Systematization of technology roadmapping

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Abstract: Technology roadmapping is increasingly being used by companies to guide the team in charge to plan the new products in a strategic way and to deal with competitors, customer expectations, a need for reducing in the product development time, and the rapid pace of technological change. A literature review of this process revealed the need for a simplified and practical guide to support the team in the systematization of information on technologies, products and markets, and in the positioning of this information in each layer of the roadmap in a given planning horizon. This process has been primarily presented in general terms without detailing the procedures required to facilitate the work of the planning team. Hence, this paper presents a review of the main approaches and different types of maps found in the literature, highlighting and analyzing the best practices suggested and the critical points. Based on this, a detailed and logical sequence of ativities is proposed along with a set of methods and tools to support the process of technology roadmapping illustrating the main steps by means of examples.

Keywords: planning of new products and technologies, technology roadmapping.

1. Introduction

In recent decades, an exigent and dynamic environment has imposed on companies the need to innovate differentiated products and processes in order to conquer new markets and maintain a competitive position.

In this context, companies, regardless of their size, age or sector, need to continuously monitor the progress of the technologies used in their products and processes, as well as those that can provide new product development. With this pro-active attitude, a company can also foresee, early enough, the abilities and skills needed to dominate the technology before it is incorporated into the product.

According to Deitos (2002), the traditional practices of management, by nature, are not always pertinent to technology planning. They are more oriented to the management stability and coherence of the company. In this regard, new methods are needed to support the search for, monitoring, analysis and systematization of information geared to the development of new products.

Despite companies being conscious of the strategic importance of the planning of new technologies, not all move in this direction. They know what it is necessary to do, but not how to do it, or they have difficulty in incorporating knowledge into their management practices, whether for cultural, financial, structural, or other reasons.

Against this background, technology roadmapping is presented as a method appropriate for the facilitation of technology planning in companies and the minimization of the barriers associated with this process.

In Brazil there are still few studies that address the use of this method. One implementation study focused on a small technology-based company in the Mobile Internet sector (MATTOS, 2005) has been reported. According to the author, there are still several issues to be explored with respect to the operation of the method: how to obtain and analyze the information necessary for the construction of the layers of the roadmap; how to use other methods and techniques to support the construction of the roadmap; how to detail the inputs and outputs of the roadmap; how to structure the layers in a logical way which indicates the information required and places it in a given planning horizon, among others.

Inserted in this context, this paper presents the basic concepts related to the subject and the most relevant characteristics and types of maps. It also discusses the main procedures already developed which address the topic. On this basis, it introduces a systematic easy-to-use procedure for application in the construction of a technology map, illustrating the main steps through examples. It aims to provide support to companies in exploiting the technology planning process for the development of new products and to contribute to the study of methods and tools to support the innovation of products.

2. Literature review

2.1. Technology roadmap

Technology roadmapping (TRM) is a method with the main objective of assisting in the management of product development at the strategic level, integrating information on the market, the product and technology over time (CHENG; MELHO FILHO, 2007). The resulting document of this process, the technology roadmap, can be presented in several ways, but generally the basic structure comprises several layers (Figure 1) with information positioned and linked along a timeline.

The top layer is generally used to represent the market and business drivers, i.e., the objectives (why) that the company aspires to achieve. The lower layer represents the technologies, and sometimes the R&D projects and the resources necessary to reach the central layer, the product or the service (what). This information is positioned in terms of time (when), considering the past, present and future.

Although the initial roots of the method lie in the American automotive industry, it was popularized by Motorola and Corning in the 1980s. Some authors, such as Kappel (2001) and Probert and Radnor (2003) have emphasized that the purpose of Motorola was to encourage the staff of the company to give special attention to the technological future with regard to the technologies necessary in a long-term perspective to fulfill the needs of future products.

Since then, due to its flexibility, different companies have adopted (and adapted) this method for different strategic purposes, including Philips Electronics (GROENVELD, 1997), Lucent Technologies (ALBRIGHT; KAPPEL, 2003), and General Motors (GROSSMAN, 2004). Recently, it has been used by industrial sectors and national programs to

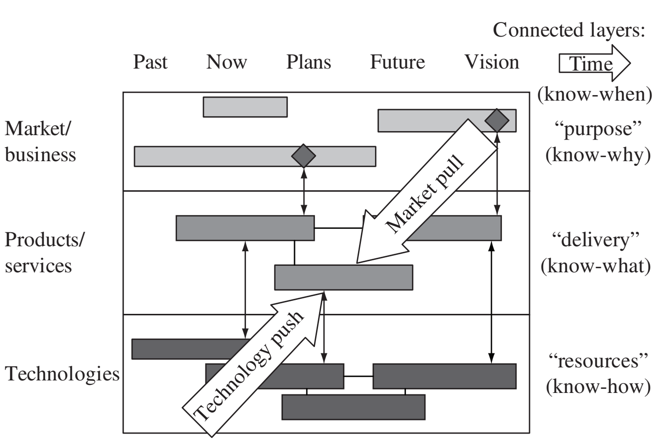

Figure 1. Basic of the technology roadmap structure (PROBERT et al., 2003).

support technological forecast initiatives in strategic sectors (SCHALLER, 2004; PHAAL, 2002).

Currently, there are also research centers that seek to develop best practices for this process. These include CTR (Centre for Technology Roadmapping) of Purdue University and the Center for Technology Management of the University of Cambridge. In addition, there are support software programs for the construction of the roadmap, such as that developed by Motorola, in partnership with Alignent Software: Geneva Vision Strategist®; and another developed by the US Office of Naval of Research (ONR) called the Graphical Modeling System (GMS).

In the literature, different types of roadmaps can be found aimed at the planning of the technology and product, based on practical applications in companies. Six of them are shown in Figure 2.

The first map (a) is the most common type, adopted by Philips Electronics (GROENVELD, 1997). This format in layers facilitates the visualization of how the products of a family of products and the technologies evolve over time. It also shows the planning of the introduction of technologies into products. However, it doesn't contain the layer market.

The second map (b), adopted by the General Motors, is formed only of the technology layer. It shows, through bars, which technologies are being developed by the company in the form of projects and when they should be available (project completion) to be introduced in the product. The status of the investment of resources is also represented in each project, characterized by the line type in the contour of the bars – funded and not funded. Although this format can be less complex, having only the technology layer, it has two disadvantages: i) it doesn't allow the visualization of its integration with the product and market layers; and ii) it doesn't allow the visualization of the potential of alternative technologies for the product in order to follow their evolution, showing only the development of those already resolved in the technological strategy.

In the sequence, the third map (c) is the classic one used by Motorola in the form of bars, similar of the Philips map (a), except for the arrows. Among the maps found in the literature, this one provides more information about the map outputs. It shows, on the ordinate axis, the technology areas or the main components that determine the value for the product. On the abscissa axis, the evolution of the technology is foreseen for each area, which is represented by bars that denote the time that the technology will be used in the product. For example, for the tuning component of a radio, three generations of technologies were foreseen: push button, touchpad and voice actuated. Based on this forecast, Motorola plans how this technology will contribute to the evolution of the features of its products in the course of time. However, support methods to obtain this information are not indicated and, in addition, the map doesn't consider the

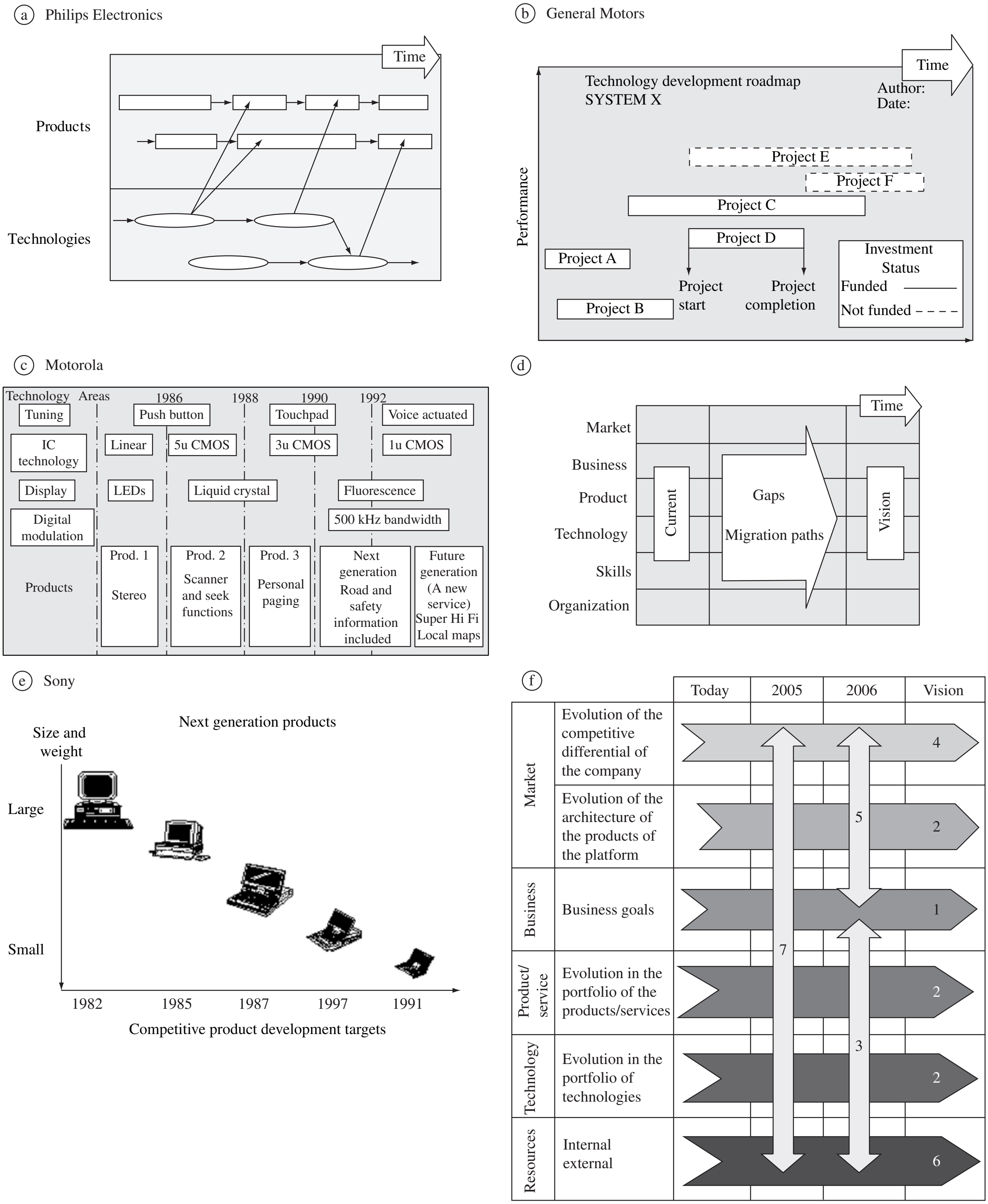

Figure 2. Examples of structures of technology roadmaps. Adapted from: a) Phaal et al. (2001); b) Grossman (2004); c) Koen (1997); d) Phaal et al. (2004b); e) Boulton (1993); and f) Cheng et al. (2005).

market layer, which is vital to an analysis of the commercial viability of the product with a given technology.

This type of format in bars (without the use of arrows), compared with those of Phaal, Farrukh e Probert (2001, 2004a), is advantageous since it condenses the required outputs, facilitating the communication, visualization and integration of the layers of the map without it becoming complex. It also facilitates the automation of the process with the development of software. One example is the software Geneva Vision Strategist® developed by Motorola based on this format.

The fourth map (d) used in companies by Phaal, Farrukh and Probert (2004b), serves as a support to evaluate the different opportunities and future threats of the market in a strategic way. It aims to support, based on the current position, the definition of a future vision for the company, through the identification of gaps and necessary changes in the map layers.

Other companies, such as Sony, use drawings to better visualize the evolution of its products (current and next generation) and to stimulate the creativity of the design team, as illustrated on the map (e). The map is built starting from the vision of the company, which in the example shown is to continuously reduce the price, weight and size of its products. Based on this vision, their products have evolved from mainframe, to PC as desktop, notebook and, more recently, palmtop. To achieve this vision of continuous miniaturization and portability, it is necessary to forecast new technologies through R&D. However, the technology layer is considered apart.

The sixth map (f) was adapted by Cheng et al. (2005) for a technology-based company, adding some layers. The numbers indicate the sequence of steps required to complete the map. This approach starts with the definition of the business goals. The mapping of the necessary changes in the architecture of the products and prioritization of product design and technology over time then follow. After this, the projects are aligned with the business goals. The evolution of the desired competitive differential is then mapped and aligned with the business goal. Resources must then be allocated to the projects. Finally, the alignment is reviewed, weaknesses are identified and the action plan is elaborated. The first difference found on this map is related to the planning horizon. Here, the mapping is firstly in the present, and subsequently it passes to the subsequent years, and it doesn't include past information.

As can be seen, technology maps have been used by companies of different industrial sectors. Some use only one layer, others use several. However, for most companies, the true value of the map is not in the map itself, but in the learning acquired in the process of its construction through continuous discussions and interactions among the members of the team and the top management. However, despite this importance, a gap was observed in relation to how to develop the technology roadmap. The approaches presented are general and they don't detail the procedures, the nature of the information, nor the form of the relationship between different pieces of information. On the other hand, as highlighted by Mattos (2005), the "flexible" nature of the roadmap is advantageous and facilitates its adaptation to the particularities of each company, but this can also complicate its application. It is necessary, therefore, to understand in greater detail the process of technology roadmapping and present alternatives to facilitate its use.

2.2. Technology roadmapping process

The technology roadmapping processes found in the literature (PHAAL et al., 2004b; ALBRIGHT; KAPPEL, 2003), despite having a few differences, comprise three basic stages (Figure 3), which are: i) initial planning; ii) construction of the roadmap; and iii) generation of an action plan.

The planning stage consists of developing the plan for the roadmap construction specifying the scope, time, cost and necessary resources. In the roadmap construction stage, based on the plan defined, the team – usually consisting of the staff of the company and hired specialists – records the information in each layer of the map. This process is guided by a facilitator and makes use of methods such as brainstorming, focal groups and Delphi to develop the information relevant to the issue in question. In the last stage – generation of an action plan –the next steps are planned based on the results of the mapping, which can be the development of new pojects.

For the technology roadmapping, the companies, mainly of large size, hire specialists who have knowledge and experience in the area of the company performance and/or a specific technology. However, this option is considered very costly for small and medium-sized enterprises (SME). Thus, in the first instance, the challenge is in developing

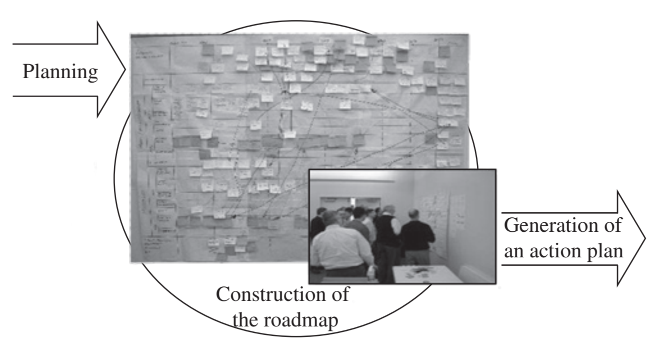

Figure 3. Process of technology roadmapping (adapted from PHAAL, 2005).

procedures to support the technology roadmapping process for more restricted conditions in terms of resources and which can be accomplished by the company's own staff. Also, it is necessary to define and explain several practical aspects related to the construction of the map, such as the obtaining and analysis of the information, the form of representation, the attributes to be employed in each layer and the relationship between the different pieces of information contained in each layer.

These issues appear to be relatively simple, they require systematized procedures to develop important information. In the past, the deficiency of information was due to the difficult access to the sources. But nowadays, the abundance of information sources available has created a new problem: how to identify and select the information (scientific and technological, and related to techniques, economics and the market, etc.) which is relevant and appropriate to the needs of company and able to be operationalized (DEITOS, 2002). Procedures are therefore necessary, that guide, step by step, the roadmap construction and which offer support mechanisms for the analysis of the pieces of information obtained and how they should be linked.

3. Systematization of technology roadmapping

The systematization of technology roadmapping (SyTRM) was developed based on the study and organization of information related to this process in order to guide, step by step, the building of the technology roadmap to aid companies in the technology planning for the development of new products and minimize the barriers presented in the process. This systematic approach aims to reinforce the planning of companies for the future, so that they can reduce their business risks, increase their capacity to respond to change and introduce new products on the market in an easier and faster way, thus facilitating the consolidation of the company in the market.

The general representation of the systematic approach was elaborated based on the representation of the reference model proposed by Romano (2003) for the product development process, which presents, in a synthesized way, the process and its macrophases and phases. In this model (Figure 4), the adaptations of Leonel (2006) with respect to the product planning phase and the technology roadmapping are inserted. As can be observed in the figure, the systematic proposal provides support for the decision making required in the innovation strategic planning, for the exploration of opportunities, and for the generation of ideas and solutions, which comprise the phases of product planning and conceptual design. In this way, it reinforces ideas for priority projects of technological innovation in the short-, medium- and long-term.

The systematic proposal (SyTRM), illustrated in Figure 5, is composed of three macrophases:

- roadmap construction planning;
- roadmap construction – this macrophase is composed of four phases: identification of future innovation opportunities, definition of strategic direction of the company, planning of product line and technology

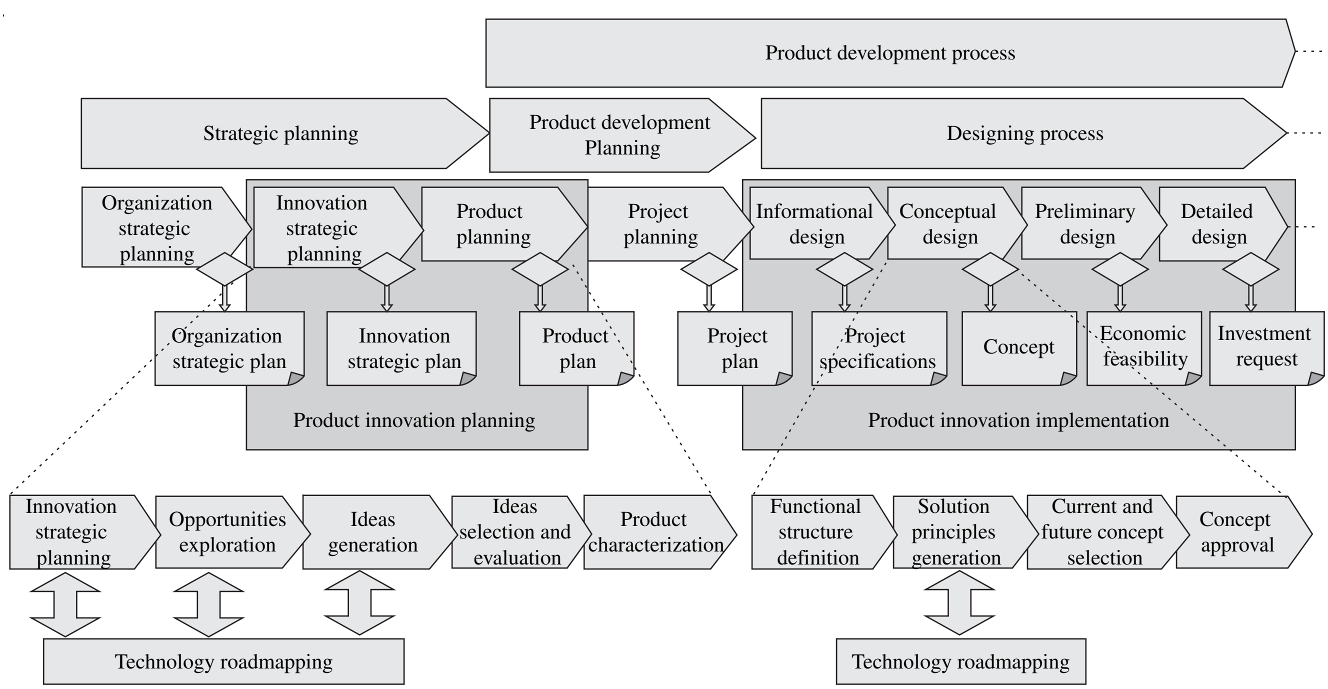

Figure 4. Positioning of the SyTRM in the product development process (adapted from ROMANO, 2003; LEONEL, 2006).

evolution. The results of the implementation of these phases correspond to the goals of the layers of the technology roadmap. Although described in sequence for the purpose of the proposal for the systematic approach, this macrophase is, by nature, iterative and continuous, and as the company learns more about its environment, its own capabilities and how to develop them with success over time, the roadmap is filled out with more information, the fruits of the discussions and interactions among the members of the team. In the systematic approach, according to Figure 5, methods and integrated tools to assist in the identification, analysis, prioritization and alignment of information relevant to the roadmap construction are considered; and

- generation of new project recommendations.

At the end of each phase in Figure 5, an evaluation of the results is carried out (represented by the lozenges in the figure) and the corresponding outputs.

The general structure of the roadmap that is being proposed, with the characterization of each layer, is shown in Figure 6.

The market layer is related to monitoring the competitive environment of the company, in terms of market trends, changes, and developments in the social order, politics, economics, and technology, and it configures the external opportunities for the company to innovate.

The business layer is linked to the business planning of the internal strategic goals of the company. These two layers comprise the motivation (the why) to develop the product. The required information is of a strategic nature – characterized by long-term estimates – in which decisions

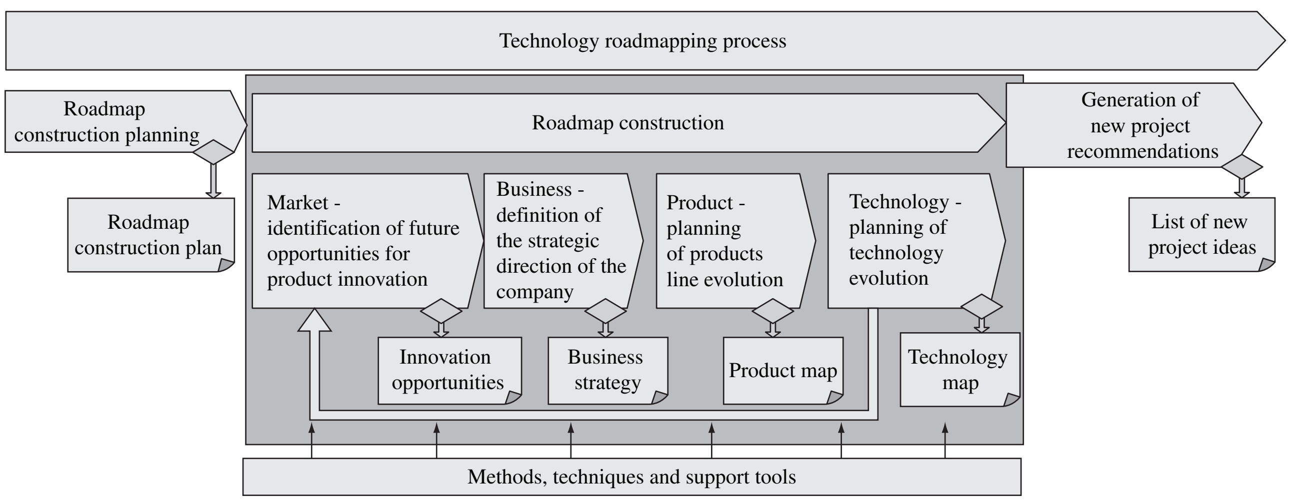

Figure 5. Snapshot of the systematization of the technology roadmapping (SyTRM) (IBARRA, 2007).

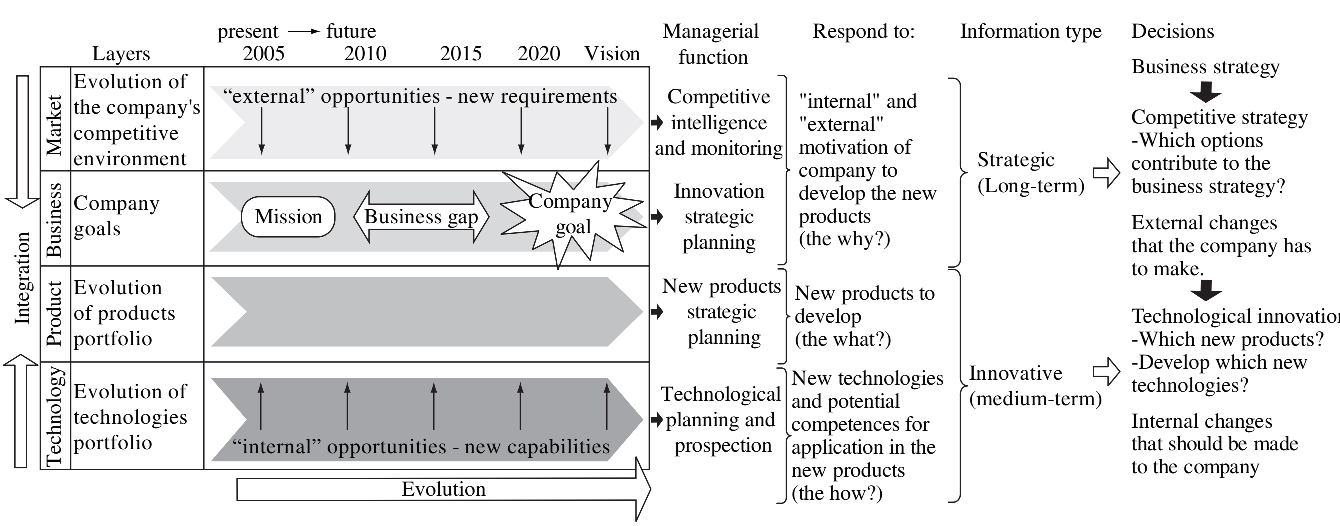

Figure 6. Generic representation of the technology roadmap and its layers (IBARRA, 2007).

are made concerning the necessary external changes that the company must make to contribute to the business strategy.

Based on this, the product and technology layers aid in the planning of the internal changes in the company necessary to achieve this strategy, that is, the new products (the what to develop) and technologies and skills (the how) to be developed within the company. The central layer – product – on the roadmap forms the bridge between the external and internal opportunities of the company. Internal opportunities result in the exploitation of internal research, new competences and skills developed by the company. This information is considered to be of an innovative nature, the planning of which is generally in the mid-term.

Thus, the map can be interpreted and used by the company in two directions: from top to bottom (top-down) and from bottom to top (bottom-up). Similarly, it is important to point out that the technology factor in the systematic approach is considered twice on the map. Firstly, the top layer (market) seeks to monitor the form of continuous evolution and the availability of external technology on the market, the innovation of which is of interest to the company. The layer below this (technology) registers the technological needs in relation to achieving the strategy discussed by the team. Thus, it is intended to prevent useful ideas being discarded. The six phases of the proposed systematic approach are described below.

3.1. Roadmap construction planning

The first phase of the SyTRM seeks to guide the review of the context and particularities of the company to establish the plan for the roadmap construction. Figure 7 shows the flow of the proposed activities and summarizes the input and output information of the phase and indicates the support tools in each activity.

The process starts with the identification of the product line to be analyzed in the process (activity 1.1), seeking to identify which product line offers the biggest business opportunities for the technology roadmapping. Then, in activity (1.2) the time scale for the planning is defined, which depends on the life cycle of the product under analysis. That is, for products with short life cycles, such as mobile phones and laptops, the time scale is generally around 1 or 2 years. On the other hand, for traditional products such as automobiles, with a longer life cycle, the scale can be around 5 years (MATTOS, 2005).

In activity (1.3), participants of the process are identified, analyzing those affected by the results of the map and who is involved, in terms of knowledge and experience, in structuring the layers. These participants are: technical

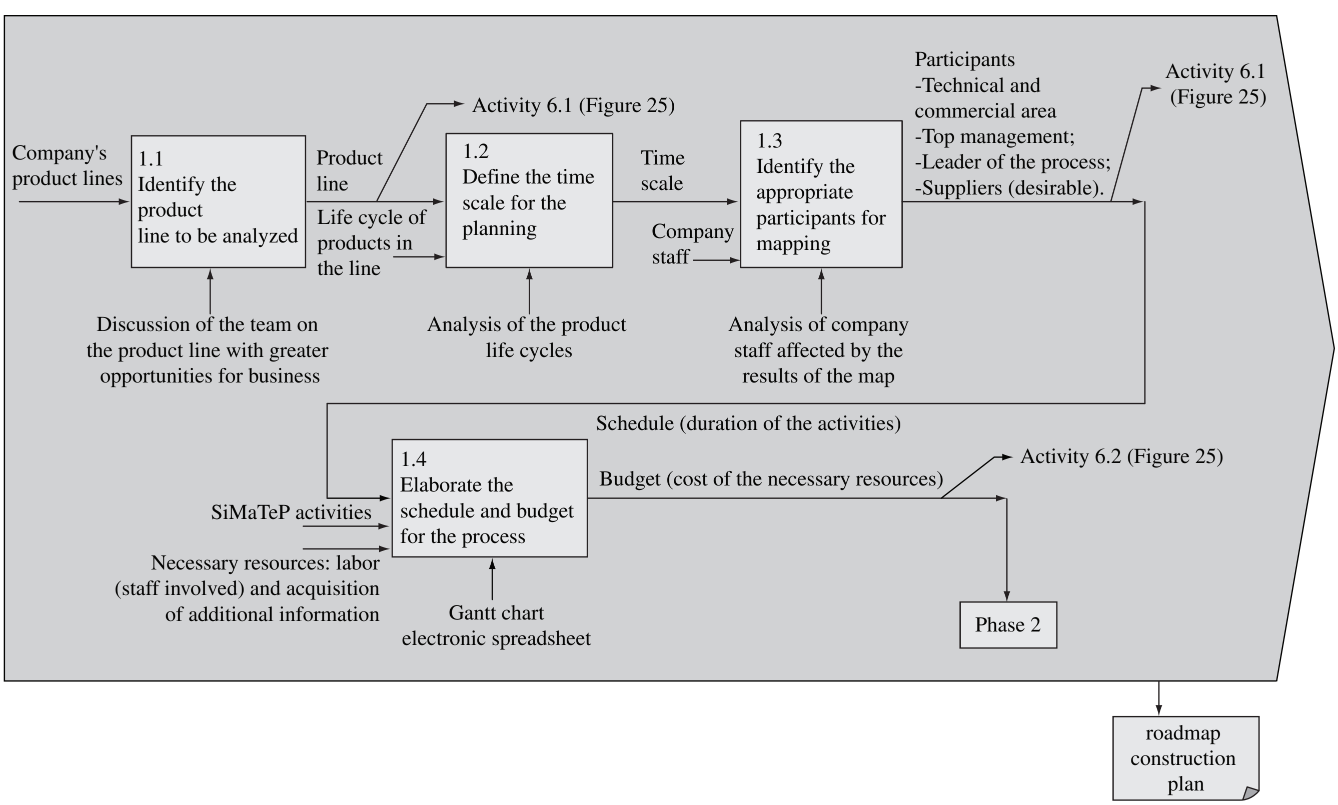

Figure 7. Flow of activities of phase of roadmap construction planning (adapted from IBARRA, 2007).

staff (e.g. R&D, engineering and production), commercial staff (sales, marketing and finance) and top management, since they are responsible for determining the strategies to compete on the market. A maximum of between 5 and 10 participants is recommended to give the best results. Among these, a leader of the process must be identified, the person who has a direct interest in the results of the map, who will have an active voice in the decisions of the process and will be responsible for updating the map with new information.

Finally, the last activity (1.4) of this phase, elaborates the schedule and budget to execute the activities of the roadmap construction, in order to manage its progress. To represent the time planning of the activities a bar chart, or Gantt chart, can be employed. According to the experience of some authors, such as Phaal et al. (2003b), based on the assumption that the information and resources required will be available to the company during the meetings for the roadmap construction, the process usually varies between 1 and 4 days. However, this time period is related to the construction of the first map. After that, the process becomes continuous, in which the leader of the process can be designated to periodically update the map. At this stage, the cost planning for the resources required can be obtained with the aid of a spreadsheet with information on labor costs (staff involved) and acquisition of additional information when necessary. Other resources, such as the use of computational equipment or a physical space for the meetings, are considered to be generally available within the company. Conducting of activities outside the environment of the company is also an option. In this case, the costs must also be considered.

At this stage, the team will have defined a roadmap construction plan. The process then proceeds with the construction of each layer of the map, and the relative activities are described in items that follow.

3.2. Roadmap construction

3.2.1. Identification of the future opportunities for product innovation

The objective of this phase is to identify how the organization must change its strategic focus to meet the future needs of the product. The information resulting from this phase is positioned in the market layer of the map. In Figure 8 the flow of activities proposed for this phase is presented. The information and knowledge involved are predominantly those of the marketing staff, who can perceive the needs and changes in relation to the customers and the environment. However, the work team and other specialties involved reinforce a more comprehensive evaluation of future opportunities for the company.

The first activity (2.1) of the phase is the identification of the customer priorities at the time of purchase (qualitative aspects) and the market potential (quantitative aspects). A survey of the qualitative information can be carried in different ways: user panels, observation in the field, consultation with lead users, conjoint analysis and direct consultation with the consumers by means of interviews and the application of questionnaires. Through the conjoint analysis, for example, General Motors determines the value that consumers give to each attribute of the product before even being developed, by showing potential consumers drawings, pictures or descriptions of the product (URBAN; WEINBERG; HAUSER, 1996). Another way to obtain information from users is by consulting industrial specialists who are in the vanguard of the trend. The bibliographical research reported in secondary sources, such as specialized magazines, newspapers, television, publications of companies specialized in market research and government R&D agencies and, most importantly, the Internet, facilitates the access to this type of information.

As an example, an automobile company obtained information on the priorities of purchasing customers through qualitative research, as a function of the frequency with which they where cited by respondents. For around 70% of potential customers the priority at the time of purchase was drive, handling and performance, followed by comfort, styling and exterior design (Figure 9). It should be noted that customer priorities may vary from region to region.

On the basis of research of this nature, the targeted segment for which the company will develop its products can be determined, that is, the customers with similar needs, but with significantly different priorities of purchase. In the research shown in Figure 9, two different clients in the passenger car market can be determined: i) customers who like speed and trends that valorize more drive, handling and performance (sportive segment); and ii) buyers in general that value the comfort of their families and the exterior design (sedan segment). The customer priorities for targeted segment are included in the market drivers, which will guide the planning process for each product in the next phases.

The quantitative research allows the market potential to be determined by means of sales projections for each product of a given product family, analyzing the size of the market, market share and expectation of growth, as illustrated in the example of Figure 10.

Through an analysis of this type one can determine the probable behavior of the market and the sales expectations for each product to determine which products offer the company greater market opportunities. However, the reliability of these data will depend on the information source and more than one source must be analyzed to minimize the uncertainties in the estimates. Also, alternative scenarios

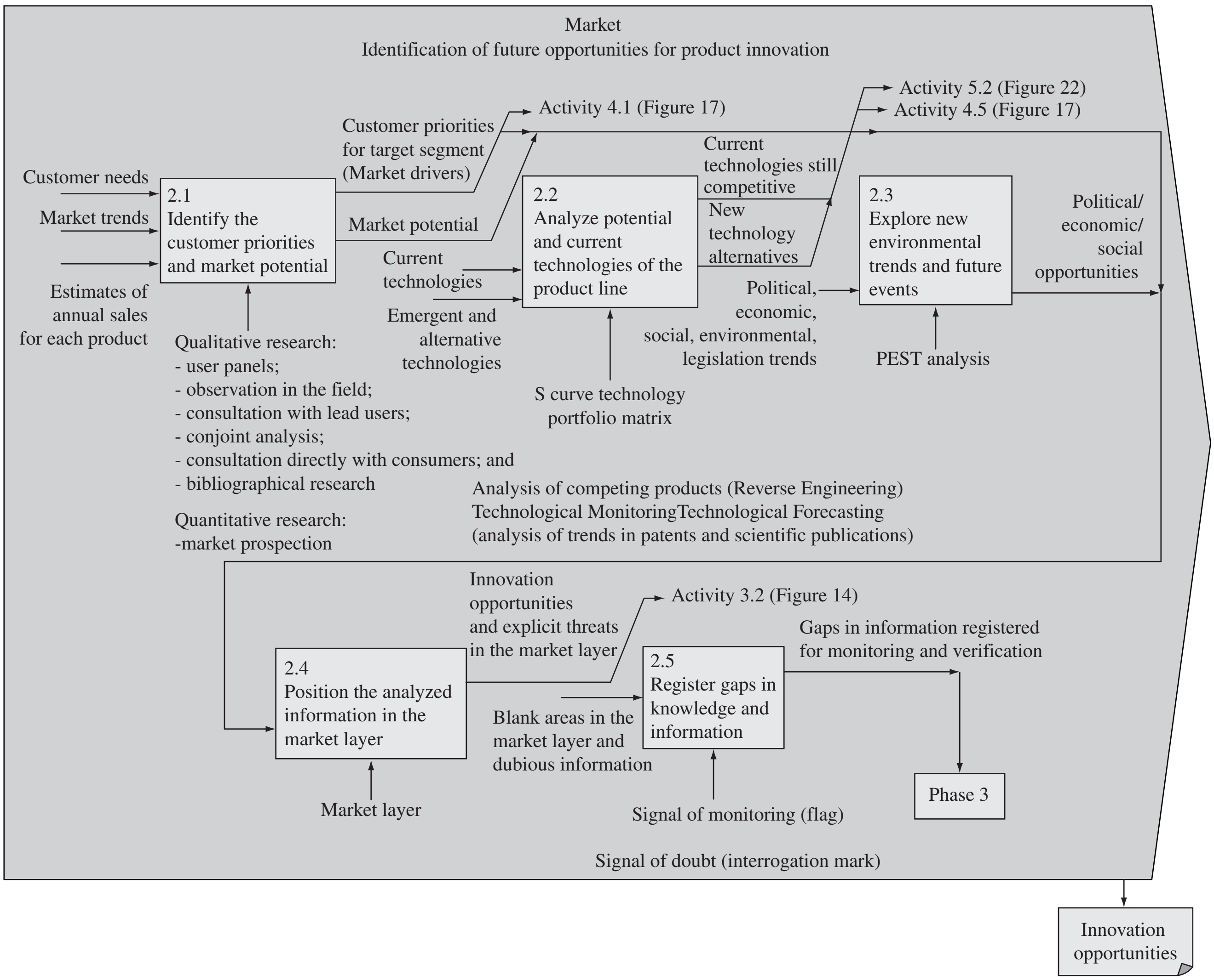

Figure 8. Flow of activities of the phase to identify the future opportunities for product innovation (adapted from IBARRA, 2007).

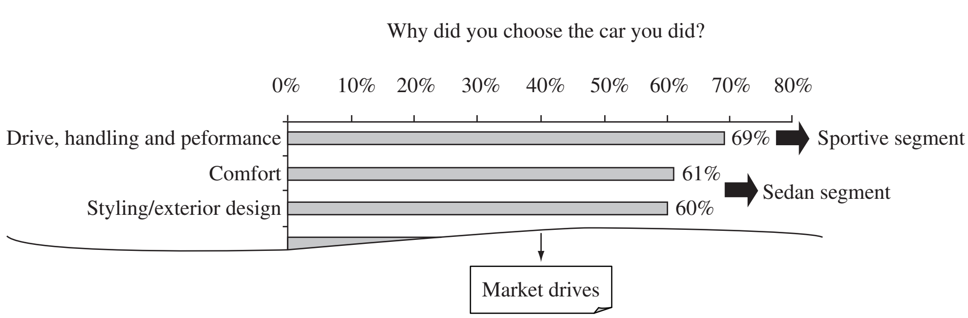

Figure 9. Partial illustration of the customer priorities and targered segment (adapted from MCMANUS, 2003 apud ALBRIGHT; NELSON, 2004).

can be created, that is, different estimates (%) of growth: optimistic, pessimistic and most likely. After identifying the market opportunities, in the second activity (2.2), the current and potential technologies of the product line are analyzed in the search for technological opportunities to evolve the product performance, and then plan the product and technology as a function of this, as shown in Figure 11. For this, the obsolescence of the current technology, the introduction of new products using new technologies, and the emergence of new technologies are analyzed. Firstly, it is important to analyze the technologies currently used in the product line, by means of a hierarchical decomposition of the product into its components down to the technologies, using editing software. In this way, the situation of each current technology is analyzed through the S curve and the technology portfolio matrix. The development and monitoring of the S curve through an evaluation parameter are essential to estimate the limits of the technology, either to anticipate changes or avoid investment in obsolete technologies. In Figure 11, for example, the case of the evaluation of the fuel consumption for internal combustion engines is illustrated. Note that, at present, the technology is at the limit of its maturity. Additional advances will need great efforts and investments to reduce the consumption. In this case, to increase the consumption efficiency, it is necessary to change the focus of the technology effort, or change and invest in new technologies to create a greater attraction for the product.

Another way to analyze technologies is through a technology portfolio matrix. Figure 12 shows an example of the application of this matrix. For its elaboration the following variables must be estimated through the evaluation of the team: i) the company's technological position in relation to the competitors in the market; ii) the stage of the technology life cycle of the company in the industry; and iii) the amount of resources allocated to the respective technology, represented by the area of the circle.

With this analysis, the company evaluates the strengths and weaknesses of its technology to verify whether it will be investing in attractive areas in which technology is an additional skill necessary to become a leader and to place the company better in the market. That is, for a technology to have a high possibility of success, it must be placed in the upper left part of the matrix (in the example of Figure 12, technologies 2 and 3 are reasonably well located). A technology that is in the area of decline (technology 4) must be shelved because no technological advance is expected and the area which indicates a competitive deficit position (new technology 1) must be redirected by means of a stronger strategy to move up or, if not, it should be shelved. The area of the circle indicates the importance given to the technology within the portfolio of the company, in terms of

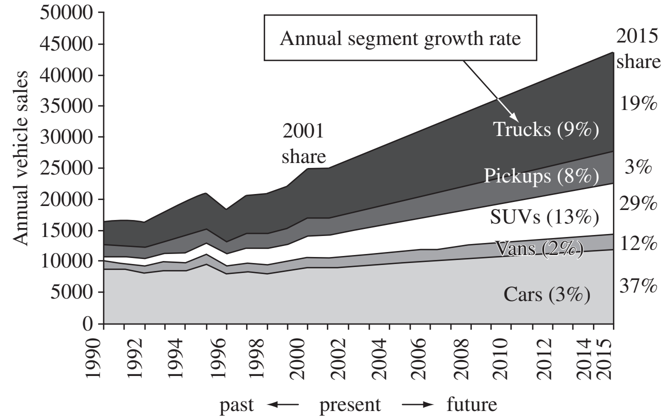

Figure 10. Analysis of the company's market potential (adapted from ALBRIGHT; NELSON, 2004).

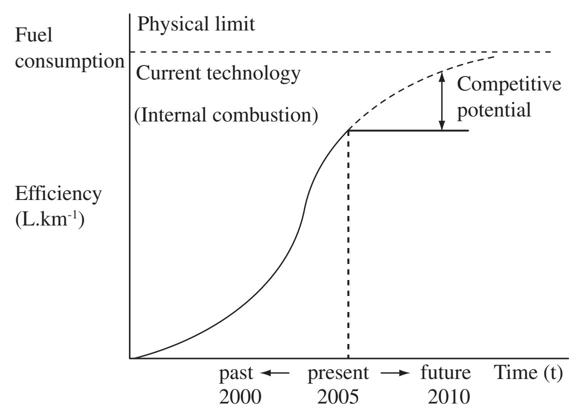

Figure 11. S curve of the technology of internal combustion engines (adapted from TWISS, 1992).

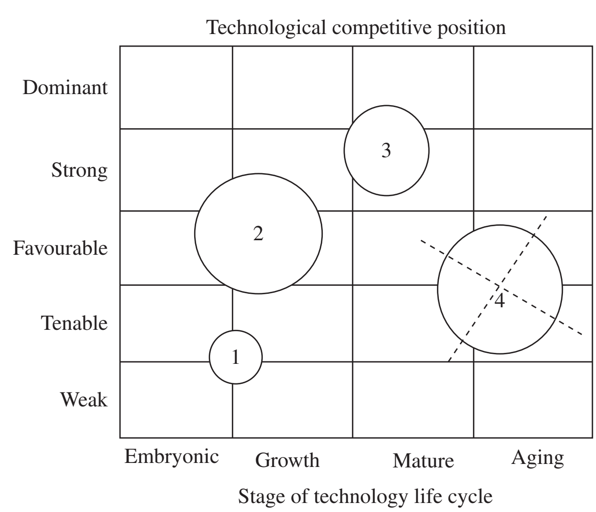

Figura 12. Example of the matrix: technological competitive position x stage of technology life cycle (adapted from COTEC, 1999).

the resource distribution among projects of highest priority and which are of interest to the company.

Through analyzing the current technologies, it is possible to identify the availability of alternative emerging technologies that could replace those currently used in products, that is, those with the potential to provide a greater performance and thus improve the attractiveness of the product. To assist this activity, the following are recommended: i) the analysis of the competing products through Reverse Engineering; ii) technological monitoring of information sources such as technical magazines, catalogs, manuals of the sector, Internet sites (such as INPI, IBICT, CNPq, ABIPTI, SEBRAE), theses and dissertations, publications of government agencies, etc.; and iii) technological forecasting through the analysis of patents and scientific publications.

It is possible that the development of the product is not motivated by the market or by the technology, but by a combination of factors (economic, social, environmental, political and regulatory) acting in the market environment and which can affect the company, expanding or restricted its performance on the market. Therefore, in activity (2.3) new trends and future events considered in PEST analysis (Politics, Economic, Social and Technological) are explored. The analysis of these factors can create an opportunity to change the objectives of the company or even provide the means to fill in the gaps so that the goals can be achieved.

The information analyzed previously in activities (2.1), (2.2) and (2.3), regarding the possible opportunities for innovation in products, the threats and the opportunities created in the evolution of the sector in which the company operates, along with that in activity (2.4), are clearly placed in the market layer. Figure 13 shows the market layer with the information categories for monitoring, illustrated by the example of the evolution of passenger cars in the automobile sector (adapted from ALBRIGHT; NELSON, 2004).

The flexibility of the map allows the team to add, as sublayers, other monitoring factors considered to be relevant to the analysis. The area of the map becomes, in this case, a field to register business opportunities. For example, the information mapped for 2020 in Figure 13 in relation to the zero emissions policy in all urban areas, can be used as a business opportunity for the company to develop ecologically correct products. This will guide the team in the definition of product lines and technologies that should be developed, as regards the definition of product and technology layers.

Finally, knowledge and information gaps are registered in the market layer as blank areas of the map, at the end of the phase. For these areas, it was not possible during team meetings to forecast changes or signals due to a lack of information and/or knowledge. These areas are marked with a distinctive signal (for example, a flag) to indicate the need for further research and monitoring through other sources. Similarly, future information of doubtful reliability should be marked with an interrogation mark, as shown in Figure 13.

In summary, the market layer is distinguished as relevant for a company since it performs the function of continuous monitoring of the market and competitive intelligence. Information obtained and registered at this stage establishes a landmark for the company, a delimited area so that the company can move into the future. Below, are scenarios which may guide the team and the top management in studies of the strategic implications with respect to what was defined in the market layer.

3.2.2. Definition of the strategic direction of the company

This phase consists of establishing a strategic goal of differentiation for the company. The resultant information in this phase is positioned in the business layer. The top management of the company can contribute to this phase in a particular way. The flow of the activities is shown in Figure 14.

In the first activity (3.1) the evaluation of the positioning of the company in relation to the competition is performed, through the application of benchmarking, aiming at obtaining information for the SWOT analysis (Strengths, Weaknesses, Opportunities and Threats). Internal strengths and weaknesses are identified, together with the external opportunities and threats (explained in the market layer). Then, in activity (3.2), the SWOT analysis is carried out, as shown in Figure 15. This analysis helps the team to determine the changes required in the company, both current and future, to compete in the market.

Based on the SWOT analysis, in activity (3.3), the team must decide on the strategy for the differentiation of the company (actions to follow) in response to the positions of its competitors, in order to gain a competitive advantage. According to Mayfield (2003), companies adopt basically three generic strategies (or a combination of them): low-cost, differentiation of the product characteristics and/or the strategy of focusing on market niches. These strategic actions represent the business drivers.

In activity (3.4) the information analyzed is positioned in the business layer. The form of the positioning of this information is shown in Figure 16, for the example of automobile company.

Firstly, the company positions its current situation (where is it now), by means of its mission. After that, it defines the future strategic goal (where to go) as a function of the information of the market layer and decisions taken. In the case of the automobile company in the example, the goal consists of the development of a new source of power for the vehicles based on fuel-cell technology. Finally, it is positioned in the business strategy defined in activity (3.3)

Periodically monitor the external environment of the company, in terms of:

present → future

Market: Evolution of the company's competitive environment			2005	2010	2015	2020	Vision
			Field of register of business opportunities				
Evolution of the market "demands"		-customer needs, changes and trends in the market; -market potential (expectation of market growth)	* Drive, handling and performance(Sportive segment) * Comfort, exterior design (Sedan segment) Safetyconcerns Use of SUV (Sport Utility Vehicle)	Auto companies selling used cars	↑Smaller cars? "Green" becomes significant market driver	" I'd take the train if it were a bit more convenient"	
Other trends and events	Social, political, economic	-social and environmental trends; -political actions (national and international); -economic trends	↑Traffic/congestion ↑Prices of gasoline will this make people replace their car for a more economic one?	↑Ecological awareness Concern with the greenhouse effect	↑Government support for fuel cell development	↑Public transportation? ↓Prices of gasoline	Highways make great parks in inner city
	Legislation	-changes in the laws and regulations	Control the reduction of pollutant gas emissions to the atmosphere	Rebates encourage hybrids	Government requirements to spur hybrid	Zero emissions policy in all urban areas	
Evolution of the technology "supplies"		-Obsolescence of the current technology; -New products with new alternative technologies; -New emergent technologies	↑Fuel consumption ($L.km^{-1}$) of internal combustion engine Hybrid engine	-All-electric car for short trips; -Ford releases hybrid SUV	Every car maker has hybrid option		Will internal combustion engine efficiency make fuel cell less attractive?

Information gap (Need for monitoring)

Figure 13. Representation of the market layer with information from a company in the automotive industry (adapted from IBARRA, 2007).

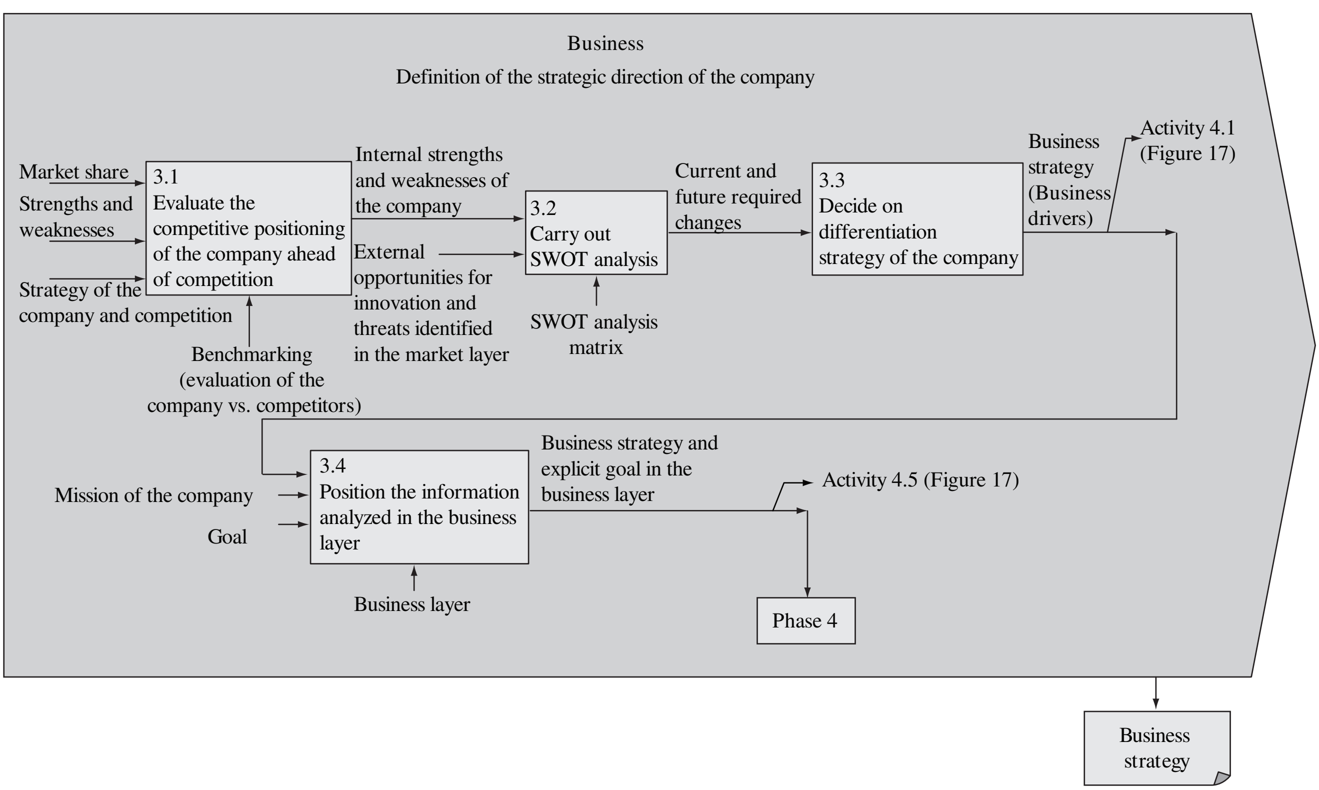

Figure 14. Flow of activities of phase of defining the strategic direction of the company (adapted from IBARRA, 2007).

(i.e. how to achieve the goal). These strategic actions represent the paths of migration that connect the current position with a future vision.

In the business layer it is important that the defined goal is highlighted by means of a signal (such as a flag), to indicate the need to monitor the development of products and technologies over time, keeping the information updated.

At the end of this phase, the team has defined in a clear form on the map the business strategy to be pursued by the company, in order to guide the opportunities that contribute to achieving its goals.

This layer is especially important to perform the function of strategic planning for innovation in the company. To address the future strategy of the company, this layer will mark out the construction of the other, in order to formulate the product and technology strategies so as to be coherent with the objectives of the company.

3.2.3. Planning of product line evolution

This phase aims at planning the evolution of the current product line of the company, its ramification for the launching of new models that satisfy the targeted segment identified and the discontinuity of models or platforms, if necessary. In Figure 17 the flow of activities in this phase is shown. The product engineering staff can contribute significantly, since they have a good knowledge of the characteristics and operation of the product.

The first activity (4.1) consists of defining the critical requirements of the product, called in the process of product drivers. With the help of the QFD (House of the Quality) method it analyzes the relationship between the priorities of the purchasing customers (market drivers), the strategic options (business drivers) and the technical requirements (product drivers), and it prioritizes these requirements according to their degree of importance (Figure 18). This method helps to specify the main technical requirements to plan new products in the product layer of the map.

In the next activity (4.2), the targets for the critical technical requirements of the product must be defined in both qualitative and quantitative terms. In qualitative terms, an evaluation is carried out of the current position of the product with respect to the satisfaction of each requirement considering the competition, the desired position of the company and the investment required to achieve this, as shown in Table 1.

As for the quantitative targets, they are defined using the method of extrapolation of trends. After positioning the data of the product requirements until the present time, a trend line is projected into the future to determine the target value. Based on these values, the team must verify whether the desired future position can be achieved by their company, comparing the result with the expected value for a competitive leader, as shown in Figure 19, in terms of the power and acceleration requirement for a passenger car. In the case shown, the projected value of 155 hp (horsepower) for the engine power of the car in the year 2010, would allow the company to lead with a safety margin of 12% with respect to the expected value for the competitive leader (137 hp).

The targets estimated can be affected by changes and trends of the sector that must be analyzed in the following

	Threats	**Opportunities**
Strengths	How to use strengths to confront the threats ?	Major possibilities of growth
Weaknesses	High level of risk	Leave these opportunities to others?

Figure 15. Typical structure of SWOT analysis (adapted from COTEC, 1999)

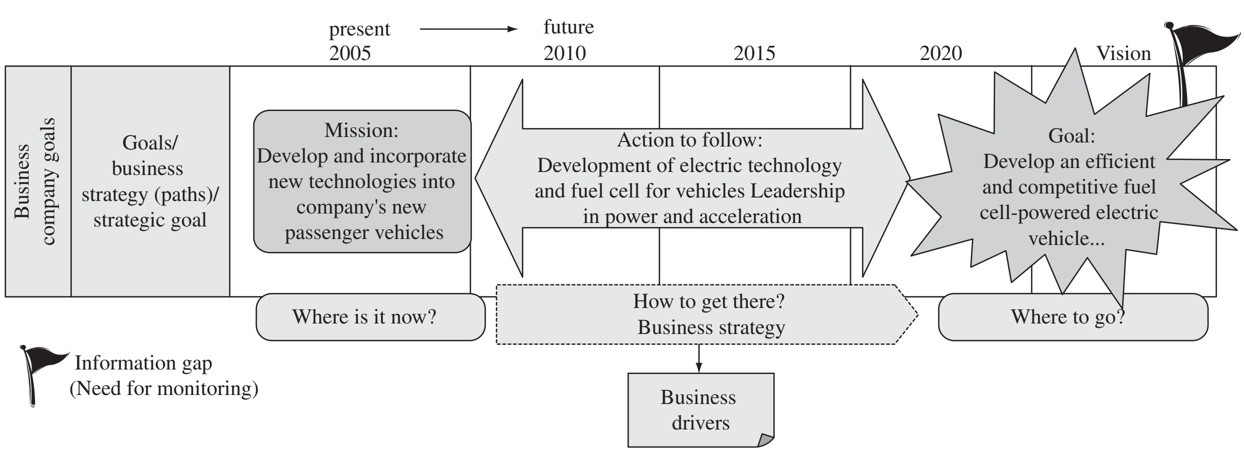

Figure 16. Representation of the business layer shown for a company operating in the automobile sector (adapted from Ibarra, 2007).

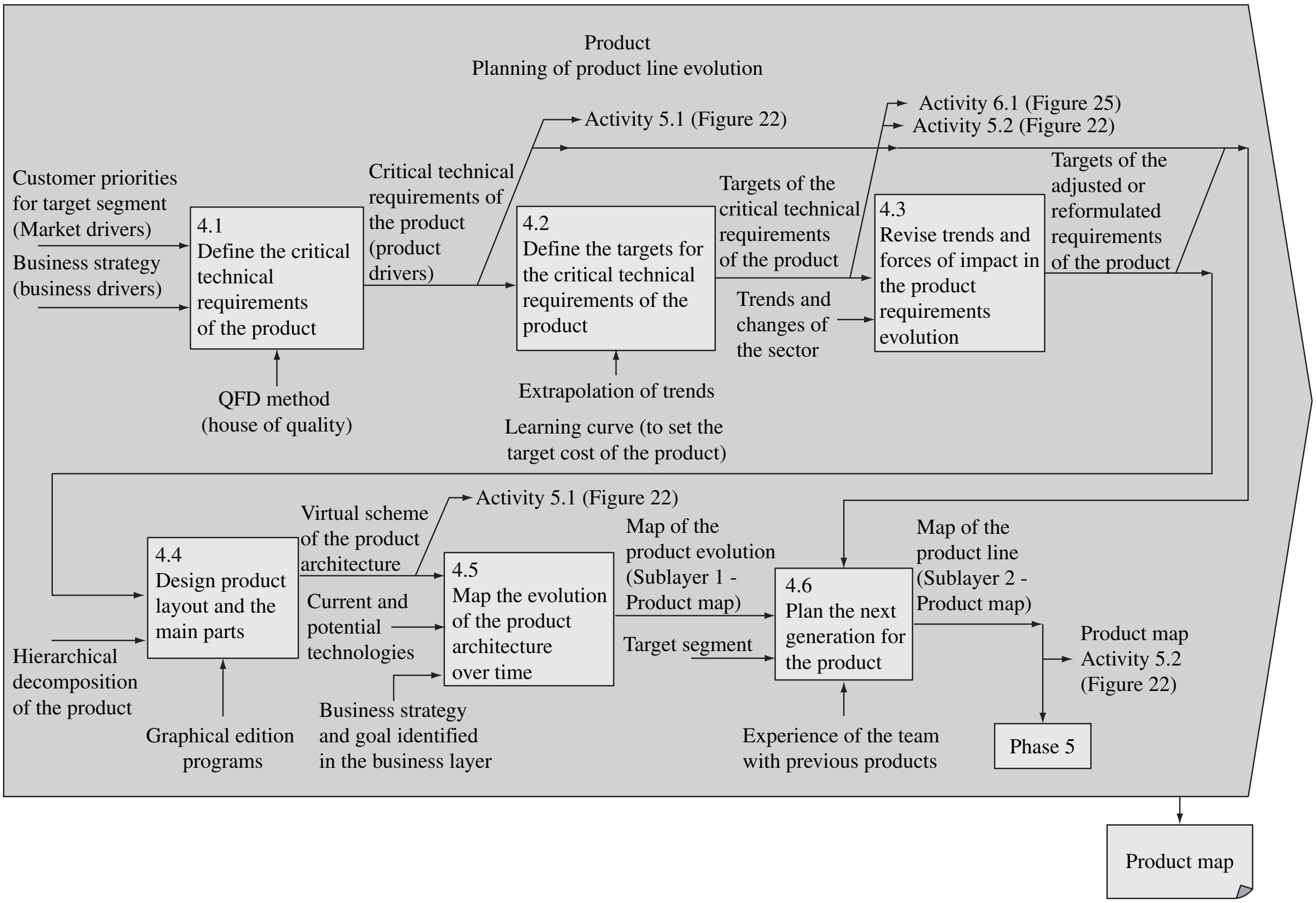

Figure 17. Flow of activities in the planning phase in the product line evolution (adapted from IBARRA, 2007).

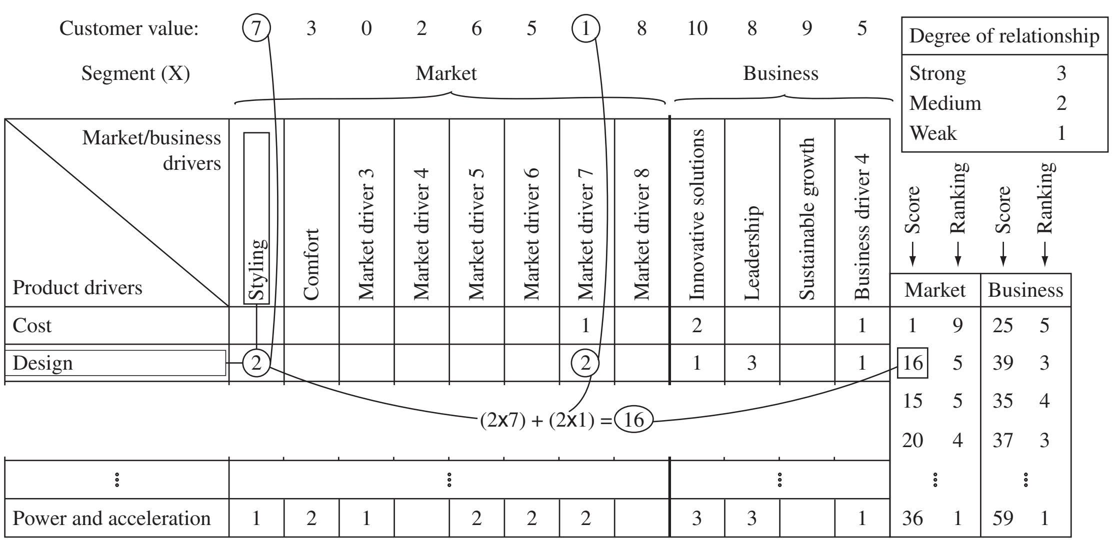

Figure 18. Illustration of the analysis and prioritization of the product requirements in the House of Quality method for the development of a passenger car (adapted from PHAAL et al., 2003a).

activity, (4.3), in order to adjust or to reformulate these values. For example, government institutions impose target limits on a given sector for a specific period (for example, 130 grams of pollutant emissions from automotive vehicles by 2012), which can change a previously defined target value. Next, in activity (4.4), the layout of the product is defined, along with the main physical parts that determine its value, with the help of graphical edition programs, in order to understand the functioning of the product and assess how the parts or functions interact.

Table 1. Example of definition of qualitative goals for the critical requirements of a car.

Product critical requirements	Current position	Target	Investment required
1. Power and acceleration	Lag	Lead	High
2. Fuel consumption	Lag	Parity	Medium
3. Cost	Parity	Parity	Low

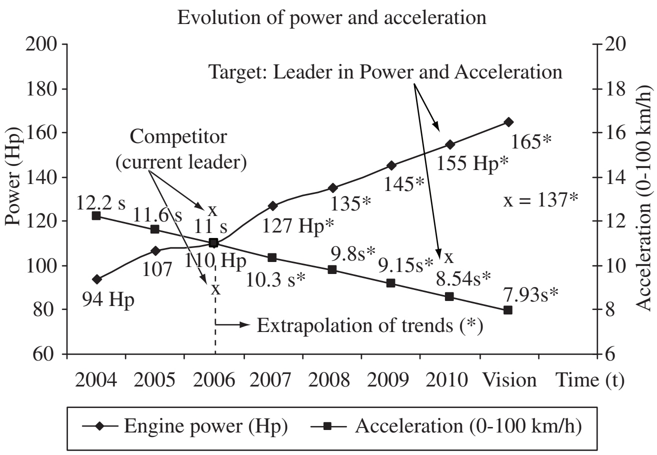

Figure 19. Hypothetical example of target value for the requirements of power and acceleration of a car with an internal combustion engine.

In activity (4.5) the evolution of the product architecture over time is mapped as a function of the new alternative technologies (identified in the market layer) and of the business goal and strategy (given in the business layer). This represents the product development strategy. To illustrate this activity, Figure 20 shows the example of the architecture evolution of a family of passenger cars, in particular the powertrain system (engine and transmission), in relation to the opportunity identified in the evolution of fuel technology in the market layer. From the future vision of the team (to develop an electric car) the mapping of the current platform of the car was carried out using a hybrid model until the goal was achieved. In this case, as indicated by Albright and Nelson (2004), the intermediate hybrid project allows the company to acquire and develop the competence required while it decreases the price of fuel cell technology, for the future reaching of its goal.

These architectures of the product constitute the basis for the next activity (4.6), the planning of new products derived from each one. The mapping of the product platforms in a time horizon stimulates the creativity of the team in the proposal of new product opportunities, both for the present and for the future. It also facilitates the visualization and understanding of the whole product, to raise questions and remove development barriers, and it enables the integrated

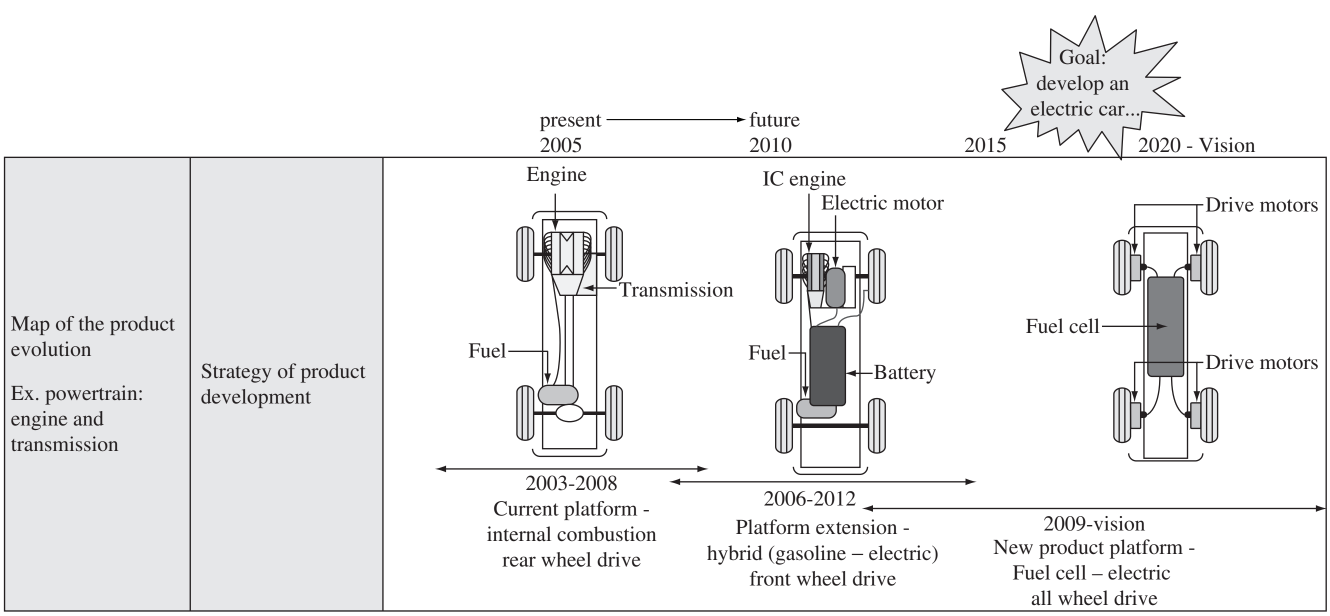

Figure 20. General representation of the map of the product evolution (sublayer of the product layer) (adapted from ALBRIGHT; NELSON, 2004).

development of new technologies shared in the product line to achieve the goal and to reduce the time and costs involved.

To illustrate the construction of the map with activity (4.6), Figure 21 shows the typical format of a map of the product line and the characterization of its elements.

Firstly, the targeted segment determined in activity (2.1) is positioned on the map. Then, the map is organized according to the product platforms (defined in activity (4.5)). Each product within the platform is subject to a life cycle: development, introduction, growth, maturity and decline. In the map, bars are used to represent the probable time of product release (based on the experience of the team with previous products, which depends on, among other factors, the rapidity of the market evolution and internal capacity of the company) and withdrawal from the market (forecast of when it will be saturated) in a time horizon. Here, only these stages are considered so that the map does not become too complex. The detailed planning of each phase of the product development must be carried out separately.

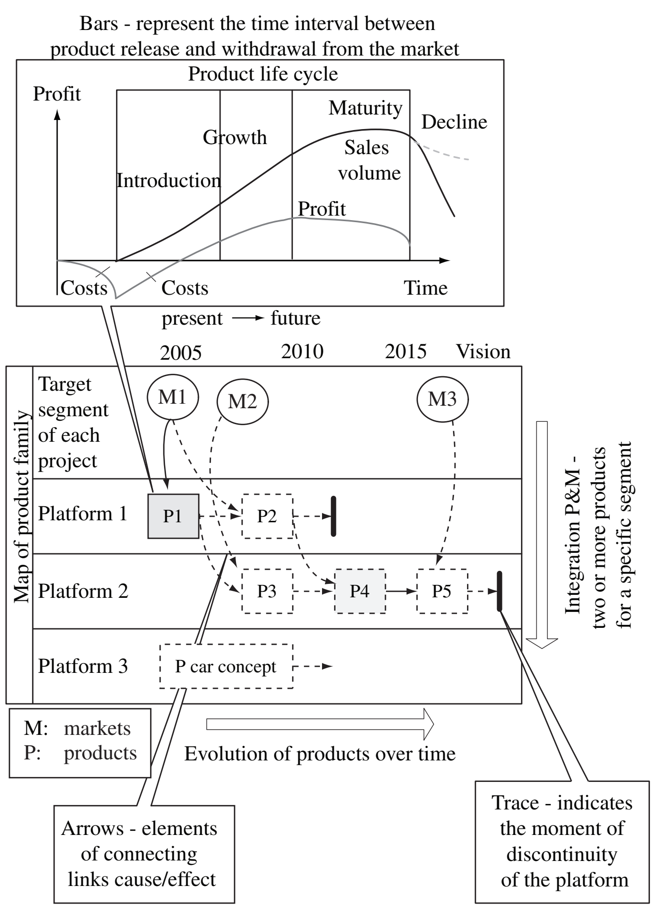

Figure 21. Typical format of a map of the product line (sublayer of the product layer) and characterization of the elements used (IBARRA, 2007).

In the filling in of the spaces on the map, the current model of the product family is positioned first, inside a bar, indicating that the market target is currently met. Next, by means of dotted arrows (indicating the future), it is indicated how the current product will evolve for the launching of the new models, with the incorporation of new functionalities that better fit the priorities of the targeted segment. On this map (Figure 21), the improved version of P1 will support two new models, where P3 will satisfy the needs of the market segment M2, still not satisfied. In this case, the best sub-systems of platform 1 (internal combustion) are used for the new platform 2 (hybrid), which results in a shorter development time and lower development cost and, therefore, a shorter time to market. This makes it feasible, in economic terms, to develop products for small market niches.

Thus, as technological and market conditions evolve and there is access to new information, the team continues to include on the map new models of products for specific segments of the market. In the end, by means of a vertical trace, the moment of discontinuity of certain platforms is indicated. A product platform can be discontinued: i) when the market conditions change (requiring another type of product); ii) as a strategy to consolidate the newer line in the market; and/or iii) when the market is not yet prepared to assimilate a new generation of products with high technology.

This planning activity is called by some authors, such as Rinne (2004), virtual innovation, because to attempts to plan new products without having to develop the design and to build the prototype, aiming at selecting the promising concepts. Thus, the team can consider completely new products on the map, for which a market niche will be sought (in the case of a car, it could be a car concept as illustrated in Figure 21) or it could represent intermediate products (P4 in Figure 21) as being a step toward achieving another product (P5), and filling new market niches (M3). Even if the intermediate product (P4) is not placed in the market, it can be kept in a virtual form to internally speed up the development of the product goal (P5). In this case, it is necessary to distinguish this product on the map. With this map it is possible to plan and to visualize products (belonging to different platforms), which will be developed in parallel or simultaneously, and this is increasingly important in companies of emerging sectors, due to the rapid changes that they experience.

Ultimately, the map shows the genealogy of product releases that carries on being filled in by the team over time. The output of this phase is the product map (containing two sublayers: Figures 20 and 21) which indicates the roads to be covered, that is, the internal changes that must occur to reach the desired vision. Thus, the product layer is distinguished from the company plan for the strategic design of new products.

3.2.4. Planning of the technology evolution

The objective of this phase is to plan the evolution of technology that will be used in the product line over time. The flow of proposed activities for this phase is shown in Figure 22. The staff of the technical and R&D areas can particularly contribute to the construction of the technology layer.

The first activity of the phase (5.1) consists of defining the critical elements of the product to meet the targets for the requirements, called technology drivers in the process. This activity is performed with the aid of the QFD method (House of quality), and it analyzes the relationship between the critical technical requirements of the product (product drivers) and the technological elements of the product (technology drivers), defined in the previous layout of the architecture, prioritizing them as shown in Figure 23.

For this process, the elements classified by importance are positioned on the left side of the technology map, horizontally. In the case of the example of the passenger car, to achieve the goals of power and acceleration, the key element is the engine.

In the following activity (5.2), from the identification of possible new technologies in activity (2.1), the most attractive technological options, in relation to the desired performance goals for the product to be positioned in the central part of the map, are identified. At the beginning of the horizontal lines of the map, in the technology layer, the technologies currently used (existing and in development) for each key element of the product are positioned first using bars, as shown in Figure 24.

Each technology passes through a life cycle: embryonic (period of development, where the technologies become available, but with poor performance in relation to their potential and at high cost), growth and maturity. In the technology map (Figure 24), the bars are used to indicate the probable time that each technology will be used in the product according to its attractiveness for the purposes of the company.

This map can be interpreted in two ways: horizontally and vertically. In a horizontal way, it allows a visualization

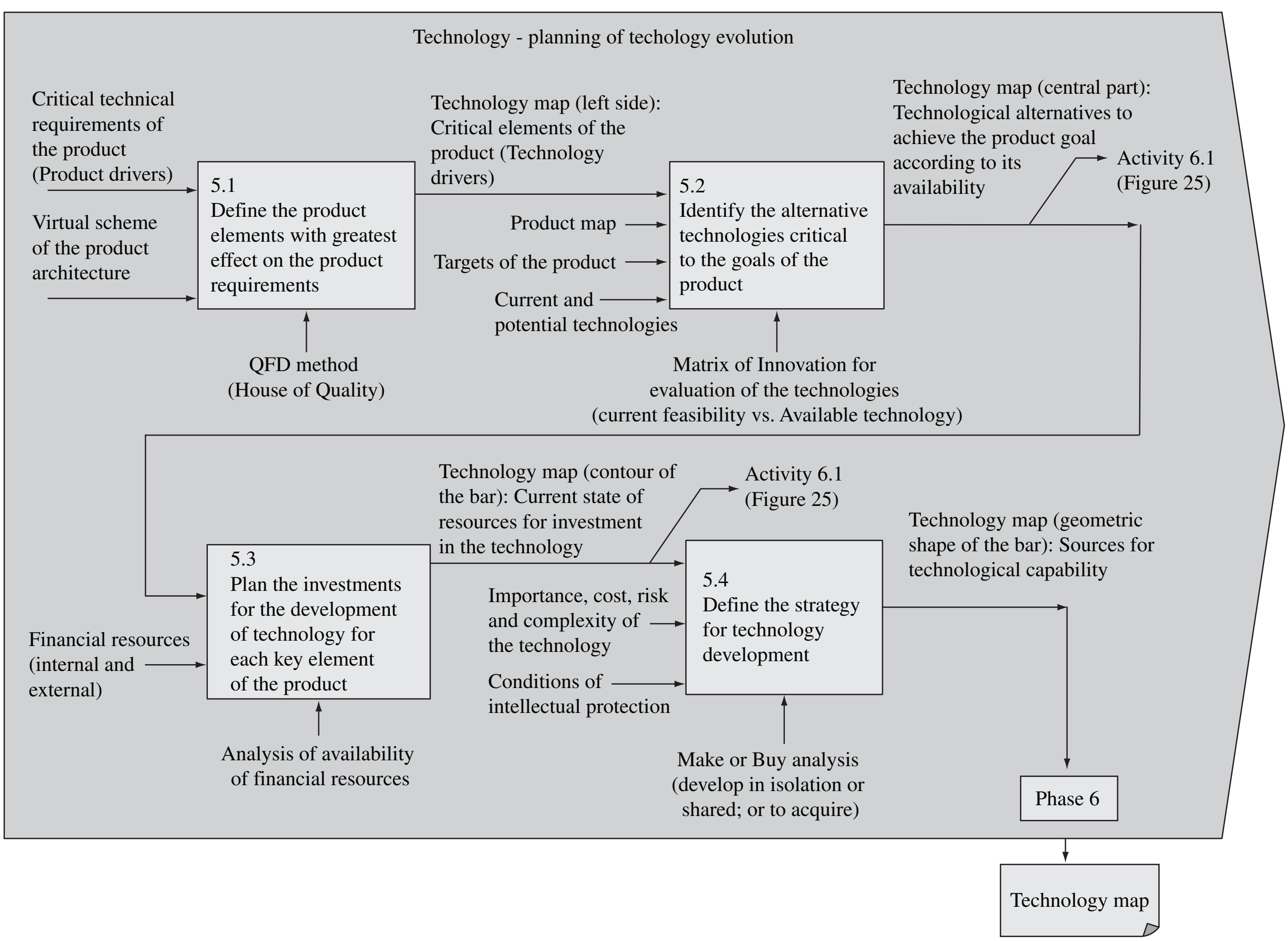

Figure 22. Flow of activities in the planning phase for the evolution of technology (adapted from IBARRA, 2007).

of the technological path to be traveled in a time horizon to reach the desired product goal where, in the last area of the map, the vision represents disruptive technologies, whose future performance is superior to the desired goal. Vertically, together with the product map, it allows a visualization of the technologies common to one or more products of the line.

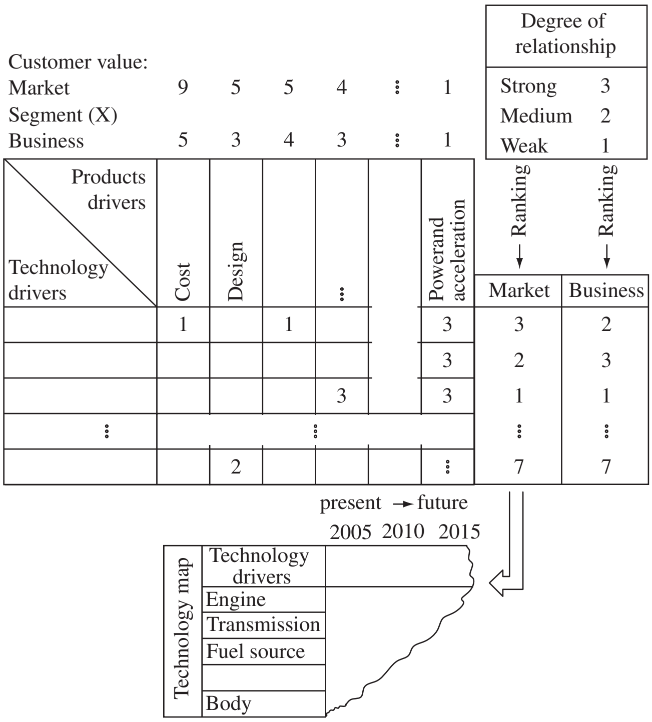

Figure 23. Illustration of the analysis and prioritization of the product elements in the House of Quality method for the development of a passenger car (adapted from PHAAL et al., 2003a).

The best technological alternatives obtained for each time period are positioned along the map, using bars, according to their availability to be introduced in the product (T2, T3, T4 in Figure 24). Finally, we place the disruptive technologies (T5 in Figure 24) in the vision column of the map to begin their monitoring or research. In the end, there may be blank spaces on the map (i.e. technological gaps to be filled), questions or several technological alternatives where nothing has been decided yet. It is worth emphasizing that advances in alternative technologies could affect more than one product target. This issue must also be considered in the choice of alternatives.

Thus, technologies relevant to the company continue to be identified, evaluated, positioned in the map and aligned in relation to the products and targeted segment. In the next activity (5.3), the team plans the financial resources (internal and external) for the development of the technologies of each key element of the product in order to allow the company to dominate such technologies. In the technology map of Figure 24, the current state of the allocation of resources to the technology is indicated by means of the thickness of the contour of the bars as being: i) allocated resources; ii) planned resources; and iii) unplanned resources indicating a potential technological gap that should be filled by the company.

Finally, in activity (5.4), the strategy to acquire the capability necessary to dominate the technology is defined. These decisions must be based on: i) the availability of

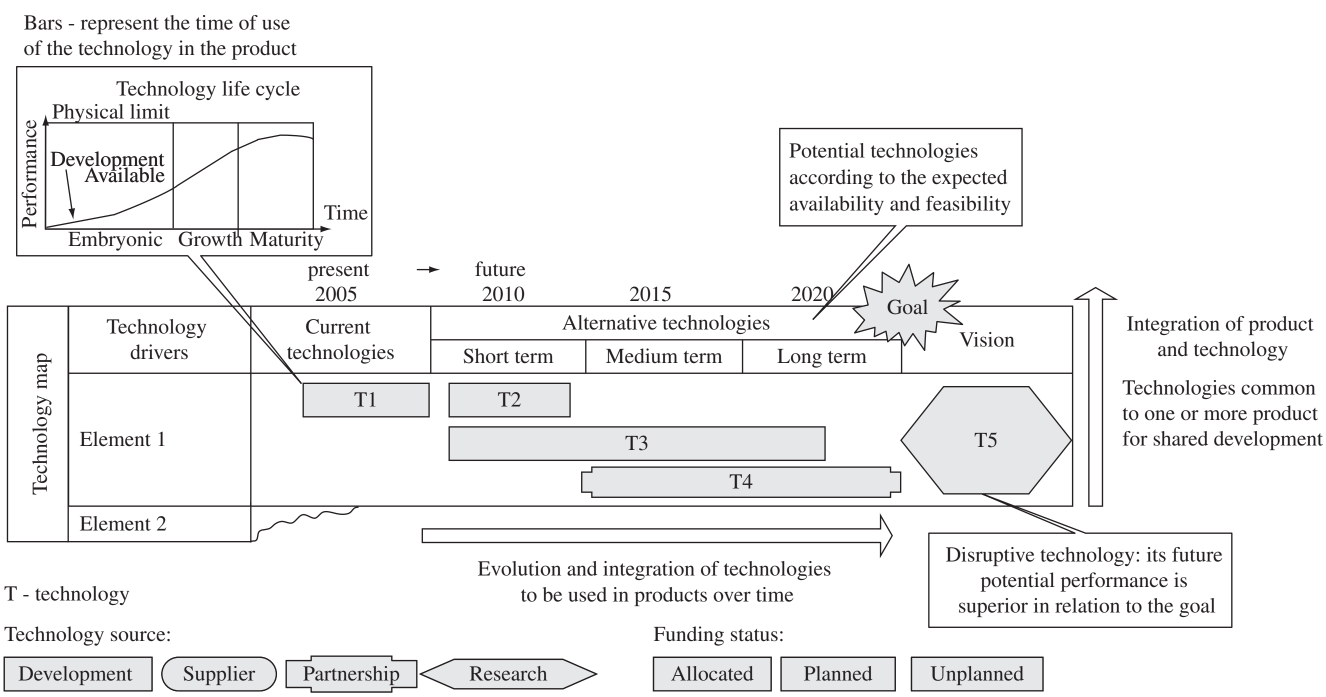

Figure 24. Typical format of a technology map and characterization of the elements used (IBARRA, 2007).

financial resources; ii) the current and future importance of the technology to the company; iii) a complete understanding of the implications of each technology in terms of cost, risk and complexity; and iv) an analysis of the conditions of the intellectual protection for each technology (for example, the stated period of protection of the patent), among other factors. In this way, the uncertainties inherent to these decisions can be reduced. The alternatives for the technological capability are defined as either: to be developed (in an isolated or shared way) or to be acquired (also known as Make or Buy Analysis). These decisions must be represented by the team on the technology map by means of the geometric shape of the bar, as seen in Figure 24.

At the end of this phase, the team will have a technology map for the product line. The technology layer is where a company carries out the exploration and strategic planning of new technologies for the products.

3.3. Generation of new project recommendations

This phase seeks to summarize the main results obtained during the process of technology roadmapping in the form of new development projects of the highest priority that must be undertaken to achieve the objectives of the company. In Figure 25 the flow of activities proposed for this phase is shown, which should involve all the participants of the process.

Firstly, (6.1), the report must summarize the main decisions of the team taken during the process with respect to the recommendations of new technological innovation projects. This report contains: i) the purpose of the technology roadmapping process; ii) the product line analyzed; iii) the participants of the process and areas to which they belong; iv) a description of the strategic goals of the product; v) justification of the choice of the selected technological alternatives; vi) implications for funding and investment of resources in projects; and vii) a summary of the recommendations. A report example is shown in Ibarra (2007). This report should be approved in its final version by all participants of the process and be included as a document in the final technology roadmap.

In activity (6.2) a critical analysis and validation of the results of the technology roadmapping process is conducted by the team. This is to verify the progress of the process in terms of fulfilling the schedule and adhering to the budget detailed in activity (1.1). It is then verified whether the team omitted any important aspects and if the map is clear and understandable for use by the team or any member of the company. The areas of the company where the document should be circulated is then determined.

At the end of the technology roadmapping process, in activity (6.3), the frequency of revision and updating of the map must be established, to monitor new developments, changes and other trends that require a change in the plans. This activity may form part of the revision of the regular strategic planning (annual, quarterly, etc.) of the company and it can be performed by the leader of the process. However, if a significant change is required well before the regular revision, the team should review how this fact is reflected in the planning of the layers and modify and update the map.

At the end of this process, the team has a detailed map with information to improve the decisions related to the selection and investment in alternative technologies, as well as a summarized report. The ideas for technological innovation projects of the map need to be evaluated in a formalized way in the phase of ideas selection and evaluation

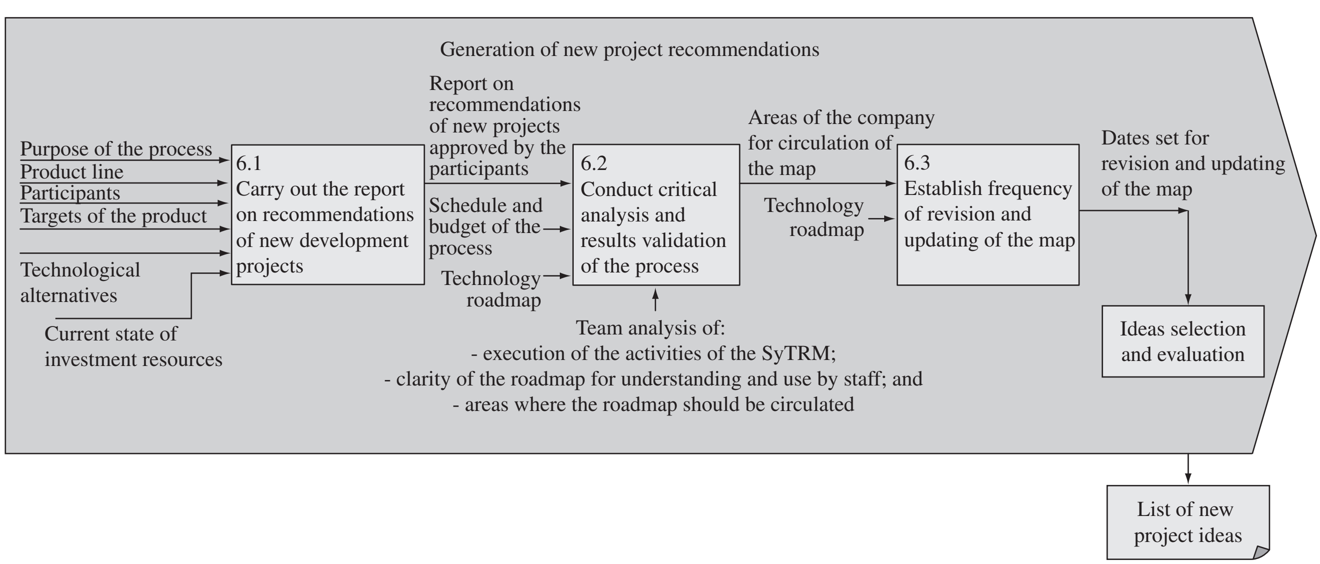

Figure 25. Flow of activities of generation phase of recommendations for new development projects (adapted from IBARRA, 2007).

of the macrophase products planning of PDP (as indicated in Figure 4), in order to determine the most promising way for the company to distribute resources and efforts during its development. The technologies forecasted on the roadmap, in turn, support the development of alternative concepts for the product in the macrophase of the conceptual design of the PDP (Figure 4), and also the product and technology drivers support the inputs of needs and project requirements in the informational design phase of the product.

4. Final considerations

In the literature relating to the technology roadmapping process, different approaches can be found including the T-Plan, different types of maps for practical applications in companies, and centers that research the best practices of the process as well as support software. Even so, it was verified that there is a need for a practical guide, which is simple and clear, to provide instruction and support to companies during the technology roadmapping process. Thus, this research resulted in the systematic SyTRM, which aims to guide, step-by-step, the construction of the roadmap with information on trends and changes in the market and technologies in a time horizon, in order to facilitate and expedite the decision making process for new projects.

Besides this benefit, the systematic approach suggested can be used to enhance the process of technological innovation in companies, in particular for the SMEs, which often encounter great difficulties in performing this function. Through this process it is possible to visualize and monitor the evolution of the sector over time using the market layer, to anticipate and respond rapidly to the changes. This information guides the company in the definition of a more effective strategic goal to deal with competition, in the business layer; and on this basis to better plan for the future, using the product and technology layers, prioritizing the technological innovation projects in the mid- and long-term, and improve the planning resources and efforts in order to consolidate itself in the market.

The resultant technology roadmap of the process allows companies to control and manage, in a simultaneous and flexible way, its portfolio of projects, in relation to the most appropriate time at which to introduce and withdraw innovations onto or from the market, according to market changes and to the goals of the company. In this regard, the systematic approach and the resultant map are presented as tools for current engineering practices.

For the implementation of a systematic proposal it is necessary, firstly, that the top management understands its importance and is willing to compromise by creating conditions for its development. The minimum resources necessary for its implementation basically concern staff and information. Thus, it is expected that, although it is a practice commonly implemented in large companies, other types of companies, such as SMEs, will be able to use the resources proposed, which do not require staff exclusively dedicated to the mapping nor permanent resources for its execution.

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