COMBINING THE KANO MODEL, P-DIAGRAM AND QUALITY FUNCTION DEPLOYMENT (QFD) TO BUILD AN ADAPTED TECHNOLOGY ROADMAPPING (A-TRM) PROCESS

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Abstract. *The Technology Roadmapping (TRM) method is applied to capture the changes in the elements – market, product and technology – and the impacts of these changes on an organization over time. Basically, it may be used to support the management decision for which technology should be developed and, therefore, where and when the resources of a company should be applied. This paper presents a novel process called Adapted TRM (A-TRM) that integrates other three product development tools – Kano Model, P-diagram and Quality Function Deployment - to translate the customer needs and technical characteristics of a system into a technology plan. The method may be applied to analyze and compare technologies of a specific system whose functions affect customer perception. This work also details the interaction between each of the selected tools and how the QFD may be interpreted to generate a technology roadmap. As a case study, the cold start system of flex fuel vehicles is used to exemplify the proposed process.*

Keywords*: Technology Roadmapping, QFD, Kano Model, P-diagram, Cold Start System*

1. INTRODUCTION

With the increasing development of new technologies, it is necessary to a company to keep innovating and, fundamentally, making the right choices about which technologies should be brought to the market. In the automotive industry, develop and implement non-appropriate technologies, besides consuming valuable resources, might impact negatively not only to the applied vehicle model, but also to the brand in the whole sense. To capture changes in the elements – market, product and technology – and the impacts of these on an organization over time is a key process to support the management decision on which technology should be developed and, therefore, where and when the resources of a company should be applied.

These critical choices must be taken into account right from the beginning of the product development cycle – the informational project phase (Rozenfeld *et al*., 2006). However, it is in the very earlier stages of product development that confidence level of product characteristics is low and uncertainties are high. To understand the customer needs with accurate information and foresees which kind of product will be desired or necessary in the future is one strategy to minimize course changes at further phases.

There are a number of methods available at the informational project phase to identify and analyze customer needs and customer requirements, such as QFD – Quality Function Deployment, Conjoint Analysis, Pugh Method, AHP – Analytic Hierarchy Process (Martini *et al.*, 2003). However, low emphasis is given to processes that link these tools to the company strategy planning. The strategy planning activity requires more time from the product development working group but shall result in benefits of integrating functional areas, facilitating communication, sharing information and having a clear view of what was decided and defined up in the initial phase of product development process.

The necessity of having a formal process that guides the analysis and compiles, in an intuitive way, the results and strategy obtained during the informational project phase turned out to be the motivation of this paper. The Adapted Technology Roadmapping (A-TRM) process described herein is based upon the Technology Roadmapping – TRM, an approach to support the decision making in strategic management of new technologies, and whose applications are increasing by the fact of having characteristics that allow its customization and flexibility of application (Phaal et al., 2001). The term Adapted comes from the fact that the original TRM is populated with well known quality tools – QFD, Kano Model and P-diagram. The process is composed of activities that take place in the informational project phase with the main objective of create a technology roadmap applied to a specific system, in this case, the Cold Start System of Flex Fuel vehicles.

The paper is structured as follows: Section Two lays down the necessary theoretical background. The proposed process and how tools are integrated to each other are described in details in Section Three. Section Four presents the application of A-TRM to a case study. Key conclusions and further development are presented in Section Five.

2. THEORETICAL BACKGROUND

The definitions, concepts and tools shown below are useful to better understand the proposed process. However, the usage of A-TRM assumes a basic understanding of the mentioned tools by the potential user.

2.1. Technology Roadmapping - TRM

Technology Roadmapping (TRM) is a recent approach to support the decision making in strategic management of new technologies. Its applications are ever increasing due to some characteristics that allow its customization and flexibility of usage.

Probert *et al.* (2003) states that applications include industry segment maps, frequently as part of technologic forecast program, and that, firms that adopted the TRM technique have reported positive feedback of its value, proving out its capacity. According to Ibarra (2007), the objective of TRM is to guide the team on the planning phase of new products in a strategic approach, in order to face fast market and technology changes.

In a strategic level, TRM (Phaal et al., 2001) is very useful, especially for its flexibility and ability of adaption to several contexts. Its potential, along the product development of a company, allows for evaluating many opportunities and ideas of new products prior to the formal operation of projects (Drummond, 2005).

According to Phaal and Muller (2009), the roadmap architecture is comprised of two key dimensions, as depicted in Fig. 1:

(1) Timeframes (typically the horizontal axis), which may include the past, short, medium and long-term perspectives, as well as aspirations/vision;

(2) Layers and sub-layers (typically the vertical axis), represented by a systems-based hierarchical taxonomy, which allows different levels of detail to be addressed. The common approach for these layers is to use the trinomial Market, Product and Technology (Garcia and Bray, 1997)

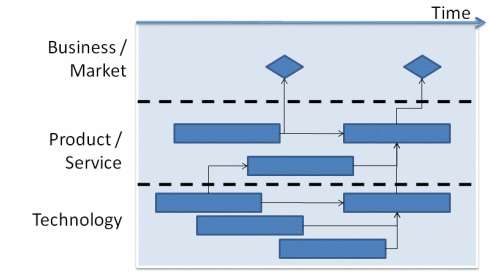


Figure 1. Schematic technology roadmap, showing how technology can be aligned to product and market opportunities (Phaal *et al.*, 2001)

Phaal *et al.* (2001), based on a collection of more than 20 roadmaps developed in collaboration with several companies, describes a management guide to support the creation of a technology roadmap. Basically, it proposes a sequence of four workshops that covers each of the three key layers of the roadmap and a fourth final one bringing the layers together on a time-basis to construct the roadmap.

Garcia and Bray (1997) states that the Technology Roadmap development consists in: (1) Identify the product that is the focus of the roadmap; (2) Identify the critical system requirements and their targets; (3) Specify the major technology areas; (4) Specify the technology drivers and their targets; (5) Identify technology alternatives and their time lines; (6) Recommend the technology alternatives that should be pursued; (7) Create the technology roadmap report.

This paper proposes a sequence of activities supported by specific tools that may guide to the creation of a technology roadmap adapted and applied to vehicle sub-systems.

2.2. Kano Model

The Kano model of customer satisfaction is a useful tool to classify and prioritize customer needs based on how they affect customer's satisfaction (Kano *et al.*, 1984). It captures the nonlinear relationship between product performance and customer satisfaction. In practice, three types of product attributes are identified:

(1) Basic quality, must-be attributes are expected by the customers and they lead to extreme customer dissatisfaction if they are absent or poorly satisfied;

(2) Performance quality, one-dimensional attributes are those for which better fulfillment leads to linear increment of customer satisfaction, and

(3) Excitement quality, attractive attributes are usually unexpected by the customers and can result in great satisfaction if they are available.

As shown in Fig. 2, the Kano Model provides a visual interpretation of the positioning of product attributes, relating Customer Satisfaction with Performance. Data to fulfill Kano Model can be provided by surveys, claim data and warranty. In this paper, the Kano Model summarizes the data gathered from a qualitative research performed to obtain the customers perception on each attribute of the vehicle sub-system.

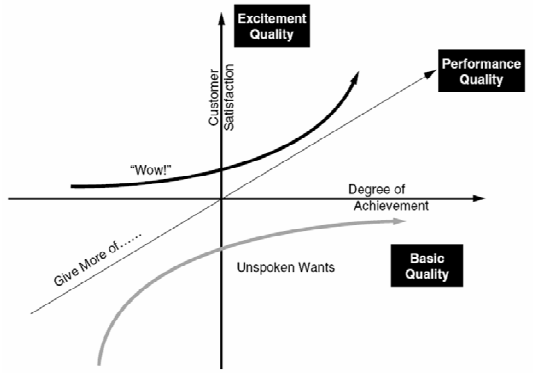


Figure 2. Types of product attributes – Kano Model (Yang and El-Hayek, 2003)

2.3. Quality Function Deployment - QFD

QFD tool is used to prioritize and understand the relations between customer needs and product characteristics. The method was created in the beginning of the seventies at Mitsubishi Heavy Industry with the objective of correlating government regulatory requirements, critical project requirements and customer requirements to the project characteristics, ranking the importance among each of them. Quickly the tool has begun to be used in the automotive industry (YANG, 2003).

Carnevalli and Miguel (2008), in a recent study, show that QFD is used as a method of product development with the objective of translating customer requirements in activities to develop products and services. According to Yang and El-Haik (2003), to know the customer needs is mandatory for a company to keep or improve its position in the market.

Quality function deployment is accomplished by multidisciplinary teams using a series of charts to deploy critical customer attributes throughout the phases of design development. QFD is usually deployed over four phases. The four phases are Phase 1—critical-to-satisfaction planning; Phase 2—functional requirements; Phase 3—design parameters planning and Phase 4—process variables planning (YANG and EL-HAYEK, 2003).

In this paper, since the A-TRM fits into the Product Planning phase, the process considers the usage of Phase 1 only.

The critical-to-satisfaction planning phase, also known as first house of quality (ROZENFELD, 2006), is shown in Fig. 3. Based on Rozenfeld (2006) and Yang and Hayek (2003), this typical structure is composed by:

(1) customer attributes, WHAT customer wants;
(2) customer desirability, the relevance of each attribute;
(3) product characteristics, HOW customer attributes are translated to product design criteria;
(4) relationship matrix, it correlates WHAT with HOW;
(5) correlation matrix, it correlates product characteristics with each others;
(6) competitive benchmarking, used to rate the WHATs of the various designs in a particular application;
(7) competitive assessment, HOW MUCH rates HOWs for the same competitor against HOWs from a technical perspective, quantifies the customers' needs and expectations and create a target for the design team. The HOW MUCHs also create a basis for assessing success.

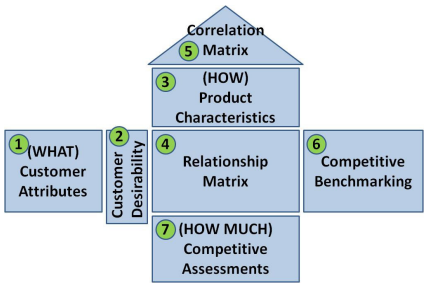


Figure 3. First House of Quality – QFD

According to Chan and Wu (2005) there are several difficulties in QFD application, among them: interpreting the customer voice, defining the correlations between the quality demanded and quality characteristics. In order minimize these difficulties, in this paper, the QFD is proposed as an integration tool supported by the P-diagram and Kano Model With the P-diagram, product characteristics are deeper investigated, and in the Kano Model, the same emphasis applies to the customer voice. A schematic flow shown in Fig. 4 presents an overview of the interaction between QFD and other tools. More details of tools interaction are provided on section three.

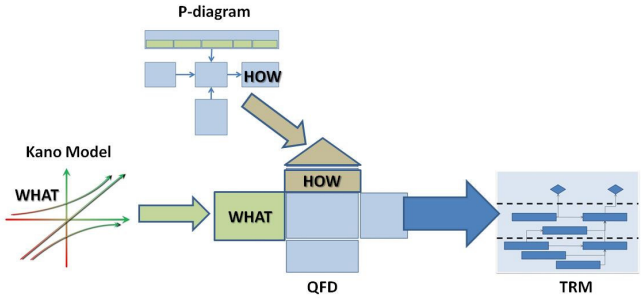


Figure 4. Interaction of QFD with other design tools

Thus, QFD shall provide a source of treated data, ready to be discussed by the team involved with product development in order to facilitate the construction of a technology roadmap.

2.4. P-diagram

For Yang and El-Hayek (2003), the P-diagram is a robust design tool that may be used to summarize and capture inputs and outputs of a product. It distinguishes the factors the team has control over, the design properties at different hierarchal levels, from the factors the design team can't control or wish not to control because of technology or cost inhibitors, the noise factors.

The P-diagram process is used in this paper as a design tool to model the product in context. As depicted in Fig. 5, it supports product characteristics identification and provides the team a critical technical analysis on the product operation since it relates:

(1) Customer intent, WHAT the customer wants;

(2) Response, the translation of HOW customers perceive result into measurable performance data in engineering terms;

(3) System, it denotes the scope of work, the system the is focusing on;

(4) Design parameters, product factors that can be controlled, adjusted; and

(5) Noise factors, variables that cannot be controlled or are not supposed to be controlled.

The P-diagram clearly helps the QFD matrix construction since it enforces the discussion of relating the Product characteristics—HOW with the Customer requirements—WHAT.

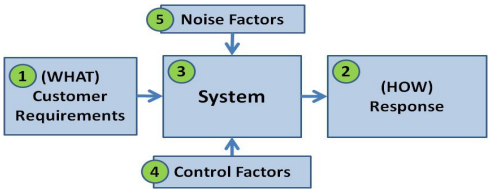


Figure 5. P-diagram

3. A-TRM Process

The A-TRM approach has been developed as part of a one-year work dedicated to define a system strategy for the Cold Start System on Flex Fuel vehicles. The A-TRM process description has been written to support the application of the A-TRM on any other products by any other teams interested on: developing a technology roadmap for a specific system; support technology strategy and planning initiatives on the firm; support communication between technical and commercial functions.

Fundamentals of A-TRM are the customization of TRM standard process with the population of selected engineering methods like QFD, P-diagram and Kano Model. The link between Kano Model and QFD has been

suggested by several authors including Ronzenfeld *et al.* (2006), Yang and El-Hayk (2003), Yadav and Goel (2008), Carnevalli and Miguel (2008), Govers (1996). Also, there are references of linking P-diagram to the QFD on Dickson (2006), Jensen *et al.* (2008), Wasiloff and El-Haik (2004).

Yang and El-Hayk (2003) proposes the usage of QFD and Kano Model, if adapted, to address the needs of the user such as technology roadmaps, to direct design toward the planned technology evolution and to prioritize resources. That's the fundamental of the A-TRM process, to use the presented tools in a process that guides the team to the technology roadmap creation.

3.1. Standard Process Description

The A-TRM process comprises five pre-defined phases as depicted in Fig. 6:

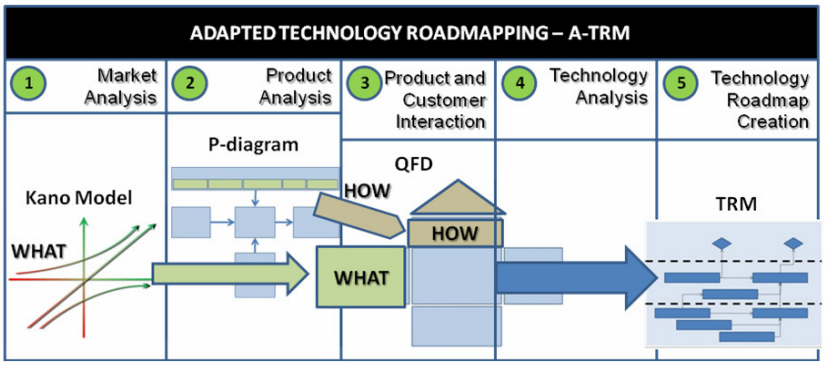


Figure 6. Adapted Technology Roadmapping – A-TRM process overview

The A-TRM requires a team leader, or facilitator, that knows the process and, therefore, guide the successful completion of each phase's objectives. The team shall be composed by the system's components engineers, marketing members, quality engineers, interfaced system engineers, attributes engineers, buyers and any other members that may contribute to the product planning discussion. The team shall perform phase activities on specific meetings, workshops or seminars.

A mandatory pre-activity that the team leader should conduct is to plan the A-TRM execution. This includes the proposed agenda, a clear scope of study, people nomination and invitation and any other resources that may be necessary like rooms, audio conferences and presentations.

3.2. Phase 1 – Market Analysis – Kano Model

The key tool of this first phase is the Kano Model. The main objective at this time is to understand customers' needs, identify the WHAT they want and the relevance of each requirement to them. The sequence of activities, as shown in Tab. 1, guides the team for building up the Kano Model.

Table 1. Quick-guide to Kano Model creation

Activity	Source	Why
a. List customer requirements	Market research, Clinic research	Focus on WHAT matters to the customer
b. Classify customer requirements by category	Structured questionnaire, Interviews, Quality history	Shows the relevance of each attribute
c. Set degree of achievement for each customer requirement	Benchmarking studies, Quality data, Customer satisfaction questionnaire	Identify opportunities / gaps for improvement

3.2. Phase 2 – Product Analysis – P-diagram

At this phase, the design team has to model the product using the P-diagram. The main objective of this phase is to relate WHAT customer wants with HOW system responds. This team's exercise requires technical discussions on how system may operate in several conditions, since it takes into account Noise factors and Control Factors. The P-diagram is a way to guarantee that the team has thought on how each customer requirement is transformed on product response, characteristic.

The sequence of activities, as shown in Tab. 2, guides the P-diagram construction..

Table 2. Quick-guide to P-diagram creation

Activity	Source	Why
a. List customer requirements (including Corporate and Regulatory) - WHAT	Kano model	Focus on WHAT matters to the customer
b. List noise factors and control factors	FMEA, Fishbone diagram, Function diagram	Forces the understanding of system's operation
c. List system's responses to each customer requirement input - HOW	System design specifications, Project attributes	Identify opportunities / gaps for improvement

3.3. Phase 3 – Product and Customer Interaction – First House of Quality - QFD

Due to its complexity, the usage of QFD is split in two steps, phase 3 and 4. Phase 3 consists in transporting WHATs and HOWs from the previous methods to the House of Quality. The main objective at this point is to merge all information available up to this point to a single structured matrix and, therefore, provide a source of treated data to be analyzed and help to create a technology roadmap.

The sequence of activities shown in Tab. 3, guides the team on the first step of QFD construction.

Table 3. House of Quality – QFD – creation guide – first step

Activity	Source	Why
a. Fill in room 1 with customer requirements (including Corporate and Regulatory) - WHAT	Kano model	Focus on WHAT matters to the customer
b. Fill in section 2 with customer requirement importance based on Kano model's classification	Kano model and Fig. 7	Weighs customer requirements
c. Fill in section 3 with product characteristics identified on the P-diagram - HOW	P-diagram	Translates to product design criteria
d. Identify, on section 4, the relationship between WHATs and HOWs	P-diagram, Kano Model and Fig. 7	Links the customer to the design
e. Identify, on section 5, the correlation between product characteristics HOWs	P-diagram, Boundary diagram, Function diagram and Fig. 7	Identifies product trade-offs and sinergies

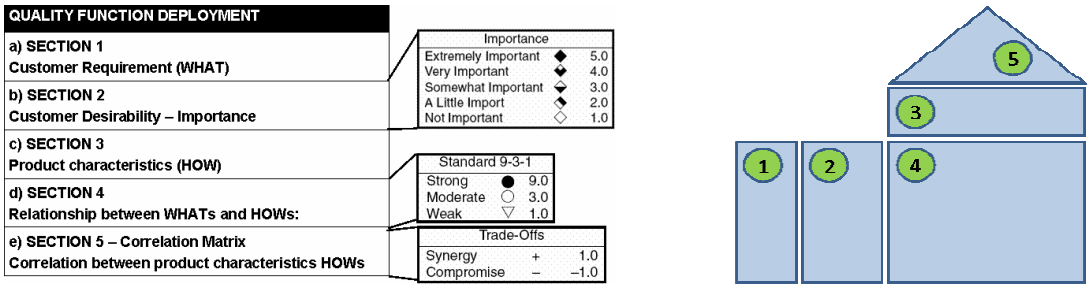


Figure 7. QFD Importance and Relationship ratings

After completion of these 5 activities, the QFD may contain a good source of information related to the scoped system. Although, in order to get benefits of using the House of Quality tool on a technology roadmap creation, it's necessary to include the technology benchmarking data on it. That's what is planned for phase 4.

3.4. Phase 4 –Technology Analysis - QFD

Phase 4 consists in adding information from technologies related to the system. This exercise includes current, emerging and future technologies. The main objective at this point is to complete the House of Quality with external and internal benchmarking information related to the listed technologies. The competitive section of Matrix 1 where is usually listed the company competitors, must be fulfilled with technology alternatives. This phase may provide the design team a complete House of Quality with a summary of information linking customer requirements, product data and technologies that shall serve as the base for creation of a technology roadmap.

The sequence of activities, as shown on Tab. 4, guides the team on the completion of the House of Quality – QFD started on phase 3.

Table 4. House of Quality – QFD – completion guide.

Activity	Source	Why
a. List all system related technologies	Benchmarking, Advanced technology data, TRIZ	Identifies different technologies levels
b. Fill in the listed technologies on section 6 and 7	Technology list	-
c. Rate the listed technologies on section 6 in relation to the Customer requirement - WHAT	Quality data, Advanced technology data and Fig. 8	Demonstrates how each technology meets customer requirements
d. Rate the listed technologies on section 7 in relation to the Product characteristic – HOW	Quality data, Advanced technology data and Fig. 8	Demonstrates HOW MUCH each technology meets product attributes.
e. Calculate on section 7 Product characteristic relevance – HOW MUCH	Sections 2 and 4	Identifies HOW MUCH each product characteristic is relevant

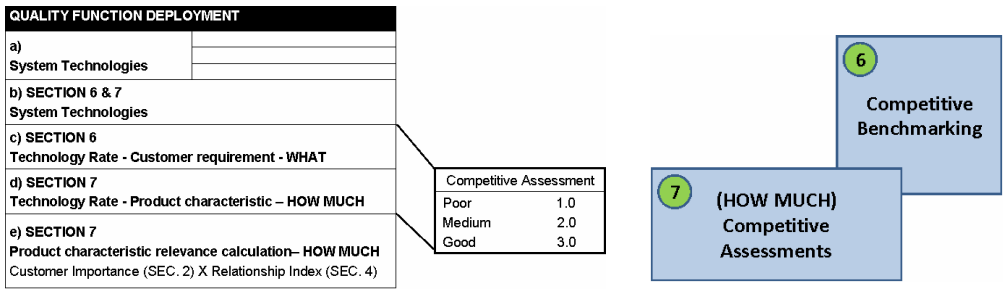


Figure 8. QFD competitive assessment ratings

3.5. Phase 5 – Technology Roadmap Creation

A-TRM Phase 5 guides to the completion of the technology roadmap template, in Fig. 9, by listing, in Tab. 5, a sequence of activities that should be pursued.

Table 5. Outlining the Technology Roadmap

Activity	Source	Why
a. List technology alternatives	QFD, Advanced technology data	Confirms which technologies will be shown on the roadmap
b. List products planned in the firm	Product cycle plan	Confirms products affected by selected technologies
c. List technologies and products time lines	Product cycle plan and Advanced technology data	Supports the range definition of the roadmap timeframe
d. Chart a blank Roadmap with Market, Product and Technology layers and Timeframe	Technology history data, Product cycle plan	Drafts the Roadmap
e. Fill in the chart with Product, Technologies and Market history,	Technology history data, Product cycle plan	States history background
f. Identify emerging technology alternatives that satisfy customer needs (High importance rates)	QFD	Defines the technology plan of firm's product
g. Link in the chart selected Technologies to Products and to Market launch milestone	Technology Roadmap	Sets the implementation timing targets for the product development plan

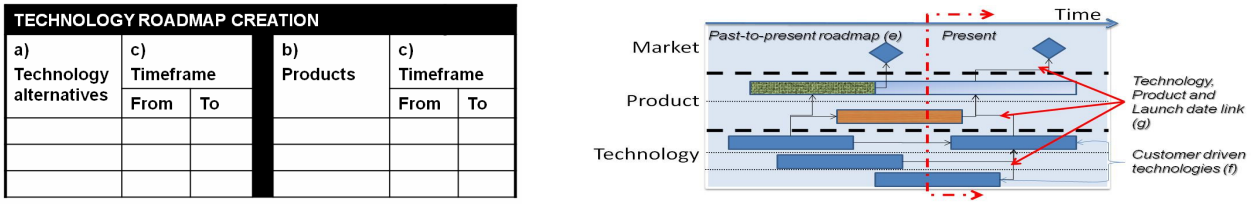


Figure 9. Technology Roadmap template

The key element of this phase is how to interpret the material raised up to this phase by the team, as described in step f of Table 5. For this reason, the understanding of the QFD matrix is essential to the completion of the technology roadmap. Competitive assessment and importance ratings, at sections 6 and 7 are developed as a basis for risk assessment when making decisions relative to trade-offs and compromises (Yang and El-Hayk, 2003).

4. CASE-STUDY: FLEX FUEL COLD START

The intention of this chapter is to clarify the usage of A-TRM. Part of the data from a case-study, flex fuel cold start, is used to illustrate the processes phases. A brief explanation of the system is presented to help the understanding of its context. A technology roadmap is provided as result of the method used and shown at the end of this section.

Cold start system is responsible for enabling engine start of flex fuel vehicles when fuel filled with ethanol at high blends and at low temperatures. The current system solution in production is an auxiliary gasoline reservoir that must be fuel filled from time-to-time. The cold start drivability performance is also poor. Emerging technologies consist in the pre-heating of ethanol, dispensing the reservoir. Both technologies have interaction with the customer, mainly during the engine start situation.

Based on this context, the following pictures and tables depict the application of the A-TRM method presenting each phase result with elucidative comments.

A-TRM PHASE 1: In the initial step, the Kano model (see Fig. 10), must capture what is relevant to the customer.

KANO MODEL

a) Customer Requirement (WHAT)	b) Category • Excitement • Performance • Basic	c) Degree of acchievement 0-100%
Easy-to-operate	Basic	80%
Safe	Basic	100%
Fast to start	Performance	60%
Not dependent on gasoline	Excitement	55%
Fuel Economy	Performance	70%

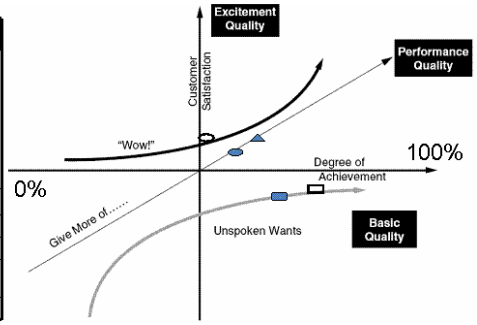


Figure 10. A-TRM Phase 1 – Kano Model

A-TRM PHASE 2: Figure 11 shows the P-diagram where the customer requirements are translated into product characteristics.

P-DIAGRAM

a) Customer Requirement (WHAT)	b) Noise and Control Factors	c) System Response (HOW)
Easy-to-operate	Humidity – N	Customer interface
Safe	Battery Voltage – C	Start drivability
Fast to start	Fuel contamination – N	Crank time
Not dependent on gasoline	Fuel Pump Pressure C	Power consumption
Fuel Economy	Air temperature - C	Emissions level

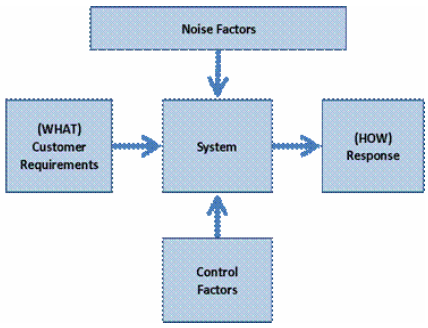
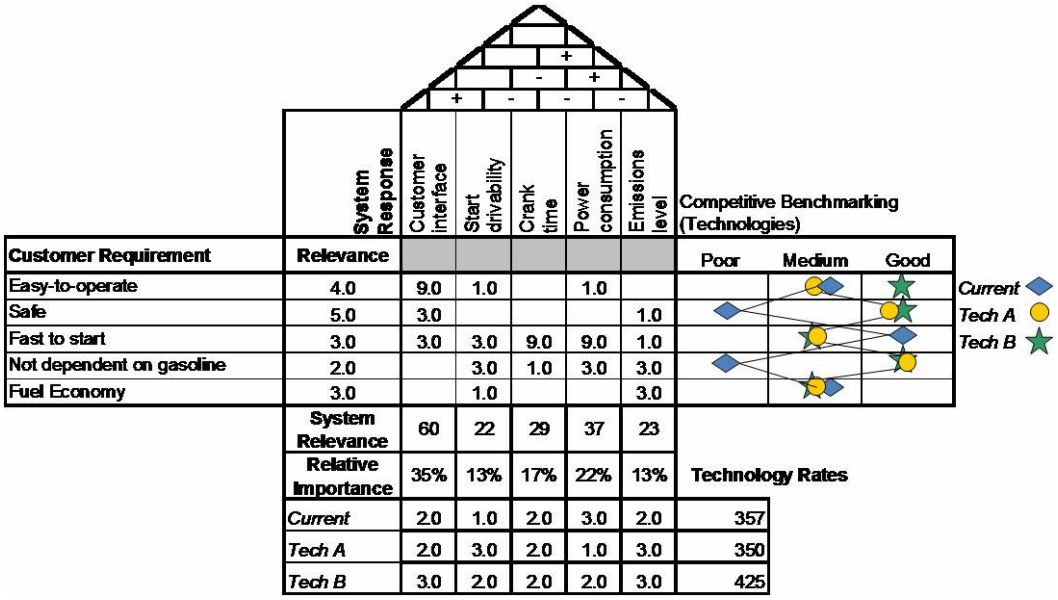


Figure 11. A-TRM Phase 2 – P-diagram

A-TRM PHASES 3 AND 4: Phase 3 of QFD fulfillment relates identified the Customer Requirements to Product Characteristics, fed by Kano and P-diagram data. Phase 4 provides the Technology Assessment. The complete House of Quality is illustrated in Fig. 12.



Customer Requirement	Relevance	System Response	Customer interface	Start drivability	Crank time	Power consumption	Emissions level
Easy-to-operate	4.0	9.0	1.0		1.0		
Safe	5.0	3.0				1.0	
Fast to start	3.0	3.0	3.0	9.0	9.0	1.0	
Not dependent on gasoline	2.0		3.0	1.0	3.0	3.0	
Fuel Economy	3.0		1.0			3.0	
	System Relevance	60	22	29	37	23	
	Relative Importance	35%	13%	17%	22%	13%	
Current		2.0	1.0	2.0	3.0	2.0	357
Tech A		2.0	3.0	2.0	1.0	3.0	350
Tech B		3.0	2.0	2.0	2.0	3.0	425

Figure 12. A-TRM Phases 3 and 4 –House of Quality

A-TRM PHASE 5: Phase 5 is an exercise of interpretation of all generated information, mainly the House of Quality. When looking at the *Technology Rate*, it can be realized that Technology B satisfies most of Customer requirements and over-achieves Current Technology performance. Technology A, however, brings no significant improvement to system response when compared to the current one. Hence, Tech B can be interpreted as a possible solution for a customer satisfaction improvement.

During the template fulfillment, it is also necessary to take into account the time that these technologies might be available, as shown on the list in Fig. 13. It is also important to note that the short range of forecasting, five years, favors more accurate predictions. Based on these considerations, the team's judgment is visually depicted on the Technology Roadmap.

In this case-study, the key message that can be perceived from the roadmap is that the team recommends:

- To pursue implementation of Technology B on Products B and C with Launch dates forecasted to 2012 and 2014 and
- To disregard the development of Tech A.

TECHNOLOGY ROADMAP CREATION					
a) Technology alternatives	c) Timeframe		b) Products	c) Timeframe	
	From	To		From	To
Current	2003	-	Product A	2003	2008
Tech A	2011	2015	Product B	2011	2016
Tech B	2012	2016	Product C	2010	2016

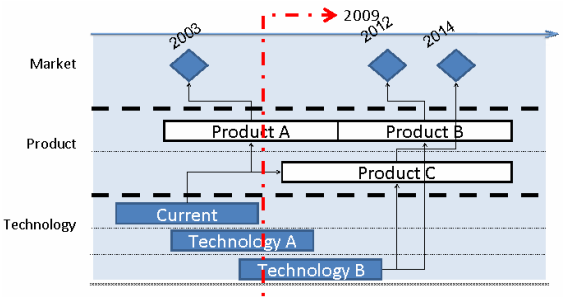


Figure 13. A-TRM Phase 5 – Technology Roadmap

5. CONCLUSIONS

The practical exercise that resulted in the customization of the TRM process and, therefore, the creation of the A-TRM illustrates the path the team walked in. The core idea of enforcing the systemic discussion, with the usage of the aforementioned tools, focusing on each trinomial guided the team to a smooth convergence on which technology to pursue, in which product to implement and when launching it into the market. Hence, to create the Technology Roadmap after all the proposed phases and discussions were substantially facilitated.

Another key factor that favored the application of A-TRM was the previous knowledge by the team members of the proposed tools. The benefits observed during A-TRM application in the proposed context were common to the standard

TRM process: the improved inter-functional alignment, better communication, the endorsed team spirit and clearly supporting integrated strategic planning.

Further opportunities of research might be:

- To evaluate the addition of financial data, such as costs and investments, related to technologies and products to enrich the analysis for the roadmap creation;
- To propose a systemic interpretation of each section of the House of Quality (Yang and El-Haik, 2003);
- To propose interpretation of the House of Quality's section 5 as source of unidentified opportunities and solutions, using methods like the TRIZ (Dickinson, 2006; Andreassa and Parreira, 2007).
- To integrate the A-TRM to the Product Development Process.

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