# Systematic Customer Value Analysis: A Case Study in the Automotive Industry

Tolga Cakmak[1], Koray Altun[2*] and Mustafa Oktay Aksoy[1]
[1] Valeo Automotive Industry and Trade Co., Bursa, TURKEY
[2] Department of Industrial Engineering, Bursa Technical University, Bursa, TURKEY
[*] Corresponding author E-mail: koray.altun@btu.edu.tr
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**Abstract**

Providing high quality with competitive prices is generally essential in the automotive industry because of the customers (directly automotive OEMs and indirectly their end-users) demanding new and costly features without showing additional willingness to pay. For this reason, accurate analysis of customer value can be very helpful for developing new concepts, and hence for correct positioning in this competitive area. Although one of the most important parts of the engine in an automobile is the clutch, there are very limited studies on its value analysis in the literature. Correspondingly, to fill this gap, this paper analyses the customer value of automotive clutch components and their functions by using a two-phase QFD methodology, and a fuzzy-logic based data-fusion methodology. While the former phase determines relative weights of the bene-fit through the House of Quality, the latter phase performs the parts (and cost) deployment to determine the costs of the clutch functions by using a reverse costing analysis incorporating the product teardown cost in-formation. Having obtained benefit, cost, and technical difficulty information, a fuzzy-logic model evaluates the competitive importance of each clutch function. This work identifies the three most important clutch functions and their related subcomponents.

*Keywords:* Automotive clutch, customer value analysis, fuzzy systems, quality function deployment.

## 1. Introduction

Cost is one of the most important factors in the developments in today's highly competitive automotive industry. Improving the durability and reliability with low-cost solutions is, therefore, the main concern of the automotive suppliers. It becomes more critical for the parts requiring maintenance or renewal by time depending on the operating conditions. As an important example to these parts, automotive dry clutch, used in the manual and automated manual transmissions do not have the same lifecycle as the vehicle, and therefore improving its functions with this concern is crucial for staying competitive. Fig. 1 illustrates a typical automotive dry clutch system. A clutch system transfers the torque between an internal combustion engine (ICE) and transmission shaft and it may suffer from excessive operating conditions that may result in service visits.

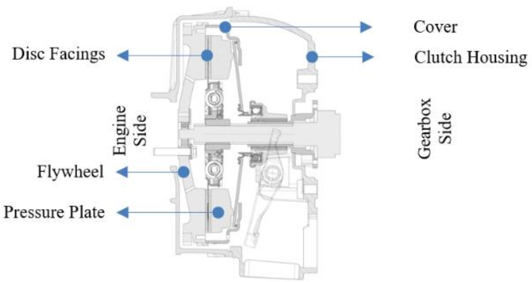



**Fig. 1.** A typical automotive dry clutch system.

Automotive clutches are not directly in interaction with drivers. However, there are many requirements linked to the clutches regarding driving functions and the comfort of passengers. These customer requirements shape the clutch design and affect its cost as well. Pedal comfort, durability, reliability, no slippage, NVH performance, allowing good gear shifting, enough torque transmission are the main customer requirements that clutch manufacturers consider.

Pushed by the necessity to lower $CO_2$ emissions, there is a clear trend towards the electrification of road transport. According to Schaeffler (2018), over the next few years, the number of powertrain concept variants for motor vehicles will continue to develop. Moreover, ICEs will still play an important role in 2030: 30% are expected to be maintained as ICE and 40% of the manufactured electric vehicle will be Hybrid Vehicle (HEV), which means with a gearbox. In the same direction, more than 1.000 market experts and automotive executives interviewed by KPMG (2019) project a balanced mix of powertrains in the product portfolio of the future: by 2040 with a similar split, being, in this case, the percentage of ICEs and HEVs equal to 45%. Regarding trucks, for example, today, the reality is that only 0.04% of all trucks on EU roads are electrically chargeable (ACEA, 2019).

Accordingly, it is anticipated that the ICEs, so the dry clutch systems will play an important role for the next decade of the automotive industry. Fig. 2 illustrates the transmission types comprising dry clutch systems and their market evolution estimation within a decade. Manual and automated transmission types comprise single dry clutch systems, while double-clutch transmission (DCT) has dry or wet double clutch systems. Their total market share is 52% in 2020, and the estimation for 2030 is 40%. On the other hand, damper systems have additional potential for being used in also HEVs having a 40% market share in 2030.

When considered the competition in the market, value analysis of dry clutch functions is an essential issue of the research and development activities. However, very few studies in the literature systematically examine the customer value of the automotive clutch. Torres et al. (2010) propose a methodology to provide design information flow between customer needs, functional requirements, key characteristics, and design parameters by integrating QFD, Axiomatic Design (AD) concepts, Failure Mode Effect Analysis (FMEA), and MOKA (Methodology and software tools Oriented to Knowledge-based engineering Applications) with support of a Computer Aided Drawing (CAD) system. Yan and Liu (2012) address the relationship between failures and design theory and experimental methods to reduce failure rate and improve product reliability. They employ the Root Cause Analysis (RCA), QFD, and D-FMEA to improve the design theory and the experimental methods. Xie et al. (2016) employ the RAHP method for rating the importance of customer requirements of the automotive clutch. In this way, they obtain a more accurate priority sequence of the final customer requirements. Likewise, Yan et al. (2018) employ a similar methodology to assess customer requirements for clutch friction material. Table 1 shows a summary of the relevant literature studying clutch applications.

The preliminary studies are restricted to doing a QFD analysis of the customer requirements, without any consideration of the benefit-cost ratio of clutch functions, and cost deployment for Value Engineering (VE). This study aims to extend these efforts by employing cost deployment (i.e., VE) and considering the benefit-cost ratio assessments.

These ratios are essential for accurate analysis of the customer value and correct positioning in this competitive area. This topic needs further investigation and therefore this has been the inspiration and starting point for the research.

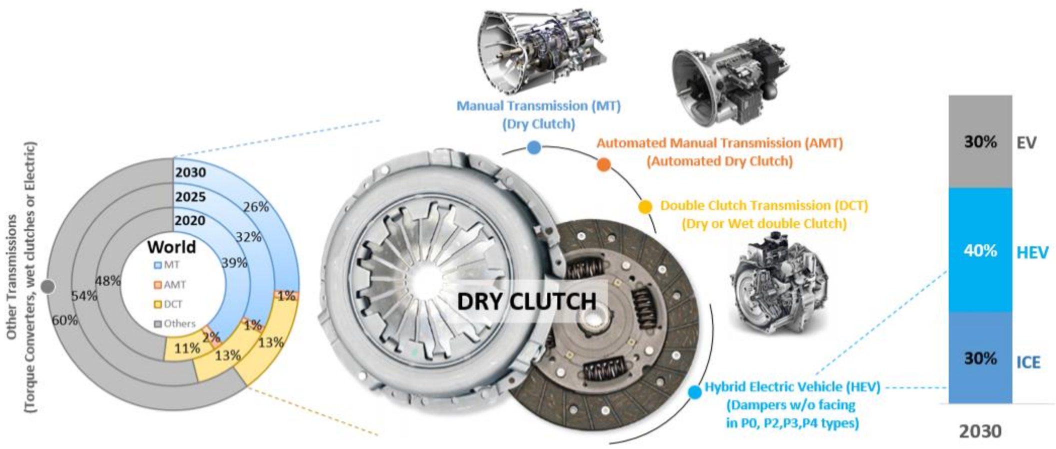



**Fig. 2.** Transmissions including dry clutch systems.

**Table 1.** A summary table of the relevant literature.

| Literature | Customer requirements | | | | | | | | | | | | | Methods |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Good performance | | | Reliability | | | Service | | | Ergonomic Comfort | | | | |
| | Slippage | Gear shifting | High speed stability | Burn | Fracture | Durability | Interchangeability | Maintanence | Pedal Comfort | Vibration and noise | Compact structure | Cost | Environmental | |
| Torres et al. (2010) | ● | ● | ◌ | ● | ● | ● | ◌ | ● | ● | ● | ● | ● | ◌ | QFD, AD, FMEA, MOKA |
| Yan and Liu (2012) | ● | ● | ◌ | ◌ | ● | ◌ | ◌ | ◌ | ● | ● | ◌ | ◌ | ◌ | RCA, QFD, DFMEA |
| Xie et al. (2016) | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | Delphi, AHP |
| Yan et al. (2018) | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | AHP, QFD |
| This work | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | QFD-VE, Kano, AHP, Fuzzy Logic |

With this purpose in mind, this study performs an advanced investigation of clutch functions to obtain the benefit-cost ratios (which are crucial to prioritize the product development attempts). This investigation is based on a systematic customer value analysis procedure employing the two phases of QFD (i.e. House of Quality, and Parts-costs deployment), Kano, AHP, and fuzzy logic (to support VE). It should be noted here that this study is a real case, and conducted by a team of clutch experts. This advanced investigation identifies and maps critical clutch functions and their correlated subcomponents, concisely. This concise map could help the developers to arrange and assess the worthy systematic innovation attempts. This study also addresses a case of Theory of Inventive Problem Solving (TRIZ) as an illustrative example.

The rest of the paper is organized as follows. Section 2 presents the methodology. Section 3 presents the "House of Quality" assessing the customer benefits of clutch functions. Section 4 presents the "parts deployment" assessing cost shares of each clutch function. A customer value analysis using a fuzzy inference system is given in section 5. An innovative clutch concept is provided in section 6. Finally, conclusions and future work are given.

## 2. Methodology

Yoji Akao introduced the concept of QFD in 1969, and later many researchers enhanced the power of QFD through several methods. The review by Sivasankaran (2020) and Singh et al. (2018) encompasses a range of approaches used in the literature. Typical QFD processes are generally based on data expressed in natural language. A great majority of works in recent literature have therefore addressed the issue, computing these ambiguities regarding the voice of customer, by proposing fuzzy QFD approaches. Reviews on fuzzy QFD can be found in Abdolshah and Moradi (2013), and Singh and Rawani (2020).

A typical QFD process focuses on customer satisfaction. On the other hand, providing the functional needs at a low cost is the main topic of Value Engineering (VE) literature. Providing better customer value with retaining the cost of the product has been overlapping literature of QFD and VE. Correspondingly, some integrated QFD and VE (QFD-VE) approaches have also been proposed in the literature by integrating cost deployment into QFD to achieve the target cost by keeping a balance with customer satisfaction. A recent literature review for the integration of QFD and VE in improving product quality can be found in Ishak et al. (2020).

Rather fewer attempts at analyzing automotive dry clutch functions have been reported in the literature. It is worth pointing out that some authors have used the QFD methodology for analyzing customer requirements, but previous research typically only investigated the "House of Quality", the first phase of QFD. Further investigations are required for such a complex part to assess the sub-functions and their correlated subparts.

With this purpose in mind, this study employs a QFD-VE approach performing a three phases procedure (that is summarized in Fig. 3) to analyze automotive dry clutch functions. While the first phase (i.e. House of

Quality phase) aims to clarify the "benefit" of each functional requirement from the point of the customer view, the second phase (i.e. parts-cost deployment phase) calculates the "cost" share of each functional requirement by considering the function-part relations. In the final phase (i.e. customer-value analysis phase), a type-1 fuzzy inference system helps in fusing these benefits, costs, and technical difficulties data to infer the "importance" of each functional requirement under consideration. This study provides a systematic customer value analysis for automotive dry clutch functions. It should be noted here that this study employs fuzzy logic to support the VE process. Therefore, the methodology of this work is related to the integrated QFD and VE, instead of fuzzy QFD literature. The use of fuzzy logic in QFD-VE is not common when compared to fuzzy QFD literature. Ishak et al. (2020) review the literature of QFD-VE. This review study has listed only one fuzzy approach for QFD-VE enabled target costing (Gandhinathan et al., 2004). Gandhinathan et al. (2004) employ the fuzzy logic to strengthen the QFD-VE model through better handling the uncertainty associated with the cost of various elements. In contrast to this use of fuzzy logic, this study employs a type-1 fuzzy system as a data-fusion methodology, to fuse the difficulty, benefit, and cost data, for inferencing the importance of clutch functions.

Through the procedure followed by this work, we provide a comprehensive customer value analysis for the automotive clutch, one of the most important parts of an automobile. In this way, we have identified the most important clutch functions and their related subcomponents as a concise list for consideration during the new product development process. On the other hand, from the methodological point of view, the procedure proposed in this work is a practical framework incorporating an enhanced QFD methodology through fuzzy systems and the Kano model for an accurate customer value analysis.

## 3. House of quality for automotive clutch

Customers are generally considered as "those companies want to create value for." Linking the "voice of customers" to the "voice of technicians" is essential to fulfilling customer requirements, and hence to create "customer value." The first phase of QFD (also called HoQ – House of Quality because of its house-shaped diagram) is the unique phase providing a systematic procedure for illustrating this link with a conceptual map. Correspondingly, the procedure of a typical HoQ is conducted to analyze "customer value" for the automotive clutch in this study. Fig. 4 shows a conceptual map of the relationship between "customer requirements" and "clutch functions."

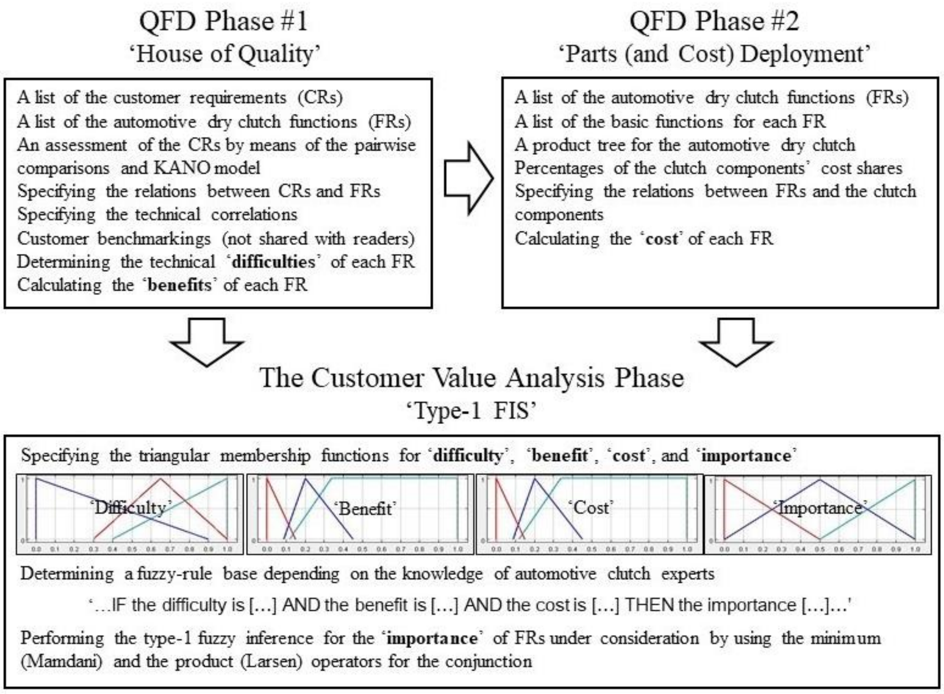
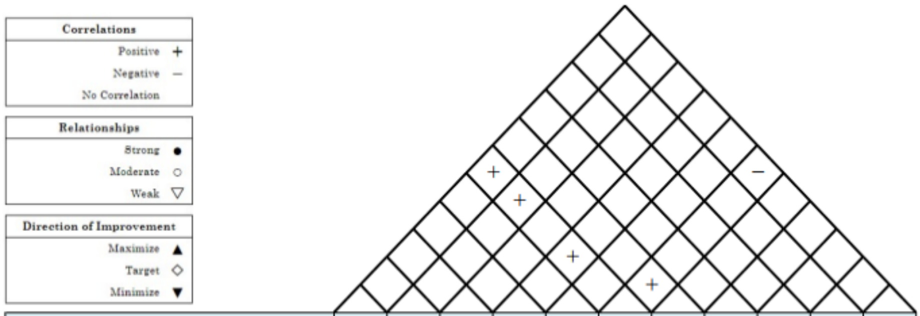



**Fig. 3.** A summary of the procedure followed by this study.




| Row # | Relative Weight | Maximum Relationship | Customer Requirements (Explicit and Implicit) / Functional Requirements | Transmitting the torque between engine and gearbox | Allowing the disconnection between engine and gearbox during gear shifting | Assuring correct installation and correct assembly at customer's site | Ensuring engine starting/shut down | Allowing the right packaging and transport | Assuring reliability | Filtering vibrations / rotations irregularities of the motor propulsor unit | Absorb misalignments and eccentricity of the input shaft as regards the crank shaft | Avoid noise during slippage phase (gearshifting and start-up) | Not polluting | Being recyclable |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Column # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | | | Direction of Improvement | ▲ | ▲ | ▲ | ▲ | ▲ | ▲ | ▲ | ▲ | ▲ | ▲ | ▲ |
| 1 | 15,0% | 9 | (P) Enough power, without slipping | ● | | | | | ● | | | | | |
| 2 | 15,0% | 9 | (P) Engage and disangage function | ○ | ● | | | | ● | | | | | |
| 3 | 7,5% | 9 | (P) High-speed stability | ● | ○ | | | | ● | | | | | |
| 4 | 4,9% | 9 | (R) Friction plates does not burn | ● | | | | | ● | | | | | |
| 5 | 9,8% | 9 | (R) Parts not fracture | ○ | | | | | ● | | ● | | | |
| 6 | 9,8% | 9 | (R) Long life for use | ▽ | ○ | | ▽ | | ● | | ● | | | |
| 7 | 4,5% | 9 | (S) Parts of good interchangeability | | | ● | | | | | | | | |
| 8 | 1,9% | 9 | (S) Disassembly, adjustment and maintenance | | | ● | | | | | | | | |
| 9 | 8,5% | 9 | (ER&CO) Pedal comfort | | ● | | | | ○ | ● | | | | |
| 10 | 13,4% | 9 | (ER&CO) Vibration and noise | | ● | | ▽ | | ● | ● | ○ | ● | | |
| 11 | 1,2% | 3 | (ER&CO) Simple and compact structure | | | ○ | | ▽ | | | | | | |
| 12 | 3,5% | 9 | (ECO) Cheap price | | | | | | ● | | | | | |
| 13 | 4,8% | 9 | (ENR) Meet environmental protection requirements | | | | | | | | | | ● | ● |
| | | | Technical difficulty (Low 1-10 High) | 6 | 7 | | 5 | | | 10 | 8 | 9 | | |
| | | | Max Relationship | 9 | 9 | 9 | 1 | 1 | 9 | 9 | 9 | 9 | 9 | 9 |
| | | | Technical Importance Rating | 331,5 | 384,8 | 61,3 | 23,2 | 1,2 | 737,1 | 197,5 | 217 | 120,8 | 43,3 | 43,3 |
| | | | Relative Weight | 15,3% | 17,8% | 2,8% | 1,1% | 0,1% | 34,1% | 9,1% | 10,0% | 5,6% | 2,0% | 2,0% |

**Fig. 4.** House of quality for automotive dry clutch.

The HoQ has been criticized because it does not consider the distinct relationship between "performance" and "satisfaction" and it assumes that there is a linear relationship between them. Integrating the Kano Model (Kano et al., 1984, Löfgren and Witell, 2005) into the HoQ is a common way to enhance the understanding of CRs (Tontini, 2007). Tontini et al. (2014) propose the Improvement-Gaps analysis (IGA) to overcome some limitations of the Kano Model as well. Clarifying design trade-offs corresponding to CRs with a negotiation process, as a part of customer co-creation is another way proposed in Altun et al. (2016).

Taking the shortcoming of traditional HoQ into account before calculating the relative weight of each CR is crucial to assess "customer value", properly. This study integrates the Kano Model to enhance traditional HoQ. Kano Model determines which CRs bring more satisfaction than others do. For each CR, a pair of questions examine whether the customer would feel satisfied or dissatisfied. Table 2 shows the priority categories of each CR obtained from this analysis. The hierarchy of the AHP pairwise comparisons is confirmed by using these priority categories.

The hierarchy class of "good performance" includes the CRs, which have the "performance" tag in the Kano priority list. Similarly, the "reliability" hierarchy class includes the CRs having a "must-be" priority tag except for the CR, "parts of good interchangeability." Some CRs have intentionally assigned to the hierarchy of the "service" by considering the suggestions of the experts. Similarly, the "attractive" CRs are generally the members of the hierarchy class of "ergonomic and comfort." The relative weight of each CR is calculated by "consistent" AHP pairwise comparisons (consistency ratios are less than 0.07). Table 3 shows the importance rates calculated.

After determining CRs and their relative weights, the next step is to create a list of the functional requirements (FRs). The team of clutch experts lists eleven main functions of an automotive dry clutch. The HoQ includes the relationship matrix to deploy CRs to FRs. 1, 3, and 9 scales are used to define the relationship between CRs and FRs (to represent weak, moderate, and strong relationships, respectively). This relationship matrix has been completed through organizing a multi-functional and multi-organizational workshop addressing each relation pair. The list of maximum relationships illustrated in Fig. 4 indicates a true deployment because each CR has a strong relationship, except the eleventh CR that has a moderate maximum relationship.

Some of these FRs under consideration are interrelated to each other. The roof of the HoQ, also called as "Technical Correlation Matrix" identifies which of these FRs must work together. In this phase, the team of clutch experts determines the existing interrelationships among these FRs as indicated in Fig. 4. Mainly, "assuring reliability" has positive relations with other FRs regarding the reliable operating conditions on the vehicle. On the other hand, "being recyclable" necessitates the use of low reliable parts in some specific cases and therefore a negative relation is considered.

This work does not share the customer benchmarking section because of the privacy policy of the company. The team rates the technical difficulty of execution of FRs using a 1 – 10 (low to high) scale showing how hard or easy to improve. Some of these FRs do not have technical difficulty rates in the HoQ because they are redundant when considered customer benchmarking assessments.

**Table 2.** An assessment of customer requirements with KANO analysis.

| Customer Requirements | How would you feel if this was present? | How would you feel if this was absent? | Priority | Hierarchy Class |
|---|---|---|---|---|
| Enough power, without slipping | Like | Dislike | Performance | Good Performance |
| Engage and disengage function | Like | Dislike | Performance | |
| High-speed stability | Like | Dislike | Performance | |
| Friction plates do not burn | Expect it | Dislike | Must-be | Reliability |
| Parts not fracture | Expect it | Dislike | Must-be | |
| Long-life for use | Expect it | Dislike | Must-be | |
| Parts of good interchangeability | Expect it | Dislike | Must-be | Service |
| Disassembly, adjustment, and maintenance | Like | Live with | Attractive | |
| Pedal comfort | Like | Live with | Attractive | Ergonomic & Comfort |
| Vibration and noise | Like | Live with | Attractive | |
| Simple and compact structure | Don't care | Don't care | Indifferent | |
| Cheap price | Like | Live with | Attractive | Economic |
| Meet environmental protection requirements | Don't care | Don't care | Indifferent | Environmental |

**Table 3.** Calculated relative weights of customer requirements.

| Class | Class rates | Customer Requirements | Sub-class rates | Relative weight |
|---|---|---|---|---|
| Good Performance | 0.376 | (P) Enough power, without slipping | 0.400 | 0.150 |
| | | (P) Engage and disengage function | 0.400 | 0.150 |
| | | (P) High-speed stability | 0.200 | 0.075 |
| Reliability | 0.245 | (R) Friction plates does not burn | 0.200 | 0.049 |
| | | (R) Parts not fracture | 0.400 | 0.098 |
| | | (R) Long life for use | 0.400 | 0.098 |
| Service | 0.064 | (S) Parts of good interchangeability | 0.700 | 0.045 |
| | | (S) Disassembly, adjustment, and maintenance | 0.300 | 0.019 |
| Ergonomic & Comfort | 0.231 | (ER&CO) Pedal comfort | 0.368 | 0.085 |
| | | (ER&CO) Vibration and noise | 0.579 | 0.134 |
| | | (ER&CO) Simple and compact structure | 0.052 | 0.012 |
| Economic | 0.035 | (ECO) Cheap price | 1.000 | 0.035 |
| Environmental | 0.048 | (ENR) Meet environmental protection requirements | 1.000 | 0.048 |

## 4. Parts (and cost) deployment

With the help of the HoQ phase, the relative importance of each FR is obtained in terms of the customers' points of view. The second phase of the QFD examines the cost of clutch functions. FRs and their basic functions are listed to map relations between clutch components. Automotive dry clutch main components (flywheel, disc, and PPCA) and their subcomponents are listed as well. Relation rates between basic functions and subcomponents are determined with the help of design FMEA reports. Approximate cost shares of subcomponents in total cost are given in terms of percentages. By considering relations between basic functions and subcomponents, cost shares of basic functions and FRs are calculated.

Fig. 5 illustrates how parts and cost deployments are executed. In the line of "avoid slippage", the values of X1, X2, and X3 indicate the allocated relation degrees between the "avoid slippage" function and the corresponding subcomponents. As seen in Table 6 in detail, a standardization is conducted for each subcomponent as their correlated basic function relations are disseminated. Therefore, the total of each column of the relation matrix is one. Cost shares of the corresponding parts are C1, C2, and C3. By taking these relation degrees and their coefficients (i.e. cost shares of the subparts) into account, we calculate the cost of the "avoid slippage" function (it is as Y in the figure). The complete table is given in Table 6 (in Appendix A).

## 5. A customer value analysis of the clutch functions

A simple ratio between benefit and cost neglecting core competencies may not be helpful to model the value leading its users to a competitive advantage. While the first phase of QFD helps us to calculate the benefit weights of clutch functions, the second phase of QFD calculates the costs of clutch functions. By also considering the technical difficulty data as an indicator of the firm's competency on each function, this study performs a competitive assessment of automotive dry clutch functions.

In this phase, a type-1 fuzzy inference system evaluates the competitive importance of each clutch function by fusing benefit, cost, and technical difficulty data as inputs of the system. This fuzzy system uses triangular membership functions for input fuzzy sets. Degree of "benefit", "cost" and "technical difficulty" fuzzy sets are represented by three membership functions as "low", "medium", and "high" (within the interval of [0,1]). By considering the spectrum of input data, the linear standardization process helps us to specify sensitive membership function parameters being able to differentiate the assessments. Fig. 6 shows the membership functions of the fuzzy inference system.

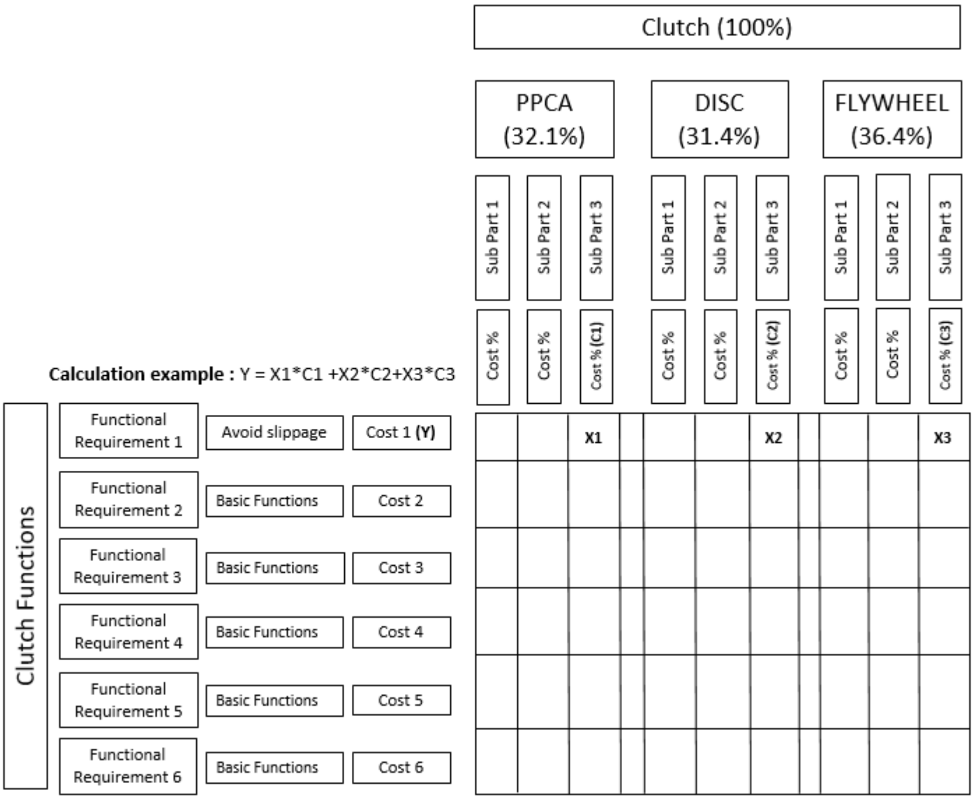



**Fig. 5.** An illustrative calculation for parts (and cost) deployment.

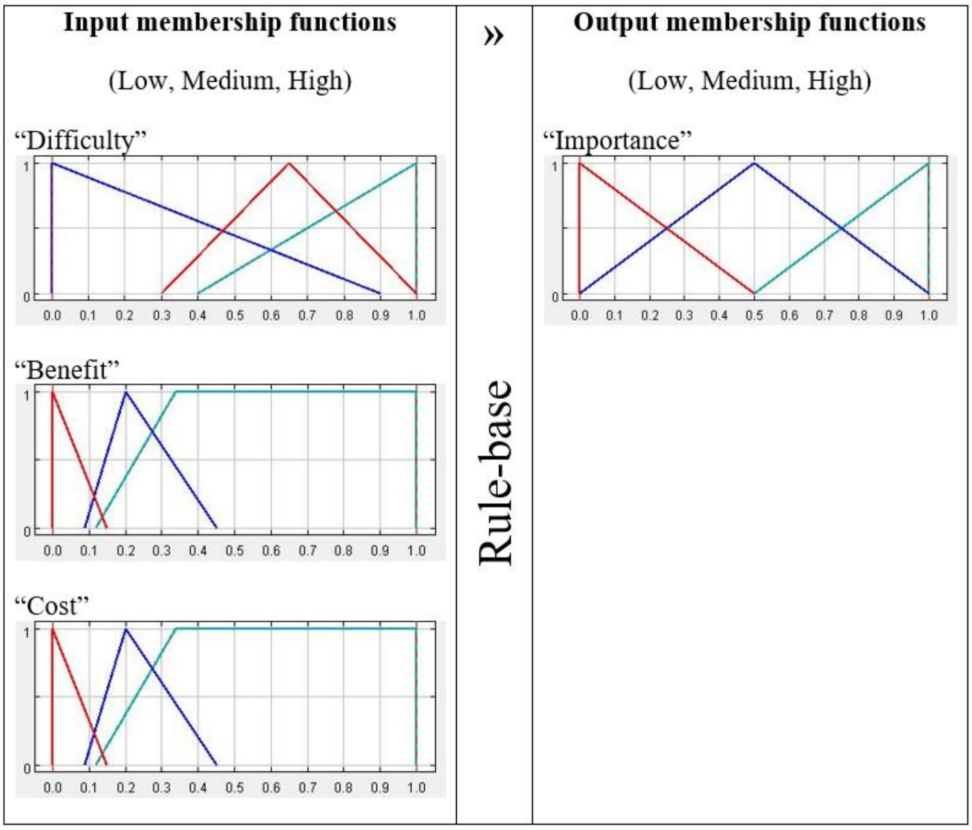



**Fig. 6.** Membership functions of the fuzzy inference systems.

After determining the parameters of fuzzy sets, a rule-base is needed to obtain competitive importance appraisals of clutch functions. In this phase, the knowledge of the clutch experts has been converted into a fuzzy rule-base. The list of the rules is given in Table 4 (in Appendix C).

When parameters of the clutch functions are entered into the system, the importance of each clutch function is obtained employing this fuzzy inference system. In this study, we present a real case of a clutch manufacturer. The technical benchmarking results show that there are six relevant functional requirements to improve the relative overall customer value. In this phase, the minimum (Mamdani) and the product (Larsen) operators are used for conjunction in the fuzzy inference system.

Table 5 shows the assessment results of the importance. We marked the top three functional requirements using bold font. Both operators used for the conjunction lead to the same rank order of the considered automotive dry clutch functions. According to these assessments, the three most important clutch functions are "Allowing disconnection between engine and gearbox during gear shifting," "Transmitting the torque between engine and gearbox," and "Ensuring engine starting/shut down." These top three clutch functions are placed in the improvement list of the company with the highest priority tags.

As seen in Fig. 4, "assuring reliability" has positive relations with these important clutch functions. Although it is intrinsically important because of these relations, in our case, we neglect it in the further analysis since the results of our customer benchmarking say that improving "assuring reliability" does not make sense on the customer value.

Once the component level of these functions is considered through the parts (cost) deployment matrix, the top three components corresponding to these functions are pressure plate, disc facings, and clutch cover. The following components are ED hook rivet sub-assembly, diaphragm, and flywheel cast iron. The outcome of this study proves beneficial to research in discovering not only the clutch components costs, but also in detailing the importance of clutch functions.

**Table 5.** Importance rates of clutch functions.

| | Inputs of the fuzzy system | | | Obtained results | |
|---|---|---|---|---|---|
| **Clutch functions under consideration** | **Difficulty** | **Benefit** | **Cost** | **Importance (Minimum)** | **Importance (Product)** |
| **FR#1** – Transmitting the torque between engine and gearbox | 0.6 | 0.153 | 0.154 | 0.441 | 0.485 |
| **FR#2** – Allowing disconnection between engine and gearbox during gear shifting | 0.7 | 0.178 | 0.116 | 0.599 | 0.526 |
| **FR#4** – Ensuring engine starting / shut down | 0.5 | 0.011 | 0.010 | 0.369 | 0.369 |
| FR#7 – Filtering vibrations / rotations irregularities of the motor propulsor unit | 0.999 | 0.091 | 0.064 | 0.225 | 0.237 |
| FR#8 – Absorb misalignments and eccentricity of the input shaft as regards the crankshaft (with a rigid flywheel or DMF) and secondary flywheel (with DMF) twisting | 0.8 | 0.010 | 0.010 | 0.265 | 0.256 |
| FR#9 – Avoid noise during slippage phase (gear shifting and start-up) | 0.9 | 0.056 | 0.024 | 0.168 | 0.187 |

## 6. Developing innovative clutch concepts

The results obtained in this work provide a new perspective on project portfolio management. The company uses these results to determine worthwhile innovation paths. Having obtained the importance rates of clutch functions, where to focus to innovate is clearer. The three most important clutch functions have been listed in this systematic customer value analyses process.

The R&D center of the company has conducted some workshops to generate innovative ideas corresponding to these clutch functions. Through some sensitivity analyses based on these results, ideas generated in these workshops have been assessed whether they improve the customer value. Two examples of these ideas have been discussed in Cakmak et al. (2021a) and Cakmak et al. (2021b).

One of the most important three functions is FR#1, transmitting the torque between engine and gearbox. As seen from the parts deployment for automotive dry clutch functions (Table 6), FR#1 is heavily in relation to the pressure plate and cover assembly (PPCA). The basic functions of FR#1 are also listed in Appendix.

A pressure plate is a part, which is cast iron manufactured, and it is the heaviest part of the automotive dry clutch system. Repetitive clutch engagements cause dramatic temperature rise. Temperature change affects negatively the torque transmission (FR#1) since the friction coefficient reduces by temperature rise.

On the other hand, in parallel to recently released greenhouse gas regulations, “lightweighting” is a strong trend that pushes OEMs and suppliers to present lighter solutions without compromising their performance. Improving the weight of moving objects without worsening shape is one of the main contradictions to handle. The 40th TRIZ Inventive Principles for this contradiction is the 40 IP, composite materials, from the TRIZ Contradiction Matrix.

Correspondingly, in a recent study (Cakmak et al., 2021a), reducing the weight of the clutch pressure plate by using aluminum foam has been researched. Fig. 7 illustrates the proposed concept design. This lightweight concept design prevents the dramatic temperature rise during repetitive engagements. This concept design enhances the convective heat transfer, as well. Enhancing the convective heat transfer of clutch pressure plate through ventilation channels has also been researched in another recent study (Cakmak et al, 2021b).

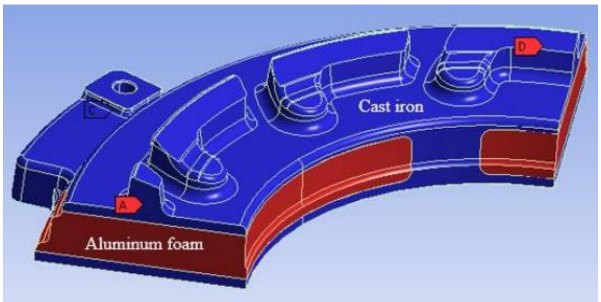



**Fig. 7.** Lightweight innovative composite dry clutch pressure plate (adapted from Cakmak et al., 2021a).

## 7. Concluding remarks

Porter’s three generic strategies (i.e. cost leadership, differentiation, and focus strategies) describe how to be competitive in the market while fulfilling the customer needs. Although it is common to see different business strategies when considered the automotive original equipment manufacturers (OEMs), it is generally not a similar case for their (co-designer) tire-1 and tire-2 suppliers. According to a report of Deloitte (2017) discussing the future of the automotive value chain, “the automotive industry is in a state of constant pressure: from customers demanding new and costly features – often without showing additional willingness to pay.” For this reason, providing high quality with competitive prices can be considered as a necessity to be competitive in the automotive industry. To work with the (price-sensitive) OEMs, the automotive suppliers generally target the cost leadership strategy, producing a standardized product at very low per-unit costs.

Even though the trend towards electrification of road transport over the next few years, Internal Combustion Engines (ICEs) are still to play an important role in 2030: 30% are expected to be maintained as ICE and 40% of the manufactured electric vehicle will be Hybrid Vehicle (HEV), that means with a gearbox. Thus, dry clutch systems are expected to still have an important market share. Although most of their components have changed in their evolved versions, the “automotive dry clutch” can also be considered as one of these conventional parts. In the case the competition is strong and the customer needs have nearly been fulfilled, the manufacturers may improve their product functions to be balanced in their benefit and cost rates to stay competitive. Correspondingly, this study has addressed a real case for the assessment of “automotive dry clutch” functions. By taking these assessments into account, worthy technical contradictions and innovative clutch concept designs can be addressed in future works. The techniques used in this assessment can be generalized to some of the automotive parts (e.g. automotive seats) and therefore future work can address the implementation of such a procedure for other important automotive parts.

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## AUTHOR BIOGRAPHIES

**Dr. Tolga ÇAKMAK** received his BSc, MSc and PhD in Mechanical Engineering from Uludag University, Turkey in 2004, 2007 and 2018, respectively. He works in VALEO Automotive Company in Turkey since 2007. He has received a Research Fellowship at the von Karman Institute, Belgium in 2006 during his master thesis study. He has experience in sheet metal cold and hot forming, heat treatment, casting technology and metallurgical analysis. His research interests include vehicle dynamics, design optimization, simulation and testing. He has been nominated as VALEO expert in January 2016 due to his innovative achievements in his field, the proven depth and range of his personal expertise and ability to transfer the benefits of this expertise to others.

**Dr. Koray ALTUN** is an Assistant Professor of Industrial Engineering at TU Bursa, and a Research Collaborator at GLORAD Center for Global R&D and Innovation. He is also the founder and manager of a start-up focused on digital innovation & software consultancy. He holds PhD and BSc degrees of Industrial Engineering from Gaziantep University and Erciyes University, respectively. He has published his papers in some well-respected journals and he has led many consulting engagements in many reputed companies with the focus on R&D, technology and innovation management. His recent research interests include; Innovation Excellence Model, Systematic Innovation, Technology and Innovation Management, R&D Management.

**Mustafa Oktay AKSOY** received his BSc and MSc in Mechanical Engineering from Uludag University, Turkey in 1985 and 1989, respectively. He has been working in VALEO Automotive Company in Turkey as R&D Coordinator since 2015. Before VALEO-Turkey, he worked in Grammer Seating Systems-Turkey as Project Coordinator for 6 years and in Magneti Marelli-Turkey as project engineer, project leader and R&D Section Manager for 18 years respectively. During this period, he managed numerous national and international projects for automotive industry. Currently, he is in charge of university-industry cooperation projects, R&D Projects funded by government and innovation activities in VALEO-Turkey.

## Appendix

### A. Parts deployment for the automotive clutch functions

**Table 6.** Parts (and cost) deployment for automotive dry clutch functions (FR1 – FR3).

| BENEFIT | FR | BF | COST SHARES | | Sub Part 1 | Sub Part 2 | Sub Part 3 | Sub Part 4 | Sub Part 5 | Sub Part 6 | Sub Part 7 | Sub Part 8 | Sub Part 9 | Sub Part 10 | Sub Part 11 | Sub Part 12 | Sub Part 13 | Sub Part 14 | Sub Part 15 | Sub Part 16 | Sub Part 17 | Sub Part 18 | Sub Part 19 | Sub Part 20 | Sub Part 21 | Sub Part 22 | Sub Part 23 | Sub Part 24 | Sub Part 25 | Sub Part 26 | Sub Part 27 | Sub Part 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 100% | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | PARTS | PPCA | | | | | | | | | DISC | | | | | | | | | | | | | | | | FLYWHEEL | | |
| | | | | | 32,1% | | | | | | | | | 31,4% | | | | | | | | | | | | | | | | 36,4% | | |
| | | | | | 14,1% | 52,3% | 11,4% | 12,8% | 2,7% | 2,7% | 1,0% | 1,0% | 2,0% | 27,5% | 1,1% | 4,2% | 1,1% | 11,1% | 1,7% | 5,0% | 1,4% | 10,5% | 1,7% | 1,2% | 4,6% | 1,3% | 22,7% | 2,7% | 2,2% | 21,7% | 70,1% | 8,2% |
| | | | | | 4,5% | 16,8% | 3,7% | 4,1% | 0,9% | 0,9% | 0,3% | 0,3% | 0,6% | 8,7% | 0,3% | 1,3% | 0,3% | 3,5% | 0,5% | 1,6% | 0,4% | 3,3% | 0,5% | 0,4% | 1,5% | 0,4% | 7,1% | 0,8% | 0,7% | 7,9% | 25,5% | 3,0% |
| 15,30% | FR 1 | BF 1 | 0,154 | 0,036 | 0,050 | 0,093 | 0,082 | 0,130 | 0,073 | | 0,100 | 0,100 | | 0,098 | 0,167 | | | | | | | | | | | | | | | | | |
| | | BF 2 | | 0,030 | 0,038 | 0,093 | 0,082 | | 0,122 | | | | | 0,098 | | | | | | | | | | | | | | | | | | |
| | | BF 3 | | 0,030 | 0,050 | 0,093 | | | | 0,081 | 0,167 | 0,167 | 0,333 | 0,078 | 0,222 | 0,049 | | | | | | | | | | | | | | | | |
| | | BF 4 | | 0,003 | 0,063 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 5 | | 0,024 | 0,050 | 0,056 | | | | 0,081 | 0,167 | 0,167 | 0,333 | 0,078 | 0,278 | | | | | | 0,129 | | | | | | | | | | | |
| | | BF 6 | | 0,012 | | | | | | | | | | | | | | | | 0,250 | | | 0,13 | | 0,103 | 0,190 | 0,065 | | | | | |
| | | BF 7 | | 0,020 | | | | | | | | | | | | 0,066 | 0,147 | 0,119 | | | | 0,077 | 0,13 | | 0,128 | | 0,109 | 0,108 | 0,086 | | | |
| | | BF 8 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17,80% | FR 2 | BF 9 | 0,116 | 0,036 | 0,050 | 0,056 | 0,066 | 0,217 | 0,122 | 0,081 | 0,100 | 0,100 | | 0,078 | | 0,082 | | | | | | 0,077 | | | | | | | 0,069 | | | |
| | | BF 10 | | 0,026 | 0,038 | 0,074 | 0,049 | | 0,073 | 0,065 | | | | 0,098 | | 0,066 | | | | | | | | | | | | | | | | |
| | | BF 11 | | 0,011 | 0,050 | | 0,082 | 0,130 | 0,073 | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 12 | | 0,013 | 0,050 | | 0,066 | 0,174 | 0,098 | 0,048 | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 13 | | 0,007 | | | | | | | | | | 0,059 | | 0,066 | | | | | | | | | 0,077 | | | | 0,052 | | | |
| | | BF 14 | | 0,003 | | | 0,082 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 15 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 16 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 17 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 18 | | 0,018 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,071 | |
| 2,80% | FR 3 | BF 19 | 0,129 | 0,032 | 0,063 | 0,056 | 0,049 | | | 0,081 | | | | 0,059 | | 0,049 | 0,118 | 0,095 | | | | 0,046 | 0,094 | | | | 0,065 | 0,081 | 0,069 | | | |
| | | BF 20 | | 0,050 | 0,050 | 0,056 | 0,082 | 0,130 | 0,073 | 0,048 | 0,100 | 0,100 | 0,333 | 0,059 | | 0,049 | | | | | 0,097 | 0,077 | | | | | 0,065 | | 0,052 | 0,077 | | 0,208 |
| | | BF 21 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 22 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 23 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 24 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 25 | | 0,023 | | | 0,066 | | 0,098 | | 0,100 | 0,100 | | 0,059 | | | 0,147 | 0,119 | | | | | | | 0,077 | 0,143 | 0,087 | 0,081 | 0,069 | | | |
| | | BF 26 | | 0,018 | 0,050 | 0,074 | | | | 0,081 | | | | | | | | | | | | 0,077 | | | | | | | 0,069 | | | |
| | | BF 27 | | 0,006 | | | | | | | | | | | | | | | | | | | | | | | | | | 0,077 | | |

**Table 6.** Parts (and cost) deployment for automotive dry clutch functions (FR4 – FR11).

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 100% | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | PPCA | | | | | | | | | DISC | | | | | | | | | | | | | | | | FLYWHEEL | | |
| | | | | | 32,1% | | | | | | | | | 31,4% | | | | | | | | | | | | | | | | 36,4% | | |
| | | | | PARTS | Sub Part 1 | Sub Part 2 | Sub Part 3 | Sub Part 4 | Sub Part 5 | Sub Part 6 | Sub Part 7 | Sub Part 8 | Sub Part 9 | Sub Part 10 | Sub Part 11 | Sub Part 12 | Sub Part 13 | Sub Part 14 | Sub Part 15 | Sub Part 16 | Sub Part 17 | Sub Part 18 | Sub Part 19 | Sub Part 20 | Sub Part 21 | Sub Part 22 | Sub Part 23 | Sub Part 24 | Sub Part 25 | Sub Part 26 | Sub Part 27 | Sub Part 28 |
| | | | COST SHARES | | 14,1% | 52,3% | 11,4% | 12,8% | 2,7% | 2,7% | 1,0% | 1,0% | 2,0% | 27,5% | 1,1% | 4,2% | 1,1% | 11,1% | 1,7% | 5,0% | 1,4% | 10,5% | 1,7% | 1,2% | 4,6% | 1,3% | 22,7% | 2,7% | 2,2% | 21,7% | 70,1% | 8,2% |
| BENEFIT | FR | BF | | | 4,5% | 16,8% | 3,7% | 4,1% | 0,9% | 0,9% | 0,3% | 0,3% | 0,6% | 8,7% | 0,3% | 1,3% | 0,3% | 3,5% | 0,5% | 1,6% | 0,4% | 3,3% | 0,5% | 0,4% | 1,5% | 0,4% | 7,1% | 0,8% | 0,7% | 7,9% | 25,5% | 3,0% |
| 1,10% | FR 4 | BF 28 | 0,010 | 0,010 | | | | | | | | | | | | | | | | | | | | | | | | | | 0,128 | | |
| | | BF 29 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 30 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 31 | | 0,000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0,10% | FR 5 | BF 32 | 0,115 | 0,054 | 0,063 | | 0,049 | | 0,073 | | | | | | 0,167 | 0,049 | | 0,095 | | | | 0,046 | 0,094 | | | | 0,087 | | 0,052 | 0,077 | 0,095 | 0,167 |
| | | BF 33 | | 0,061 | 0,050 | 0,074 | | | | 0,081 | | | | 0,059 | | 0,066 | | | | | | 0,062 | | | | | | | | 0,103 | 0,095 | 0,167 |
| 34,10% | FR 6 | BF 34 | 0,285 | 0,027 | 0,063 | | 0,082 | | | 0,081 | | | | | | 0,082 | 0,147 | 0,119 | | | 0,129 | 0,077 | 0,13 | | 0,128 | | 0,109 | 0,081 | 0,086 | | | |
| | | BF 35 | | 0,010 | | | | | | | | | | | | | | | | | | | | | | | | | | 0,128 | | |
| | | BF 36 | | 0,030 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,119 | |
| | | BF 37 | | 0,041 | | | | | | | | | | | | | | | | | | | | | | | | | | 0,128 | 0,119 | |
| | | BF 38 | | 0,051 | 0,063 | 0,056 | | | | 0,065 | 0,100 | 0,100 | | | | 0,082 | 0,088 | 0,071 | | | | 0,077 | | | | | | 0,108 | | | 0,119 | |
| | | BF 39 | | 0,030 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,119 | |
| | | BF 40 | | 0,069 | 0,063 | 0,093 | 0,082 | 0,217 | 0,122 | 0,081 | | | | 0,098 | | 0,082 | 0,118 | 0,119 | 0,286 | 0,250 | 0,129 | 0,077 | 0,156 | 0,263 | 0,128 | 0,190 | 0,109 | 0,135 | 0,086 | | | |
| | | BF 41 | | 0,027 | 0,050 | 0,074 | | | | 0,081 | 0,167 | 0,167 | | | | 0,082 | 0,147 | 0,119 | | | | 0,077 | | | 0,128 | | | | 0,086 | | | |
| 9,10% | FR 7 | BF 42 | 0,064 | 0,010 | | | | | | | | | | | | | | | | | | | | | | | | | | 0,128 | | |
| | | BF 43 | | 0,037 | | | | | | | | | | | | | | | | | | | | | | | | | | | 0,119 | 0,208 |
| | | BF 44 | | 0,016 | 0,050 | 0,056 | 0,082 | | 0,073 | 0,048 | | | | | | | | | | | | | | | | | | | | | | |
| | | BF 45 | | 0,001 | | | | | | | | | | | | 0,082 | | | | | | | | | | | | | | | | |
| 10,00% | FR 8 | BF 46 | 0,010 | 0,010 | | | | | | | | | | | | | | | | | 0,161 | 0,077 | | 0,211 | | | 0,065 | 0,108 | 0,069 | | | |
| 5,60% | FR 9 | | 0,024 | 0,024 | | | | | | | | | | | | | | 0,071 | 0,286 | 0,313 | 0,161 | 0,062 | 0,094 | 0,211 | 0,077 | 0,190 | 0,109 | 0,135 | 0,052 | | | |
| 2,00% | FR 10 | | 0,046 | 0,046 | | | | | | | | | | 0,078 | | | | | 0,214 | | 0,097 | 0,046 | 0,094 | 0,158 | 0,077 | 0,143 | 0,065 | 0,081 | 0,052 | 0,077 | 0,071 | 0,125 |
| 2,00% | FR 11 | | 0,047 | 0,047 | | | | | | | | | | | 0,167 | 0,049 | 0,088 | 0,071 | 0,214 | 0,188 | 0,097 | 0,046 | 0,094 | 0,158 | 0,077 | 0,143 | 0,065 | 0,081 | 0,052 | 0,077 | 0,071 | 0,125 |

## B. List of subparts and basic functions

List of subparts:
Sub Part 1 Cover
Sub Part 2 Pressure Plate
Sub Part 3 Diaphragm
Sub Part 4 ED hook-rivet S.A
Sub Part 5 Delta Rivet
Sub Part 6 Straps
Sub Part 7 Cover-straps rivet
Sub Part 8 Pressure plate - straps rivet
Sub Part 9 Balancing Rivet
Sub Part 10 Facing
Sub Part 11 Facing rivet
Sub Part 12 Metallic Disc
Sub Part 13 Fastening Rivet
Sub Part 14 Retainer Plate (GB&FW)
Sub Part 15 Pre-damper hysteresis device
Sub Part 16 Main damper hysteresis device
Sub Part 17 Pre-damper friction washer
Sub Part 18 Hub
Sub Part 19 Damper washer with tabs
Sub Part 20 Pre-damper elastic washer
Sub Part 21 Drive Plate
Sub Part 22 Damper elastic washer
Sub Part 23 Damper & Predamper Springs
Sub Part 24 Bushing & H2 H3 Sub groups
Sub Part 25 Stop pin
Sub Part 26 Ring Gear
Sub Part 27 Flywheel Cast Iron
Sub Part 28 Dowel pin

List of basic functions:
BF 1 Avoid slippage
BF 2 Avoid high wearing
BF 3 Avoid burst
BF 4 Ensure the right fastening to the flywheel
BF 5 Withstand torque and over torque in drive and coast
BF 6 Avoid pumping
BF 7 Withstanding torque/over torque during engaging and release
BF 8 Ensure the right fastening to the crankshaft
BF 9 Avoid "not pulling off" / Grant pedal reserve
BF 10 Avoid judder
BF 11 Avoid "stay-out"
BF 12 Allow the disengagement with no excessive loads
BF 13 Allow gear shift without wearing the synchronizers too early
BF 14 Grant suitable hump
BF 15 Transmit load from clutch pedal to the external gearshift lever

BF 16 Avoid noise during pedal actuation
BF 17 Guaranteeing correct clutch fastening face position
BF 18 Withstanding bearing load
BF 19 To be assembled correctly on the flywheel
BF 20 To be assembled correctly on the gearbox
BF 21 To be assembled correctly on firewall/pedal box
BF 22 To be settled correctly into the engine compartment
BF 23 Permit empty and filling on line
BF 24 Avoid pollution from external agents
BF 25 Being identifiable
BF 26 Withstanding shocks
BF 27 Being able to be fitted correctly on crankshaft
BF 28 Transmit the torque of the starter
BF 29 Grant the starting / shut down of the engine
BF 30 Ensure right rising / drop off from idle speed
BF 31 Supplying information to the engine control sensors
BF 32 Withstanding corrosion
BF 33 Withstanding shocks
BF 34 Withstanding fatigue
BF 35 Withstanding wear
BF 36 Avoiding high deformation and withstanding thermal shock
BF 37 Avoiding centrifugation
BF 38 Withstanding stress caused by axial pulsation of the crankshaft
BF 39 Withstanding stress caused by bending of the crankshaft
BF 40 Long-lasting functions
BF 41 Withstand the torsional solicitations (rigid flywheel or DMF) and resonance shocks (DMF)
BF 42 Reducing irregularities of the engine in rotation (inertia)
BF 43 Avoiding rotation noise (unbalance)
BF 44 Avoiding clutch pedal vibrations
BF 45 Filtering axial vibrations
BF 46 Allow movements related to input shaft-damper

### C. Fuzzy rule-base

**Table 4.** Fuzzy rule-base depending on the knowledge of automotive clutch experts.

| If Difficulty is […] | and Benefit is […] | and Cost is […] | then Importance is […] |
|---|---|---|---|
| Low | Low | Medium | Low |
| High | High | High | Medium |
| Medium | Medium | High | Medium |
| Medium | High | High | Medium |
| Low | Low | High | Low |
| Medium | High | Medium | Medium |
| Medium | Medium | Low | Medium |
| High | Low | Medium | Low |
| Medium | Low | High | Low |
| Medium | Low | Low | Low |
| Low | High | High | Medium |
| Low | High | Low | High |
| Low | Medium | Low | High |
| High | Medium | Medium | Medium |
| Low | Medium | Medium | Medium |
| Low | High | Medium | Medium |
| High | Low | Low | Low |
| Medium | Medium | Medium | Medium |
| High | Low | High | Low |
| Medium | High | Low | High |
| Medium | Low | Medium | Low |
| High | High | Low | Medium |
| High | Medium | High | Low |
| Low | Medium | High | Low |
| Low | Low | Low | Medium |
| High | High | Medium | Medium |
| High | Medium | Low | Medium |