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Prioritizing Sensor Performance Characteristics for Automotive Seat Weight Sensors in Quality Function Deployment (QFD)

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Abstract

Quality function deployment (QFD), a key tool to convert the customer needs into product features, is generally integrated into the New Product Development (NPD) process at the design stage. Prioritizing customer needs in a QFD process leads to using the resources (time, money, and staffing) effectively by eliminating the unimportant customer needs. The overall goal of the research was to develop a textile-based optical fiber sensor for automotive seat occupancy. The findings of this paper were focused on the design of experiments in our previous publication. In this paper, a research study was conducted to better understand market demands in terms of sensor performance characteristics for automotive seat weight sensors, as a part of the QFD House of Quality (HOQ) analysis. A survey was sent to more than 20 companies operating in the field of automotive seat weight sensors, and Original Equipment Manufacturers (OEM) via e-mail. Only five companies participated in this study due to competitive concerns and confidentiality reasons. However, the companies responded to the survey were of quality relevant to the research and could be perceived as representative of the group of experts. All 5 companies participated in the survey agreed on the first 5 most important sensor characteristics: reproducibility, accuracy, selectivity, aging, and resolution, where The Analytic Hierarchy Process (AHP) was applied to prioritize the sensor characteristics.

Keywords: Quality function deployment; Automotive seat weight sensor; House of quality; New product Development; Analytic hierarchy process

Introduction

The concept of Quality Function Deployment (QFD), as an approach to design of new products, was first proposed by Dr. Yoji Akao in 1966 in Japan [1]. The first automotive companies to try QFD were Hino Motors in 1975, Toyota Auto Body in 1977, and the whole Toyota group around 1979 under the consultancy of Dr. Akao [2,3]. The start-up costs of new products from Toyota were reduced by 61 percent in 1984 with respect to 1977 costs, the new product development lead-time was reduced by one third, and the product quality improved to a great extent [4-6]. The success of Toyota accelerated the implementation of QFD to the rest of the world.

QFD can be described as a method that converts customer needs into product features by ensuring quality at each stage of the new product development (NPD) process [4,7,8]. QFD is generally integrated into the NPD process at the design stage [9-11]. A cross-functional team involving members from R&D, manufacturing, engineering, marketing, and production divisions is formed, and a common language is created among team members through QFD [12]. While the first and second generation QFD models include thirty and seventeen matrices respectively, the 'Four-Phase Model', developed by Dr. Makabe, a Japanese reliability engineer, includes four matrices [12-14]. The first phase, often called the 'House of Quality (HOQ)', analyses the relationship between customer needs and engineer-ing characteristics; the second phase includes engineering characteristics and part characteristics; the third phase includes part characteristics and key process operations; the fourth phase includes key process operations and production requirements [9,13,15]. The HOQ is the most frequently employed matrix both in Japan and the USA [13,16]. The sources indicate that a typical HOQ includes six main parts: customer needs, planning matrix, engineering characteristics, relationship matrix, technical correlation matrix, and technical matrix [4,5,13]. The explanations of the parts of the HOQ, with the exception of customer needs of which ex-planation is at the succeeding paragraph, could be found in the textbooks involved [3,13,14].

In order to determine customer needs in general, focus groups, interviews, mail, e-mail and web based surveys are used. E-mail and web-based surveys offer low cost and short response time due to the electronic format of the data by eliminating the geographical distances [17]. The Analytic Hierarchy Process (AHP) developed by Saaty in the 1970s provides a more sufficient ratio-scale importance ranking approach to prioritize the customer needs [18,19]. This is a pairwise comparison process, where customers are asked to compare two customer needs utilizing the evaluation scale of 1-9, which continues until all of the needs are evaluated according to each other [18,20]. The scale of 1 to 9 ranges from equally important to extremely important as follows.

The evaluation scale

- **1 (Equal importance):** Each activity has the **same** impact upon the objective.
- 3 (**Moderate importance**): Experience and judgment **slightly** favor one activity over another.
- **5 (Strong importance)**: Experience and judgment **strongly** favor one activity over another.
- 7 (**Very strong or demonstrated importance**): The activity is strongly or **dominantly** favored.
- **9** (**Extreme importance**): The evidence favoring one activity over another is of the **highest** possible order of affirmation.

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- **2, 4, 6 and 8 (Intermediate values between the two adjacent judgments):** If adjustment is needed.

However, there is the risk of inconsistent judgments with pairwise comparisons [13,18,20]. Therefore, one must look at the consistency ratio [18]:

The consistency ratio (CR) = CI/RI. (1)

RI: Random index that is determined from the table (Table 1).

CI (Consistency Index) = (λ-n)/(n-1). (2)

n: The number of systems being compared.

$\lambda=(\sum_i^n c_i)/n$ (3)

where c_i: Consistency vector (The calculation of consistency vector could be found in the textbooks involved [18,20].

In general, when the consistency ratio is 0.10 or less it means the customers' answers are relatively consistent [18,20,21]. If it is bigger than 0.10 it means the answers of the customers should be reevaluated and the AHP process should be restarted [18,20,21].

The overall goal of the research was to develop a textile-based optical fiber sensor for automotive seat occupancy. The findings of this paper were focused on the design of experiments in our previous publication [22,23].

Survey

A research study was conducted to better understand market demands in terms of sensor performance characteristics for automotive seat weight sensors, as a part of the QFD HOQ analysis. A survey was sent to more than 20 companies operating in the field of automotive seat weight sensors, and Original Equipment Manufacturers (OEM) via e-mail. Only 5 companies completed the survey and most of the companies declined to participate in this study due to competitive concerns and confidentiality reasons. However, the companies responded to the survey were of quality relevant to the research and could be perceived as representative of the group of experts. The director of Electronics, system engineers, and engineering managers who had more than 10 years experiences in the field of engineering including seat weight sensor design, component design and seat design from R&D and seat design departments completed the chart (Figure 1) prepared for the companies. Table 2 shows the companies' positions in the automotive supply chain.

In the automotive business

OEM (Original Equipment Manufacturer): A company that markets the final vehicle (Ford, Audi, etc.)

Tier 1: A company that is a direct supplier to OEM companies.

Tier 2: A company that is a supplier to Tier 1 suppliers. For example, in this study, Tier 2 companies could provide automotive

c	1	2	3	4	5	6	7	8	9	10
Index (R.I.)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 1: Average random consistency index (R.I.) [20].

Customer needs	Sensitivity	Dynamic Range	Accuracy	Hysteresis	Resolution	Response Time	Recovery Time	Reproducibility	Selectivity	Aging
Sensitivity	1									
Dynamic Range		1								
Accuracy			1							
Hysteresis				1						
Resolution					1					
Response Time						1				
Recovery Time							1			
Reproducibility								1		
Selectivity									1	
Aging										1

Figure 1: The chart prepared for the companies to make comparisons.

	Company 1	Company 2	Company 3	Company 4	Company 5
The company's position in the automotive supply chain	Tier 1	Tier 1	OEM	Tier 1	Tier 2

Table 2: The companies' positions in the automotive supply chain.

seat weight sensor technologies to Tier 1 companies that could provide automotive seat systems to OEMs.

Results and Discussion

As sensor attributes can vary depending on the occupant type the companies were asked to specify the occupant type to compare the sensor attributes. The occupant types for the companies were as follows:

Company 1: Rear facing child safety seat with 1-year-old infant.

Company 2: 5th percentile adult female.

Company 3: 50th percentile adult male.

Company 4: For all types.

Company 5: For all types.

The Analytic Hierarchy Process (AHP) was applied to prioritize the sensor attributes. Table 3 shows the normalized values obtained after the AHP process for each company.

The consistency ratios of the companies were 0.22, 0.32, 0.02, 0.02, and 0.29 for the Companies 1-5 respectively.

The consistency ratios of the three companies exceeded the limit (Company 1, Company 2, and Company 5); however, all the companies agreed on the first 5 most important sensor characteristics: reproducibility, accuracy, selectivity, aging, and resolution.

Company 4 indicated that selectivity and aging were the next most important ones after reproducibility and accuracy due to tremendous noise in automotive seating inputs.

Company 2 claimed that differentiating between the 5th percentile adult female and the 3 to 6 year old child was the hardest part of occupancy sensor development. The company signaled that the automotive market has moved away from classification and has now used Seat Belt Reminders (SBRs) acting like a simple on/off switch instead of classification.

According to the Company 1 the most critical seat weight sensor attribute was re-producibility; if a sensor output is not reproducible to a sensor input, it is not a vi-able sensor. The company claimed that automotive seat weight sensors were not used for real-time occupant discrimination and used a generally slower discrimination algorithm to avoid the effects of noise, and accordingly, recovery and response times would not be critical attributes. Furthermore, the company argued that sensor dynamic range should be minimized to provide accurate discrimination at the critical threshold.

Customer needs	Company 1	Company 2	Company 3	Company 4	Company 5
Reproducibility	0.31	0.11	0.22	0.25	0.08
Accuracy	0.16	0.15	0.05	0.25	0.14
Resolution	0.12	0.21	0.02	0.03	0.12
Sensitivity	0.08	0.15	0.02	0.03	0.18
Hysteresis	0.09	0.05	0.05	0.03	0.06
Selectivity	0.07	0.11	0.22	0.13	0.12
Aging	0.07	0.10	0.22	0.13	0.09
Dynamic Range	0.05	0.07	0.11	0.06	0.07
Response Time	0.03	0.02	0.05	0.06	0.05
Recovery Time	0.03	0.02	0.02	0.06	0.08

Table 3: The normalized values obtained after the AHP process for each company.

Company 3 claimed that seat trimming (fabric type, embossing style, sewing etc.) had a direct influence on sensor detecting capability, where sensor design was expected to be compatible with the upholstery. The company signified that the thickness of the lamination foam affected the sensor performance since the weight sensor was placed between the seat cushion and the trimming. Further-more, the company argued that visual appearance was also an important customer need as in some cases a sensor's existence beneath the surface fabric might be noticeable in appearance by the customers.

Conclusion

The idea of Quality Function Deployment (QFD) is principally to translate the customer wants into the engineering characteristics of the product early at the design stage in the new product development process. The success of Toyota in implementing QFD has accelerated the dissemination of it to the rest of the world.

In this paper, a research study was conducted to better understand market demands in terms of sensor performance characteristics for automotive seat weight sensors, as a part of the QFD House of Quality (HOQ) analysis. Only five companies participated in this study due to competitive concerns and confidentiality reasons by a further 15 invited companies. All 5 companies participated in the survey agreed on the first 5 most important sensor characteristics: reproducibility, accuracy, selectivity, aging, and resolution.

The overall goal of the research was to develop a textile-based optical fiber sensor for automotive seat occupancy. The most important characteristics for sensor performance determined in this study: reproducibility, and accuracy, were focused on the design of experiments in our previous publication [22,23].

Meeting customer needs would provide the customer satisfaction, which is the ultimate goal of the companies when developing new products.

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