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QFD as a tool to improve negotiation process, product quality, and market success, in an automotive industry battery components supplier

L. Fonseca[1*], J. Fernandes[2], C. Delgado[3]

1 School of Engineering, Porto Polytechnical Institute and CIDEM R&D, Porto, Portugal
2 School of Economics and Management of the University of Porto, Porto, Portugal
3 LIAAD INESCTEC and School of Economics and Management of the University of Porto, Porto, Portugal

* Corresponding author. Tel.: +00351969028568. *E-mail address*: lmf@isep.ipp.pt

Abstract

The automotive industry faces major megatrends such as climate change and emissions control, digital transformation, and increased customer power, resulting in more intensive competition, and higher sophisticated vehicles. The application of QFD (Quality Function Deployment) can be particularly valuable to link customer expectations with the technical characteristics of the product. In the case of products, such as batteries for electric vehicles, where technology is not yet mature, and the technical requirements (e.g., autonomy) are continuously more demanding, this is particularly relevant. The QFD customer-oriented product development technique is applied to a cover of a battery pack, to improve the negotiation process with the car manufacturer, the automotive industry battery components supplier company and its suppliers, to ensure market success once the product is released. The application of the HoQ revealed that Product Design and Tolerancing are the main technical requirements with the most impact over the battery cover development, followed the Leakage ratio. This research confirms that the voice of the customer could be quite generic, and it is critical that these requirements are translated into engineering requirements, which, in turn, can be translated into items that can be measured quantitatively and actionable within the company. The application of the affinity diagram was found to be quite valuable to address the significant amount of subjective information, and it is also relevant that OEMs have a desire to standardize the electric vehicle platforms at least on fewer and general sizes, hinting the need for more collaborative team approaches.

Keywords: QFD; House of Quality; negotiation process; electric and hybrid vehicles; batteries; case study.

1. Introduction

With more than 96 million vehicles produced worldwide during 2018 [1], the automotive industry demonstrates its importance to the world economy, contributing, just at West Europe, with 140 M€ for the region's gross domestic product.

The automotive industry is confronted with considerable challenges, such as increased competition, more brands, models and sophisticated vehicles, tighter regulatory requirements (e.g., emissions), and the need to manage global supplier networks with shorter development cycles. Moreover, significant megatrends such as electric mobility, digitization, and decarbonization impact the industry [2]. There is an urgent worldwide call to respond to present and future stakeholder needs and ensure a better and sustainable future for all, with a balance of economic, social, and environmental development. The 17 Sustainable Development Goals (SDG) of the United Nations (UN) 2030 Agenda and represent a shared expression of stakeholder needs at a global level balancing economic, social, and environmental development [3]. The SDGs

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specifically call for urgent action to combat climate change and its impacts (SDG13) and for industry, innovation, and infrastructure (SD09), to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.

In response to this challenging global environment, it is widely accepted that, at this moment, electric mobility appears to be at the forefront of solutions with regards to consumer concerns and sensitivity for reducing the carbon footprint [4].

There is a perception that electric mobility is the viable alternative to fossil fuels. There are massive subsidies from countries like China [5], and car manufacturers (OEM) spend large amounts of capital on research and development of energy storage batteries in order to increase their power and autonomy, allowing this option to become a real alternative to fossil fuels.

The importance of research and development of energy accumulation systems in the electric mobility makes this a relevant topic to be addressed to clarify the requirements of a component of the vehicle electrical energy accumulator, also known as a battery pack.

This paper aims to demonstrate the application of QFD as a tool to mutually improve the customer/supplier/company negotiation process, product quality, and market success, in an automotive industry battery components supplier. After the introduction, the literature review is presented in section 2 and the methodology in section 3. After the presentations of the results on section 4, the paper concludes with the discussion and conclusions (section 5), highlighting the contributions and the limitations of this study.

2. Literature Review

As stated before, market awareness indicates that some megatrends are driving vehicle sales, and the automotive digitalization is one of those. Autonomous driving, connectivity, and carsharing took the leadership of digitalization development [6].

The market demand for those characteristics led to the appearance of new OEMs, like Tesla, which is challenging the market of the typical OEMs and gaining market share at high speed. Just Tesla, more than doubled the number of vehicle sales from about 30000 vehicles per quarter in the first quarter of 2018 to about 100000 vehicles per quarter in the third quarter of 2019 [7].

Along with automotive digitalization, the awareness of the need to reduce carbon emissions and put in place environmental sustainability measures led the European Union to define a long-term strategy to achieve carbon neutrality until 2050. Currently, the European Environment Agency [8] forecasts that the transport sector is responsible for 30% of the total CO2 emissions, where the land transport accounts for 72% of that 30 %.

Motivated by the previous megatrends, the OEMs are investing actively in the development of electric vehicles. Those electric vehicles, along with the electric motors, need a battery pack with the capacity to store high energy power charges able to give autonomy to compete with conventional vehicles.

The battery pack, shown in Figure 1, is constituted by several components, like the underbody cover, battery cell, and upper cover, also known as lid or battery housing, among others.

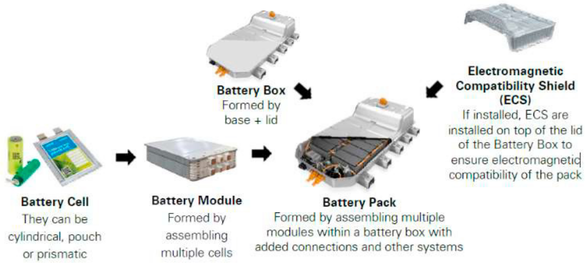


Fig. 1. Battery Pack

To ensure enduring success, it is critical to be consistently excellent in the development of new products [9], and new product development is a significant competitive advantage for companies aiming for sustained growth and profitability [10]. However, due to the high energy power stored, the development of these battery packs demanded to take active safety measures to prevent any risks during customer utilization.

Despite seeming safe, electric mobility has its risks, like any other way of mobility, and the main ones come precisely from the battery pack. This stringent requirement criterion is one of the main reasons of this study, trying to understand the product requirements of the battery pack housing cover, and learn how to improve the negotiation process and market success of the product, through the application of the Quality Function Development (QFD) methodology.

QFD provides a specific method for ensuring quality throughout each stage of the product development process, starting with design [11]. QFD, as a customer-driven product development methodology was first proposed by Dr. Yoji Akao in 1966 in Japan. QFD promotes the systematic translation of customer needs and requirements into design requirements and the evaluation of alternatives and their impacts [11, 12]. QFD was first applied in the Japanese automotive companies Hino Motors and Toyota in the 1970s. Toyota reported a reduction in startup costs of new products by 61 percent in 1984 (compared to 1977 costs, and a decrease in the new product development lead-time by one third, while significantly improving the product quality. The Toyota QFD success fostered the worldwide adoption of QFD to the rest of the world [12, 13, 14]. QFD is mostly applied during the early phases of the design stage. It starts with the identification of customers and their authentic voice. QFD links a company with its customers and assist the organization in its planning process [15]. QFD provides a systematic means of ensuring that customer demands (requirements, needs, wants) are accurately translated into relevant technical requirements and actions throughout each product development [16].

QFD is generally integrated into the New Product Development process, involving a cross multi-functional team approach (e.g., with R&D, marketing, engineering, and production). With the aim of identifying the customer requirements and translating then into technical requirements. QFD starts with the identification of the customer and the determination of their true voice. This can be done by interviews, meetings, focus groups, surveys, or customer and product data and feedback. The customer voice (often generic and vague, e.g., easy to use) will then be translated into technical requirements and subsequently into engineering and manufacturing specifications (e.g., product weight, thickness, cycle time, mean time to failures) that can be measured and action upon in the company. Customer requirements and technical and requirements are then presented in a matrix to and compared to identify their relationships.

One of the most common methods for QFD applications is the "Four-Phase Model", developed by Dr. Makabe, of Tokyo Institute of Technology, that comprehends four matrices [17]: phase I – product planning were customer requirements are compared with technical (engineering) requirements and the relationships are established; phase II- parts development or product design phase were technical requirements are matched with parts characteristics; phase 3- process planning that include the translation of the outputs of phase 3 into key process operations; and phase 4 – production planning where key process operations are contrasted with production requirements.

QFD has been successfully applied in developing new products as well as improving existing products [18].

3. Methodology

Based on the literature review, the following research themes were identified, as presented in the Table 1.

Table 1. Research Themes.

R1: What requirements the electric car manufacturers are searching on a battery cover?
R2: What technical specifications allow the improvement of those requirements?
R3: The communication/negotiation process improved due to the application of the QFD methodology?

The use of the QFD as the recommended methodology to search for answers for the research themes presented before is emphasized by several studies from other authors. According to Altuntas, Özsoy, and Mor [18], the management of the development process of new products is truly significant for the increase of market success and the achievement of competitive advantage. The QFD method is applied to capture requirements from customers and translated into technical requirements, Islam [19] stated that QFD is a methodology used to develop new products which involve the creation of one or more matrices known as quality tables.

The construction of the HoQ for the cover of a battery pack did not use all the steps of full conventional QFD, namely the four phases outlined by Makabe, focusing on the elaboration of the first matrix (House of Quality). Considering that the battery pack cover is a new product involving several OEM, this was considered a first step to foster teamwork and cooperation between all involved (external and internal) parties. It is expected that following the lessons learned with this approach the subsequent phases will be carried out later to complete the QFD. The method involved semi-structured interviews with a team (Lead Development Engineer, a Purchasing Responsible and a Cost Engineer) of a major OEM to understand the customer requirements (What's) and gather the Voice of the Customer.

The next step involved a brainstorming section with a supplier of battery covers where a company multidisciplinary team (a Product and Process Engineer, a Program Manager and a Sales Engineer) to define the technical requirements of the product through the evaluation of the customers' requirements.

The House of Quality was then completed by this investigation authors and discussed with the other involved parties for validation purposes.

The first matrix, usually known as House of Quality (HoQ), shows the customer's requirements, obtained through the Voice of the Customer (VoC) and the technical requirements, which will satisfy the customer requirements, among others. Dawson and Askin [20] considered in their studies that HoQ was widely proposed as a method to collect the VoC looking at the development of new products.

Therefore, since the battery cover is a product subjected to an in-depth development process and that it must be designed according to the customer requirements, the use of the QFD seemed a recommended tool for this study.

Figure 2 presents the HoQ, as proposed by Govers [21].

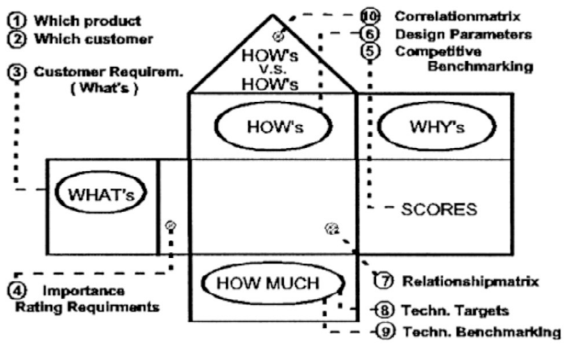


Fig. 2. House of Quality (Govers 2001)

3.1. Step 1: Customer Requirements

The first step of the HoQ tool is the understanding of customer requirements (What's) through the VoC.

To collect VoC, some authors suggest that semi-structured interviews are a valid method to achieve that.

Several authors advise doing an extended number of interviews, like Griffin and Hauser [22], who indicate that between twenty and thirty interviews are enough to identify 90% to 95% of the customer's requirements on a relative homogenous segment. However, Lam [23] interviewed only four professionals from one only company through two interviews and email exchanges, which achieved positive results as well. The fact that the knowledge about this battery covers is concentrated on a few specialists from few OEM turns this study even more difficult but considered still feasible.

Table 2 shows the questions presented to the customers, which will generate primary data, also containing the opinion of each specialist [24].

Table 2. Proposed Semi-structured Interview to the OEMs.

Questions:	Example
Q1: Which are the 10 main requirements which you look on a battery cover?	E.g., design freedom, fire resistance, weight, low cost, thermal resistance, mechanical behavior, leak tightness, EMV shielding, etc.
Q2: Can you define the importance of each requirement for the final product?	E.g., design freedom-20, fire resistance-50, etc.
Q3: Which is the direction of the goal of each requirement?	E.g., fire resistance, "+" if the increase of fire resistance is positive, "- "if the increase of fire resistance is negative
Q4: Do you think a standardization of the geometry of batteries, like the skateboard concept, is likely to occur? Why?	E.g. Yes, because; No, because
Q5: Which is the electric vehicle type you are specialized in?	E.g., BEV (Battery Electric Vehicle), PHEV (Plug-in Hybrid Electric Vehicle), HEV (Hybrid Electric Vehicle)

After the collection of all the interviews containing a significant amount of subjective information, we used an affinity diagram that allows us to process that information and transform it on clusters [19].

Q1 aims to identify the customer requirement concerning what they expect to be parts of the product specifications. This is followed by the Customer Requirement Weight or Importance (Q2), since, together with the customer requirements, the HoQ methodology also asks for the weight or importance of each customer requirement. Heru et al. [25] considered on his work that all weights should be based on a scale 1-5 where 5 represents the most important requirement and 1 the less important.

Such data analysis and treatment allowed us to collect the customer requirements and each requirement importance for the product.

3.2. Step 2: Technical Requirements

The second step of QFD is the definition of the technical requirements of the product through the evaluation of the customers' requirements. Chan and Wu [26] stated in their study that these technical requirements (How's) are the result of group brainstorming from various related sections in the factory, including ownership and the management team, marketing, production, process, and product design, and planning and warehouse departments. According to Heru et al. [25] it is sometimes referred to as the voice of the company, but in this case, we will name it Voice of the Supplier (HoQ) to avoid confusion with VoC. To promote the brainstorming, the treated VoC was presented to a supplier of battery covers where the company team answered the questions contained in Table 3, also presented as a semi-structured interview.

Table 3. Proposed Semi-structured Interview to Supplier.

SQ1: Which are the technical requirements responsible for performing the identified customer requirements?
SQ2: Can you rate the relationship between the customer requirements and the technical requirements?
SQ3: Can you evaluate the technical correlation between technical requirements?

The objective of the SQ1 (Supplier Question 1) is to identify the technical requirements responsible for performing the customer requirement. Since the customer requirements were treated through the affinity diagram, the identified technical requirements will be listed directly on the HoQ.

Through the answer to SQ2, it will be possible to know how the technical requirements represent each customer's needs, e.g., the relationship between customer requirements and technical requirements. Boonyanuwat, Suthummanon, Memongkol, and Chaiprapat [27] suggested the usage of the scale rate of 1, 3, and 9, where 1 represents a slight or possible relationship, 3 represents a moderate relationship, and 9 stands for a strong relationship.

After filling the respective fields on the HoQ, it's possible to calculate the significance level of the technical requirements, also known as importance rating, which prioritizes the technical most essential requirements and why they should be improved according to Benner, Linnemann, Jongen, & Folstar [28].

The answer to SQ3 will allow filling the technical correlation between technical requirements (a field known as HoQ roof).

The reason for this correlation assessment is not just to determine the relationship between technical requirements but also to know how each technical requirement influences other technical requirements [25]. Similarly, to other authors, Alena, Katarína, and Melichar [29] considered that when the correlation between two technical requirements is positive (if increasing of one requirement causes an increase of the second requirement), the requirement correlation is marked with the sign (+). In the case of a negative correlation (if increasing one requirement reduces the value of the other requirement, the correlation is marked with the sign (-). When a variable correlation exists (the correlation is either positive or negative), the sign (*) must be applied, if there is no relevant correlation between two the two requirements, the corresponding field must be kept empty.

4. Results

The results of the interviews of customers and its treatment, including the affinity diagram to group them in clusters, allowed us to compile the customer requirements shown in Table 4.

These results were gathered with 3 customer representatives, a Lead Development Engineer, a Purchasing Responsible and a Cost Engineer from one leading German OEM with a strong strategy on what concerns the electrification of their vehicle models.

It is also important to mention that the creation of the clusters trough the affinity diagram was supported by the VoS where they have helped to identify the similar customer requirements.

Along with the constitution of the clusters, the VoS also helped to determine the weight of the cluster from the weight of the customer requirement, given by the VoC.

Table 4. Customer Requirements.

Customer Requirements	Cluster	Weight	Direction
Dimensional accuracy Space for cell packs	Geometrical Design and Tolerancing	5	+
Material specification Stiffness Crash	Mechanical Properties	3	+
Thermal propagation Thermal resistance Fire resistance	Thermal and Fire Resistance	3	+
Weight	Weight	1	-
Stable production process	Stable Production Process	3	+
Pressure tight Leak tightness	Leak Tightness	3	+
Cost Low cost	Cost	3	-

From the interview, which included brainstorming sessions, telephone, and face to face conversations, of 3 professionals (a Product and Process Engineer, a Program Manager, and a Sales Engineer) of a leading global supplier of battery covers, shown on the Table 5. As reported in the literature, this process involved some degree of ambiguity and the need to discuss and clarify. As an example, Stable production process, would be considered as a process and production requirement, however, the OEMs representatives made the point to consider it a customer requirement to emphasize from the start the importance of ensuring timely, and just in time supply, with minimum waste and low cost. Moreover, there are similarities between the technical and the customer requirements, suggesting the need to further refine the technical requirements, which was acknowledged by the involved professionals, and will be considered for the next phases of the QFD process.

The importance relationship between the customer requirements and the technical requirements will be filled directly on the HoQ, shown on the Table 7.

Table 5. Technical Requirements

Customer Requirements (Clusters)	Technical Requirements
Geometrical Design and Tolerancing	Product design Tolerancing
Mechanical Properties	Material mechanical properties
Thermal and Fire Resistance	Thermal and fire resistance
Weight	Material’s density
Stable Production Process	Equipment and tooling capability Process parameters Operator’s intervention
Leak Tightness	Leakage ratio
Cost	Product’s cost

Table 6, presented below, shows the correlation between technical requirements, also retrieved from the VoS.

Table 6. Correlation between technical requirements

	Product design	Tolerancing	Material mechanical properties	Thermal and fire resistance	Material’s density	Equipment and tooling capability	Process parameters	Operator’s intervention	Leakage ratio	Product’s cost
Product design		*	*	*	+		*		+	+
Tolerancing						+	+		+	-
Material mechanical properties					+					
Thermal and fire resistance					+					+
Material’s density										+
Equipment and tooling capability							+		+	+
Process parameters									+	*
Operator’s intervention										
Leakage ratio										
Product’s cost										

With the data available on the previous Table 4, Table 5, and Table 6 all the needed information was gathered. The House of Quality (Ho Q) was filled as presented in Table 7. The nature of the Technical Requirement Relationships and correlations is explained in the following legends.

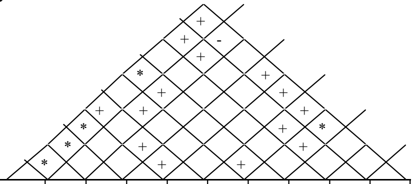
- Legend (Technical Requirements Relationship):
  ▲(9): strong relationship;
  ►(3): moderate relationship;
  ▼(1): slight or possible relationship.

- Legend (Correlation between Technical Requirements)
  +: the correlation between two technical requirements is positive.
  -: the correlation between two technical requirements is negative.
  *: the correlation between two technical requirements is variable.
  (empty): the correlation between two technical requirements is not relevant.

The application of the HoQ revealed that Product Design and Tolerancing are the main technical requirements with the most impact over the battery cover development, according their Importance rating.

The Leakage ratio seems to be also an important requirement which must be taken in account during the development activities.

Table 7. House of Quality



Technical Requirements		Product design	Tolerancing	Material mechanical properties	Thermal and fire resistance	Material's density	Equipment and tooling capability	Process parameters	Operator's intervention	Leakage ratio	Product's cost
Costumer Requirement	Weight										
Geometrical Design and Tolerancing	5	▲	▲	►	►		►	►		▲	►
Mechanical Properties	5	▲		▲		▼		►			
Thermal and Fire Resistance	3	►			▲	▼					
Weight	1	▲	▼	▼	►	►		▼			▲
Stable Production Process	3	►	▲	►			▲	▲	►	►	►
Leak Tightness	3	►	►				►	►	▼	▲	
Cost	3	►	▼			►	►	▼	▼		▲
Importance Rating		135	79	70	39	20	54	64	15	75	54

From one of the interviews to the OEM specialists, which included telephone calls, the specialist stated that the leak tightness of the product is one of the most vital requirements since it will highly contribute of the battery pack security and therefore the vehicle integrity and passenger safety.

Along with the previous results, the VoC showed different visions about the future of the standardization of the electrical vehicle platform.

While one of the specialists answered that in his opinion the standardization will likely occur due to lower platform costs and reduced project complexity, another specialist argued that he doesn´t expects standardization because the battery packs are currently designed to be integrated into the body structure with crash property requirements together with different design space and connection points from vehicle type to vehicle type.

The third specialist demonstrated a middle field opinion between the previous two answering that he believes that the trend will be one battery pack will fit in different vehicle models, but still depending on general different sizes like small (S), medium (M) and large(L).

5. Discussion and Conclusion

Concerning the R1, this study led to the identification of 14 customer requirements grouped in 7 clusters after the application of the affinity diagram tool and the importance of each requirement.

The semi-structured interview of the supplier specialists allowed us to answer R2 and to identify 10 technical requirements.

Regarding the results of the HOQ, it was possible to learn that the Product design and Tolerancing along with Leakage ratio are the main technical requirements when it comes to the development of battery covers.

According the feedback from the professionals of the supplier, if thinking without preconception, some of the customer requirements translated to technical requirements work like Go No-Go gates. For example, the Leakage ratio is measured and must be lower than a certain amount. The same thing happens with the Fire resistance which must achieve certain resistance according well-known standards. And again, the same for the material mechanical properties which must comply with specified mechanical characteristics. Therefore, seems acceptable to conclude that all these minimum requirements are defining the product specifications, leaving, for example Product's cost for a lower importance customer requirement.

Regarding R3, even before the conclusion of the HoQ methodology, the application of the VoC helped to understand with more insight and clearance the customer requirements. This clearance would support the supplier trough improved and concise communication to present an accurate quote to the customer, economically feasible, and requirements compliance, which would also lead to a better negotiation process. There are also some valuable learning points from this process. The need for cooperation between the customer, the suppliers, and the company is imperative to ensure that the product can be delivered timely according to the budget and complying with the specifications, reducing risk, and improve communication and consultation between two parties. However, it was not easy to engage the customers and the suppliers in those activities, hinting that the negotiation process should be more cooperative and with more intensive communication at the early stages.

It was confirmed that the voice of the customer could be quite generic, and it is critical that these requirements are translated into engineering requirements, which in turn, are translated into items that can be measured quantitatively and actionable within the company.

The study also allowed to clarify the vision of the OEM specialists about the standardization of the electric vehicle platforms, demonstrating that despite of the design, geometry and mechanical constraints, there's a will to standardize the electric vehicle platforms at least on fewer and general sizes like small, medium and large. It is suggested to pursue this research by applying the full QFD methodology to this relevant new product and to continue the cooperative team approach stared with this research.

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