Design Criteria for a Wheelchair Integrated Pelvic Restraint Device

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ABSTRACT

This paper describes a systematic way of gathering design requirements in order to design a wheelchair integrated pelvic restraint device for individuals who have upper-extremity impairments relating to strength, range of motion, and dexterity. A study conducted at the University of Pittsburgh to measure the upper body reach, strength and dexterity has provided the fundamental user needs and design criteria, which until now were missing in previous research and literature.

Design criteria or product specifications suggested in this study will result in pelvic restraint design concepts that operate using a single hand, require minimum hand strength and dexterity and are easy to reach by an individual seated in a wheelchair. A design tool, Quality Functional Deployment (QFD), was used to structure and further explore user needs and technical (product) requirements and to weigh the importance of each design criterion.

KEYWORDS: QFD; design; user needs; technical requirements; pelvic restraint device

OBJECTIVE

The objective of this study is to use the QFD method to structure and further explore user needs and technical requirements for a wheelchair integrated pelvic restraint device for use by individuals seated in wheelchairs that have upper-extremity limitations. In addition, to rank most important user needs and technical requirements.

BACKGROUND

People seated in wheelchairs in motor vehicles are protected in crashes and vehicle maneuvers by a two-part safety system. The wheelchair is secured to the vehicle using a four point tie-down or docking system and the wheelchair occupant is restrained to the wheelchair or to the vehicle by a restraint system consisting of a pelvic and shoulder belt [1].

Currently installed vehicle-mounted safety belts are often difficult to use independently and properly because of wide variances in occupant and wheelchair size, and interference of the wheelchair structure with the belt system [2, 3]. Additionally, existing pelvic restraint buckles and latch plate designs are difficult to manipulate and use by people with upper extremity limitations [4]. Non-use or misuse of pelvic restraint systems can result in injury during motor vehicle crashes and even during normal driving situations [5].

To enhance the safety of wheelchair users during motor vehicle transit, the ANSI/RESNA WC19 standard requires wheelchair manufacturers to include anchor points on the wheelchair to allow for an 'onboard' pelvic safety restraint. An impediment to designing safe belt systems that maximize the independence of wheelchair-seated individuals was a lack of data on functional abilities related to seat belt use and belt donning by the wheelchair using population. However, the University of Pittsburgh has recently collected this data[4], the challenge remains in the act of transforming the data into measurable specifications and conceptual designs. This study is taking the first step to transform this research data into design specifications for a wheelchair integrated pelvic restraint device that can also be used as a postural support.

INTRODUCTION

Quality Function Deployment (QFD) is a method to systematically collect and structure user needs and product design requirements and to transform design data into measurable target values needed for product development. QFD was conceived in Japan during the late 1960s when Japanese industry was revolutionizing new product development, quality control, total quality management etc [6]. QFD is the important step between unrefined research data and product solutions and conceptual designs. QFD ensures also that the "voice" of the user is present throughout the design process.

The various phases of the QFD method are illustrated in Table 1. In brief, user needs are collected and translated into technical requirements which in turn are translated into measurable product specifications or so-called "target values". The target values give a quantifiable parameter for use in the product development stage. Figure1 illustrates the graphical representation of the QFD for a wheelchair integrated pelvic restraint device.

After completion of the QFD matrix, creativity is needed when the design team uses the technical requirements in order to create solutions (design concepts). To resolve conflicting product specifications innovative design ideas are needed. Brainstorming and role-play are commonly used techniques to deliver new and innovative ideas [7]. Separate brainstorm sessions can be conducted to obtain solutions for the various technical requirements listed in the QFD.

Generated ideas proceed from conceptual design to engineering design when sufficient product detail is present. Upon compliance with product specifications, concepts are evaluated and eliminated until three or four feasible designs remain. The remaining designs need to be structurally ranked in order to evaluate which design meets the specifications best. Ranking is done by choosing key user needs from the QFD, and rating how the various designs perform with respect to the product specifications.

Thus, the QFD plays a central role throughout the multiple phases of the design process, from conception to product delivery. QFD even plays a key role in client-designer communication.

Figure1. The QFD of a wheelchair integrated pelvic restraint and postural support device.

	TECHNICAL REQUIREMENTS / USER NEEDS	weights	latch in reach zone	restraint length	latch material	restraint material	complies with safety standard	fixed latch position	stowed out of the way	latch size	latch ready	single action latch	reliable components	anchor point position	mechanism weight	readily available tools	prevent pelvic movement (normal	low cost components	restraint esthetics	no sharp edges	latch type	no restraint interference with wc structure	low strength demand	low dexterity demand	manual override	minimum amount of components	no interference with propulsion	latch color	latch strength	restraint strength	Total points:user needs
1	occupant protection	9		9			9						9	9		9	9	5		9		1			9		1		9	9	873
2	low liability	9					9	1				1	9			5	5	5		9			5	5	9		9		5	5	738
2	one handed use	9	5				1	9	1	5	5	9			5						5		9	9		1			5		621
3	easy to disengage	9	9	1	1		5	5		1	5	9									9			9	1						495
4	easy to engage	9	9	1			9	9			9	9									1		9								504
5	dual function postural support	9		5	5	5	9						5	1			1	1	1										5	9	423
6	prevents injury (normal Opr.)	9		1	9	9	1	1		5				1			9			9											405
7	comfortable	5	5	5	9	9	1		5	5	1	5		1			5			9	1		5	5							355
8	emergency egress	5	5	1	1	9	5		5	1			9	1	1	9					5				9				1		310
9	easy to reach	9	9	9			1	5	5		5			1																	315
10	easy to maintain/repair	5			9	9	1	5					5			5		9			5					5					265
11	easy to see	5	5	5				5	1	9	5	5		1					5									9			250
12	doesn't clutter wheelchair	5	5	5				5	9	5				1					5			5					5				225
13	maintain w/c function	5	1	5			1	5	5					5								9					9				200
14	allows transfer from w/c	5	1	1			5	5	9		5			1						5		5									185
15	add-on feature to w/c	5					1		5					9	1	9						1			5		1				160
16	fits all pelvic sizes	5	5	9			1			1				1			9	1				1					1				145
17	fits both genders	5	9	9						1				1	5				9												170
18	washable	5			9	9										1		1										1			105
19	affordable	1			5	5	5						9		1			9	1		1					9					45
20	low added weight	1		1	9	5	5			5					9			1			1										36
		points	420	399	377	376	341	311	285	254	215	206	194	181	174	174	170	168	165	153	148	134	120	120	113	111	98	90	69	59	
			250 mm forward and 750 mm above seat/back point	circumference	Yield strength under impact	Stretch<8% under impact	SAE-J2249 20g/30MPH FMVSS210:3000 lb WC-19 compliant	one way stowe	forward transfer space clear	P5fem-P95male hand size	max 2 components	pull/push/turn/hook motion	ISO9000 standard components	pelvic restraint angle 45deg.	<100g	use of wrench, coin etc. to adjust	<50mm forward and sideways	is Postural support (<$100)	non obstrusive design	< 3mm	turn/pull/push/hook motion	<10mm inward <30mm outward	Push/pull/turn strength P5 female	Usable with 2 fingers	no tools needed during emergency	<8	<30mm outward	custom color option	spring stiffness	FMVSS210:3000 lb	

METHOD

Previous studies show that people with upper extremity impairments have great difficulty using current pelvic restraint devices. Therefore, there is a need for a wheelchair integrated pelvic restraint device that can be operated with a level of comfort, strength, dexterity and ease acceptable to individuals with and without upper extremity impairments. The QFD process was utilized prior to the development phase of this proposed restraint device. A previous study done by the University of Pittsburgh collected user needs related to occupant restraint use by individuals with upper extremity impairments [4]

User needs were translated into technical requirements which in turn were translated into target values. An exhaustive list of users that are involved with this occupant restraint problem was created including users, manufacturers, retailers and designers. The needs of each group of users were identified and put in the QFD matrix. Special attention (higher rating) was given to those needs of people with upper extremity impairments. User needs are listed in Figure 1 in the left column.

One or more technical requirements were then generated based on each user need. Technical requirements are listed in the top row of Figure 1. For example, the user need to "easy disengage" a pelvic restraint device, was translated into the technical requirements "single action latch", "latch within reach", "fixed position of latch" etc (see Figure 1). The technical requirements were then translated into target values, (bottom row in Figure 1). For example, the technical requirement "Complies with safety standards" was translated into the target value "meets WC-19 and SAE requirements".

Relationships between user needs and technical requirements were then mapped. For example, there is a strong relationship between the user need "fits all pelvic sizes" and the technical requirement "restraint length" and "anchor point position". This strong relationship was indicated by placing a number (9) in the user needs row and the technical requirement column. The weight given to a user need in combination with its relationship with a technical requirement provides a value of importance for a target value. Strong relations were allotted with a high value (9), medium relations with a medium value (5), and weak relations with a low value (1) (see Figure1).

RESULTS

Figure 1 shows the user needs, technical requirements, target values and interrelations of a wheelchair integrated pelvic restraint device. Input on user needs was obtained from the following users: Wheelchair user, Caregiver, Designer, Manufacturer and Retailer.

Based on research, design and user input the **key** user needs were: Occupant protection, low liability for manufacturer, one handed use of the pelvic restraint device, easy dis/engagement of the device, dual function as a safety restraint and postural support and, prevents injury (during normal use), comfort and quick emergency egress. The key product requirements were: device within reach zone, restraint length (must be long enough to fit all pelvic sizes), restraint and latch material (must not cause irritation or injury to user and must be strong enough to withstand impact loads), complies with safety standards.

CONCLUSION AND DISCUSSION

The success of the QFD depends on a good definition of the design problem and input from all constituents. Proper allocation of relationships between user needs and technical requirements is also crucial. Whilst QFD may be time consuming at first, for experienced designers it is a method that easily channels data from a problem statement into user centered product development. Furthermore, the QFD acts as the backbone for all design activities, and project teams can return to it at different milestones in the project (e.g. to select design concepts, evaluate prototypes, etc.). Another benefit of the QFD is that it is a good communication tool between users, clients and designers. A lack of communication is more often than not an impediment to successful product development.

Key design requirements of a wheelchair integrated pelvic restraint device have been defined in this study. Future steps include refinement of the QFD matrix by input from constituents on importance ranking, developing conceptual designs based on target values, integrating concepts into wheelchair frames and static and dynamic product testing. A usability study with people having upper extremity limitations will be conducted to evaluate a working prototype. Finally design criteria for an easy to use pelvic restraint device can be implemented in future wheelchair safety standards and to guide restraint system manufacturers developing restraint systems that are easier to use by people with upper extremity limitations.

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Table 1. Outline of the QFD process

Phase 1:
Defining the user More than one user category is normally identified. The end user, manufacturer and retailer are examples of potential users considered.**Phase 2**:
Defining project teams Designers, testers, product planners and marketers are project teams generally involved with product development. Each project team can affect product constraints and design requirements. **Phase 3:**
Defining user needs Identifying the needs of each user group can be done through user surveys, focus groups etc. User needs can be categorized into sections such as safety, comfort, usability and operations.**Phase 4**:
Translating user needs into technical requirements Each user need is translated into one or more technical requirements which are further translated into target values. 'Whats' are translated to 'Hows' and 'Hows' are translated to 'How much'.**Phase 5:**
Assigning weights to user needs User needs are assigned to weights so that design compromises can be made and design conflicts can be resolved by giving one requirement more importance than the other.**Phase 6**:
Defining relationships between user needs and technical requirements User needs are matched to their respective technical requirements by specifying either a strong, medium or weak relationship in the relationship matrix. (See Figure 1).**Summary description:** Table1. lists the 6 steps of the QFD design process. Phase names are listed in the left column and phase descriptions are listed in the corresponding columns on the right.