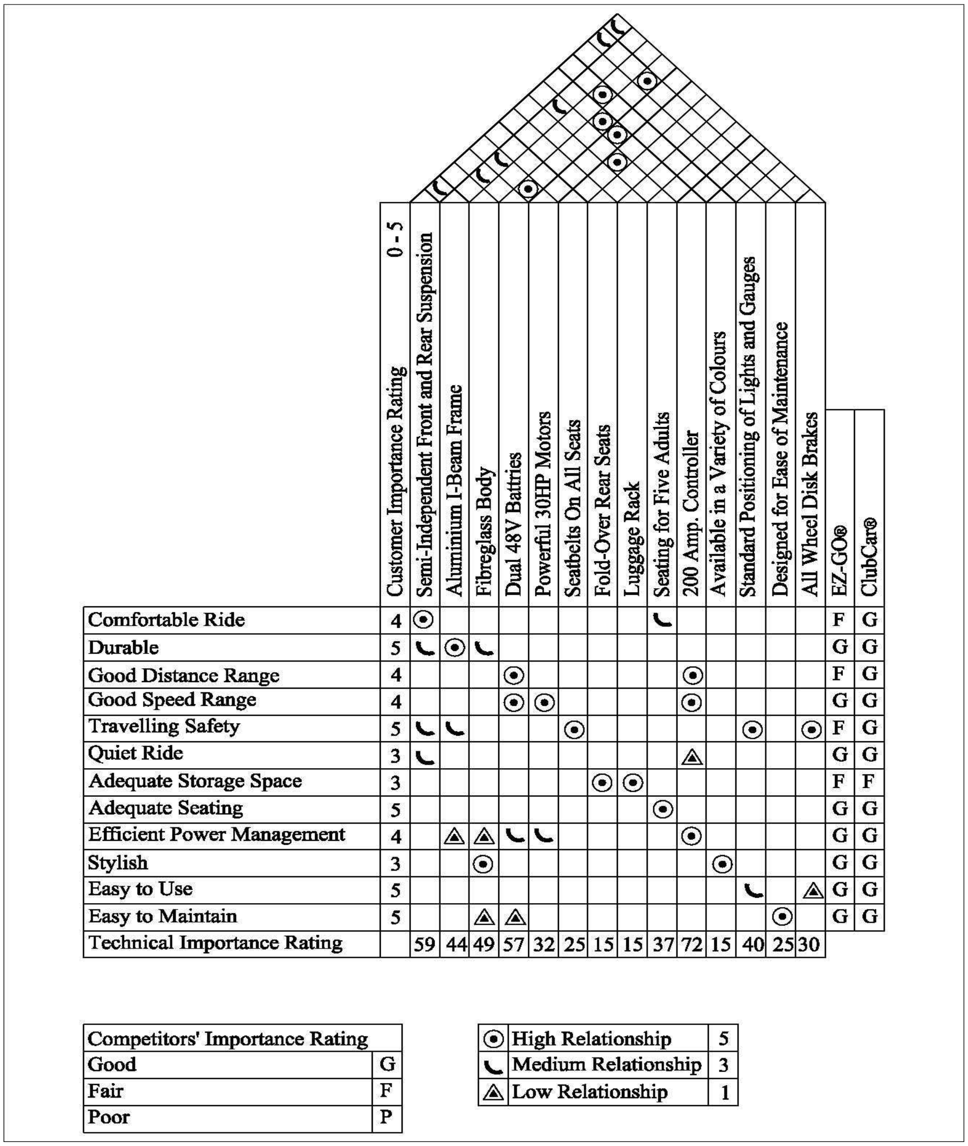

Figure 3. A house of quality for design of battery-operated cart

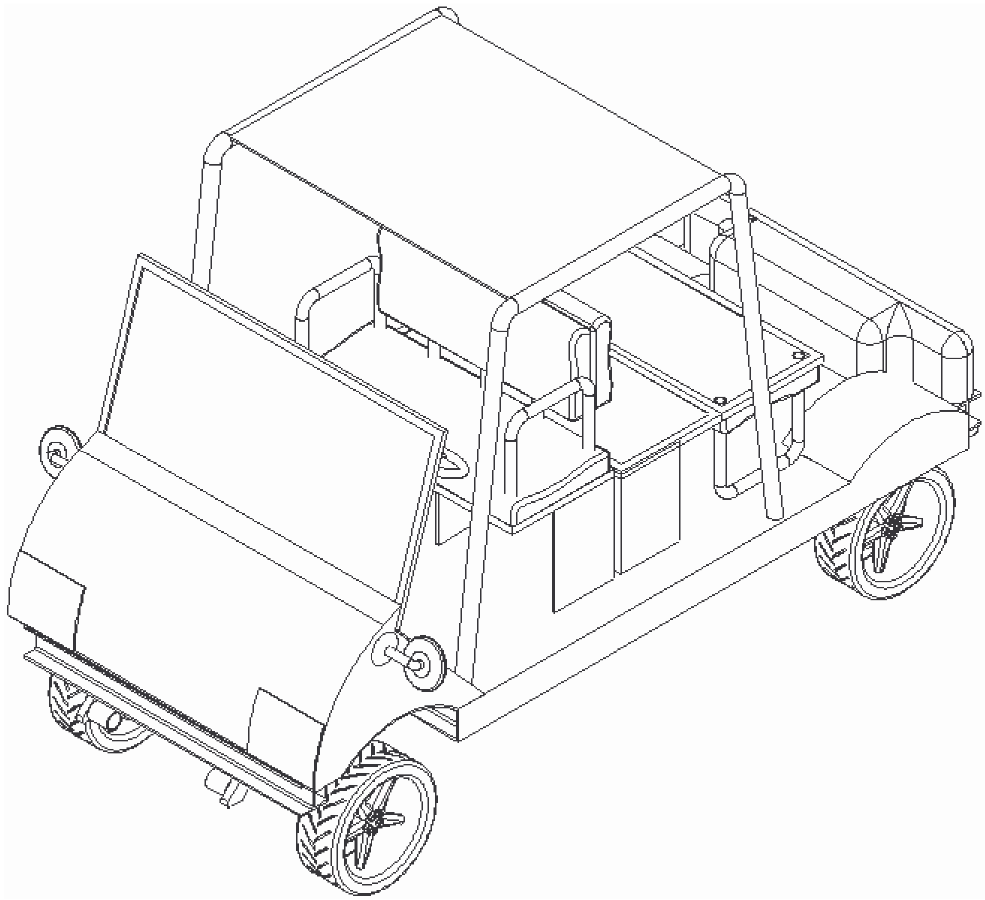

Figure 4. Preferred design of battery-operated cart