House of Quality for the all-terrain wheelchair design

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Abstract

The idea of the wheelchair goes back to the 3rd century A.D. when Chinese inventors constructed a wheelbarrow that could carry sick or disabled people over some distance. Since then the design of wheelchairs has dramatically improved and there is extensive research into the development of this product.

Below, a systems engineering approach to redesigning a wheelchair that can negotiate urban obstacles such as kerbs or unmaintained footpaths is considered. To successfully design the product that represents the customer's requirements, systems engineering deploys Conceptual System Design (CSD). CSD uses the House of Quality (HoQ) tool to link customer attributes and engineering requirements and defines the importance for both in the process of design. For the designer, HoQ means identifying conflicting engineering requirements and opportunities for further improvement of the existing product by using customer perceptions. The process employs constant feedback from the customer to ensure the final product represents the desired design.

Background

The HoQ tool is not only used in systems engineering, it is also widely used in other areas such as economics, management and marketing. There is a great deal of written literature on HoQ including how to use the tool. One of many articles, written by a group of Taiwanese scientists, outlines the complexity behind HoQ (Chen, Ko and Tseng, 2013). The article mathematically describes HoQ and suggests different methods to evaluate its elements. The authors give an example of designing a writing instrument and show the reader a step-by-step explanation of the HoQ deployment. The article also considers the topic of group decision making and discusses why it is important to have a group of people to work with the HoQ. The authors argue that it is necessary to form a large Quality Functional Deployment (QFD) group with similar expertise rather than rely upon the traditional way of team communication as QFD maximises information-sharing between group members (Chen, Ko and Tseng, 2013, p.86).

Prasad *et al* (2012) give an example of the role played by HoQ in a business designing the *correct* product for its customers. They highlight the essential importance of prioritising the customer's requirements in the beginning of the process of filling in the HoQ table (Prasad et al., 2012). The case study was conducted on domestic refrigerators and it was found that the systematic ranking of customers' requirements improved their perception of the designed product.

Another interesting case study related to the group's design idea was conducted by the American Department of Rehabilitation Science and Technology (Sawatsky, 2002). The researchers designed wheelchairs with three types of suspension. Wheelchair suspension helps reduce shocks to the spine of the wheelchair user. The experiment was conducted with the assistance of a 21 year old male and lifelong wheelchair user. Three wheelchairs were used in the experiment: one with bicycle spring suspension; one with polymer block suspension; and one without suspension. The experimenters noted that there was a significant increase in consumption of O_2 when using the suspended models. Table 1 shows oxygen use in litres per minute consumed by the chair-user (weighing 62 kilograms).

Chair	Distance (m)	Wt (kg)	O_2 (l/min)
Roc Shox	242	62	0.68
Polymer	300	62	0.72
Rigid	300	62	0.62

Table 1: Oxygen usage of suspension wheelchair

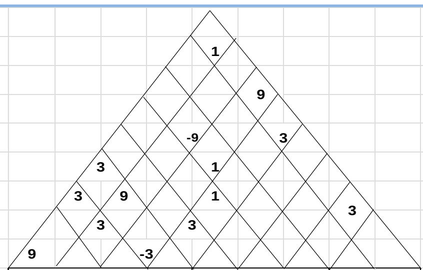
Even though the experiment above was conducted on a small scale the results are very significant for the group's design. The study contributes to the identification of trade-offs such as the additional physical strength required to move a suspended chair and concludes that the use of suspension 'may not be suitable for weak or low endurance clients' (Sawatsky, 2002).

Application of HoQ to the wheelchair design

The HoQ tool was applied to the all-terrain wheelchair design by the group of engineers. The group gathered the customer's needs through online discussion, related case studies, personal experience of bicycle riding in the allocated area and on 25 March 2013 held a meeting with the customer. The major drawback in the collected information was that the group did not have a chance to meet the actual user at the beginning of the design process. Initially the group was told that the customer has a mechanical wheelchair and was given a budget of 500 dollars. However, after meeting the customer, the group got accurate customer requirements and a better understanding of who would be using the product. The customer's requirements did not change much from the initially assumed requirement. The customer did however emphasise to the group the importance of wheelchair-stability. In addition the customer advised that the design should be electric and increased the budget to 15 000 dollars. These additional information needs to be also considered in Table 2. As Table 2 was created based on the initial customer requirements it will be re-filled at the next group meeting.

The customer's requirements were grouped and tabled as Customer Attributes (CA) in HoQ. The pair-wise analysis was performed and highlights the ranking of the customers' needs in the Relative importance column in Table 2. In the group's design, aspects such as the ability to go over obstacles, simplicity of operation, and durability were more important than the designed wheelchair's appearance, size or simple maintenance.

1	Weak relation
3	Medium relation
9	Strong relation
-	negative
+	positive



		CUSTOMER ATTRIBUTES	Relative Importance	PERFORMANCE MEASURES: Dimensions of wheelchair	Weight of the frame	+ Strength of the materials	+ Manoeuvrability	TECHNICAL DETAILS: Reachable push rims	+ Simplicity of the product	- Stiffness of suspension	Number of colours	- Amount per part	1 Poor	3 Acceptable	5 Excellent
NEGOTIATES OBSTACLES	PERFORMANCE	Appropriate size	6				3	3				3	CUSTOMER PERCEPTIONS		
		Appropriate weight	5.5	9			3			1					
		Durable	3	3	3	9				9		9			
		Be all terrain	1	3	9	9	9	3	3	9		1			
	USABILITY	Easily operated	2	1	1		3	9	9						
		Easily maintained	6.5	3				3	9						
		Comfortable	4	3			9	9	3	9		1			
		Appearance	7	3			3	1	9		9				
		Cost	3.5	3		9	3		3	9					
			Units	mm	kg	Pa	Survey	m	no of parts	N/m	no	AUD			

Table 2: HoQ for the design of all-terrain wheelchair

The CAs tell the designer *what* the customer prefers, while the job of the designing team is to translate the customer's statements into engineering requirements. The requirements were then tabulated as Engineering Characteristics (EC) and matched to description in measurable terms, of *how* the team would meet those requirements. The biggest challenge for the design team was to define the *comfort* requirement, since this term could mean different things for different wheelchair users. A compromise was reached in accordance with the SMART goal and was described as a suspension stiffness which could be measured and prototyped. The group's intention was to discuss the definition of *comfort* with the customer.

The CAs and ECs were evaluated against each other using the Pair Wise Analysis and recorded in the *Planning Matrix* in Table 2. This part of the HoQ shows to the design team how much the ECs affect the customer's requirements. It is an important reference for the future evaluation of the product against competitors' wheelchairs. If the designed chair needs to be improved on some particular feature listed in Table 2, engineers will be able to do it efficiently by using the documented interrelationship within the wheelchair system.

In filling in the 'roof of the house' the team also saw strong interconnectivity between many of the ECs which gave an idea of dynamics of the wheelchair system. For example, change in dimensions of the wheelchair will affect parameters such as weight of the frame, chair manoeuvrability, strength of material for the frame and overall cost of the product. These relationships were positively weighted since the group was not planning to increase chair size, therefore the strength of the chair frame and the cost associated with frame replacement did not affect the design. Another important factor seen in Table 2 at the 'roof' matrix is a trade-off in which achieving one EC leads to the impossibility of achieving another EC. The group identified two such trade-off pairs: strength of materials (particularly of the frame) against chair manoeuvrability, and weight of the chair against stiffness of suspension.

To design a lightweight chair that is easy to operate and which can surmount obstacles, light materials need to be chosen for its frame. Aluminium is the lightest and relatively cheap material that could be used. One drawback of aluminium is that it is very brittle with minimal bending. Use of aluminium in wheelchairs is not recommended by the American National Standards Institute and the Rehabilitation Engineering and Assistive Technology Society of North America

(ANSI&RESNA, 2013). Using durable materials such as titanium, steel or chrome alloy is preferred despite the fact that they will increase weight considerably.

Another trade-off is the group's decision on whether to fit suspension into the wheelchair. The introduction the suspension will lead to an increase in wheelchair weight. Depending on the overall weight of the chair with fitted suspension there is the possibility of reconsidering the material that is used for the frame of the wheelchair. In designing a mechanically operated wheelchair the fitness level of the potential user should also be taken into account, as indicated by Sawatsky (2002).

In completing the HoQ, the team clearly saw the limitations and areas of potential manipulation of the system. As the next step, the team is planning to consult with the customer on HoQ analysis and to implement any changes requested.

Conclusion

The process of filling the HoQ template revealed the interrelations between CAs and ECs. The group recognised the priorities in customer requirements and set the goal to achieve them in accordance with their ranked importance. In evaluating the ECs, the group identified trade-offs and took them into consideration while researching for possible solutions in the market. The literature review gave a broad understanding of the actual process of building HoQ and the current research and standards relating to wheelchair design.

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