2

Innovation Methods

2.1 Introduction to Innovation Methods in Design Processes

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2.1.1 Introduction

This section provides theory on innovation processes and innovation methods for industrial design engineering. The theory will be illustrated by results of design cases with sustainable energy technologies that have been executed with various innovation methods by students.

Here, innovation will be considered as changes of product–market–technology combinations, and the theory will refer to this framework. In this Chapter, nine innovation methods that will be discussed in this book will be briefly introduced to the reader. These innovation methods are platform-driven product development (discussed in detail in Section 2.2), the Delft innovation model (discussed in detail in Section 2.3), TRIZ (theory of inventive problem solving) and technology road mapping (in Section 2.4 and 2.5), the design and styling of future products (Section 2.6), constructive technology assessment (Section 2.7) and the innovation journey (Section 2.8), risk diagnosing methodology (Section 2.9), and the multilevel design model (Section 2.10).

First, we would like to question what innovation is and discuss the setting of innovation in product design and engineering. Innumerable definitions of *innovation* are available. Their main correspondence in meaning is related to the concept of *novelty*. For instance, *Webster's* dictionary describes "to innovate" as to make changes or to introduce new practices. Von Hippel (1988, 2005) defines an *innovation* as anything new that is actually used, whether major or minor. And Rogers (2003) describes an innovation as an idea, practice, or object that is perceived as new by an individual or other unit of adoption.

Innovation in the context of industrial design engineering is represented in Figure 2.1.1 as an innovation flower involving the following five fields: technology, design and styling,

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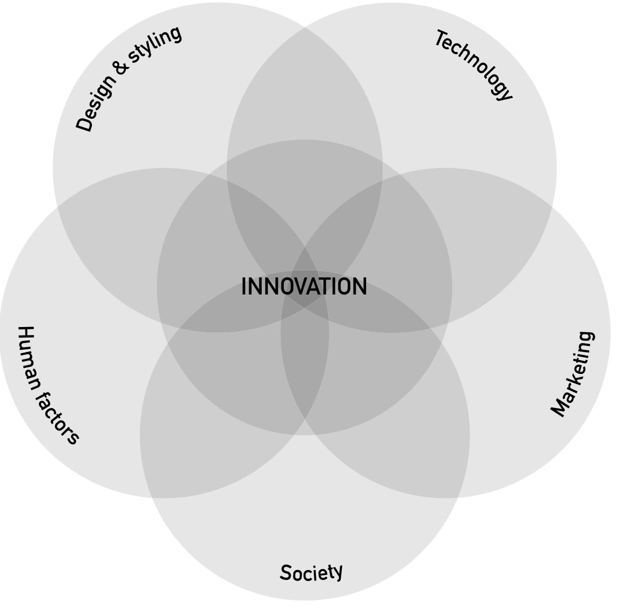

Figure 2.1.1 Innovation flower of industrial product design

human factors, marketing, and society. In Figure 2.1.1, *technology* refers to product technologies and materials, as well as manufacturing processes. *Design and styling* refers to the appearance of products and their image in the market. *Human factors* cover the user context of consumer products and the physical ergonomics. *Marketing* refers to market value costs and sales. Finally, the term *society* implies the field of policy and regulation and societal acceptance. We believe that all five components of the innovation flower are equally important to product development and the final success of a product. Therefore, in this chapter on innovation methods, we will position product development in the context of the innovation flower.

Industrial design methods (IDMs) play an important role in product development processes. IDMs convert market needs into detailed information for products that can be manufactured. IDMs vary in their approaches to problem solving. In technological design, design processes are generally viewed as heuristics. In other words, we assume that design goals can be defined by carefully describing a problem prior to formulating possible solutions to this problem. Through problem decomposition, the complexity of the problem is reduced. Next, the designer evaluates how solutions to subproblems can be merged into a solution composition that meets the design goals. The embodiment of the solution is a product.

A generally accepted approach toward this process is described in detail by Pahl and Beitz (1984) (Figure 2.1.2). It consists of four phases:

1. Clarification of the task.
2. Conceptual design.
3. Embodiment design.
4. Detail design.

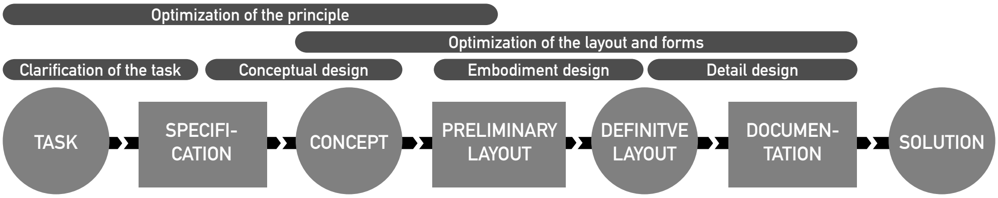

Figure 2.1.2 Flow chart representing the basic industrial design method of Pahl and Beitz

In the first three phases, product designers seek to optimize the working principle of a product. The last three phases involve optimizing the layout and form of a product. Thus, conceptual and embodiment design form the connecting links between technology, on one hand, and design and styling and ergonomics, on the other. Figure 2.1.3 shows in which phases the innovation methods that will be presented in this chapter can be applied.

Theoretically, innovations improve product performance over time. Figure 2.1.4 shows the exponential nature of such growth, which has been widely documented throughout

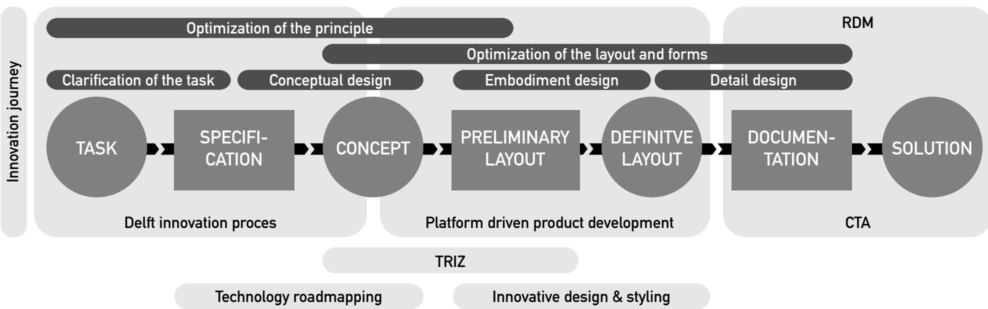

Figure 2.1.3 Flow chart representing innovation methods presented in this chapter in the framework of the basic industrial design method of Pahl and Beitz (1984). RDM: risk-diagnosing methodology; CTA: constructive technology assessment

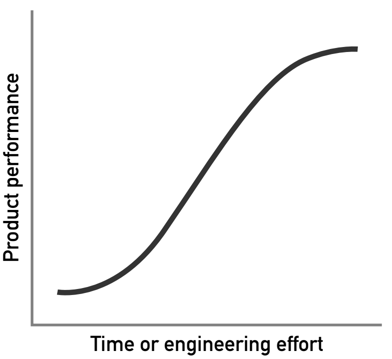

Figure 2.1.4 S curve of innovation

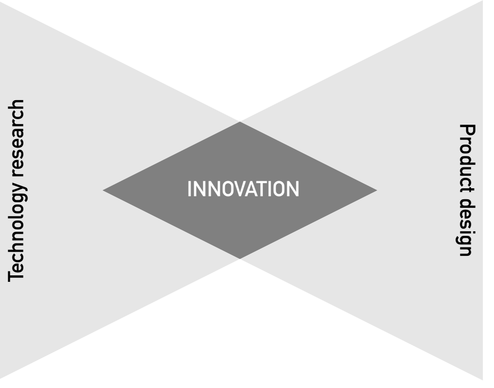

Figure 2.1.5 Innovative products result from the conjunction of technology research and product design

the history of human technology and is widely known as the *S* curve (Burgelman *et al.*, 2004).

Innovation is related to technology development. Generally it is assumed that the more a technology is developed, the less innovative its applications are. Arthur D. Little (1981) distinguishes four types of technologies depending on their level of implementation in product development. *Emerging technologies* have not yet demonstrated clear product potential. Scientists discover emerging technologies in the course of explaining working principles. Next, *packing technologies* have demonstrated market potential and are the subject of ongoing research and development (R&D) to make them fit for applications. Organic electronics is an example of packing technology. Finally, the purpose is to embed the technology in products. Such *key technologies* may be patented. Technologies that have become common to all competitors – they are a commodity – are called *base technologies*.

Technologies that are on the threshold between what Little refers to as *packing* and *key technologies* can result in innovative product design. Namely, potential applications of technology are being assessed through R&D, and they are still in the process of being integrated into products. Figure 2.1.5 shows how both technological research and product design may contribute to innovations at this stage. On one hand, the development of promising technologies may initiate product design. On the other hand, problems with the design of products based on existing technology may stimulate further technological research.

In this framework, Reinders *et al.* (2006, 2007, 2008, 2009) explored the relations between product design with existing sustainable energy technologies and the application of various innovation methods in the design process, as indicated in Figure 2.1.3. Based on these design experiences with about 70 teams of students, we can show many examples of product design with innovation methods in this chapter.

2.1.2 Platform-Driven Product Development

A product platform defines a set of related products, a so-called product family, that can be developed and produced in a time- and cost-efficient manner. Features of a product platform are modularity, connecting interfaces, and common standards (Halman, Hofer, and van

Figure 2.1.6 A solar-powered street-lighting product, exploded view by Scholder and Friso (2007) (See Plate 4 for the colour figure)

Vuuren, 2003). By using a product platform, companies can reach different markets (and customers) with less effort than by developing separate products.

An example of platform-driven product development is shown for the case of a solar-powered street-lighting product, such as in Figure 2.1.6. In order to achieve large volumes with sufficient product variations in a time-efficient manner, several modules were selected from which different product families could be composed. As a consequence, the product platforms shown in Figure 2.1.7, called City Lighting or Road Lighting, can be implemented in different markets. For a detailed explanation about platform-driven product development, see Section 2.2.

Figure 2.1.8 shows the effect of platform-driven product development in a matrix of customer value perception versus enabling technology. For instance, theoretically speaking for a manufacturer of gardening equipment, a fuel cell–powered blower would be a breakthrough product, enhancing its portfolio of conventionally powered equipment. Thus, the risk of integrating new hydrogen technology in products can be distributed over ongoing product development activities.

2.1.3 Delft Innovation Model

The Delft innovation model of Jan Buijs (2003), also known as the *innovation phase model*, aims to optimally combine the intrinsic value of technology with opportunities in the market. It consists of four phases: a strategy formulation stage, a design brief phase, a product development phase, and a product launch and use phase. For the purpose of product innovation, the strategy formulation stage, shown in Figure 2.1.9, is most important. A matrix of internal strengths of technology and external opportunities in the market results in many search ideas. Divergence, selection, and convergence of search ideas related to technology and markets

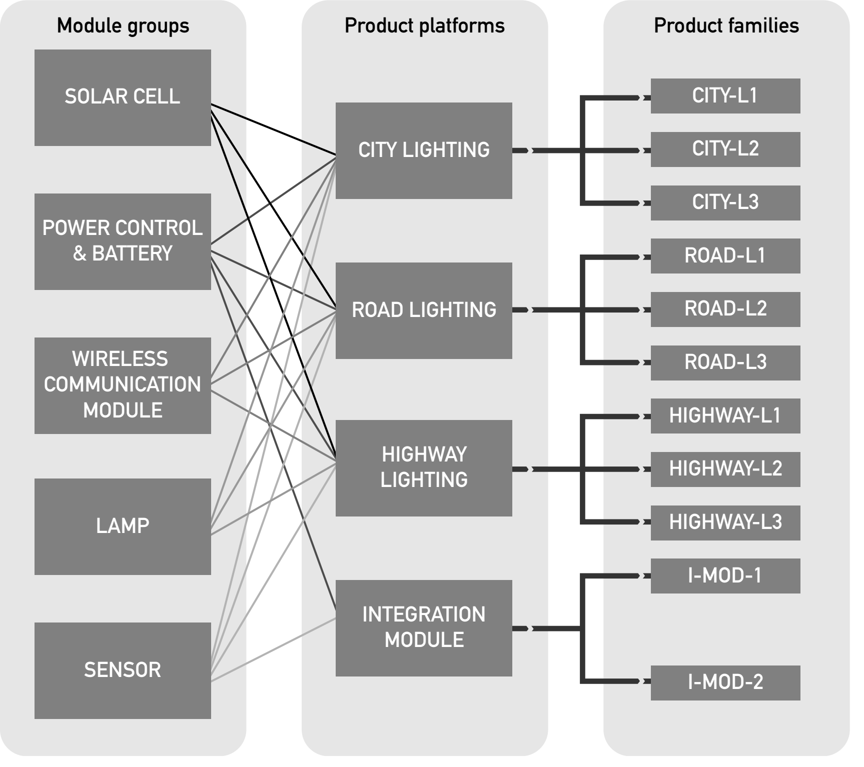

Figure 2.1.7 Product platforms of photovoltaic (PV)–powered street-lighting products consist of several modules from which different product families can be composed

lead to innovative technology–product–market combinations, the so-called *search areas*, or *search fields*.

Search field information comprises the following topics:

- Subject: the relation of the idea to markets, product (groups), and services.
- Description: a short description of the direction of the idea.
- Strength: What are the basic strengths of the idea?
- Trends: To which developments in technology and markets does the idea connect?
- Needs: Which problem(s) will be solved by the idea?
- Size: An indication of the size of the market.
- Segmentation: Which subareas and differentiation of products can be foreseen?
- Stakeholders comprise parties involved such as competitors, experts, and consumers.
- Bottlenecks: Which problems – both internal and external – can be expected?

Next, information connected to these search fields can be inputted to the design brief stage. Again divergence, selection, and convergence can be applied to select search fields to be worked out further.

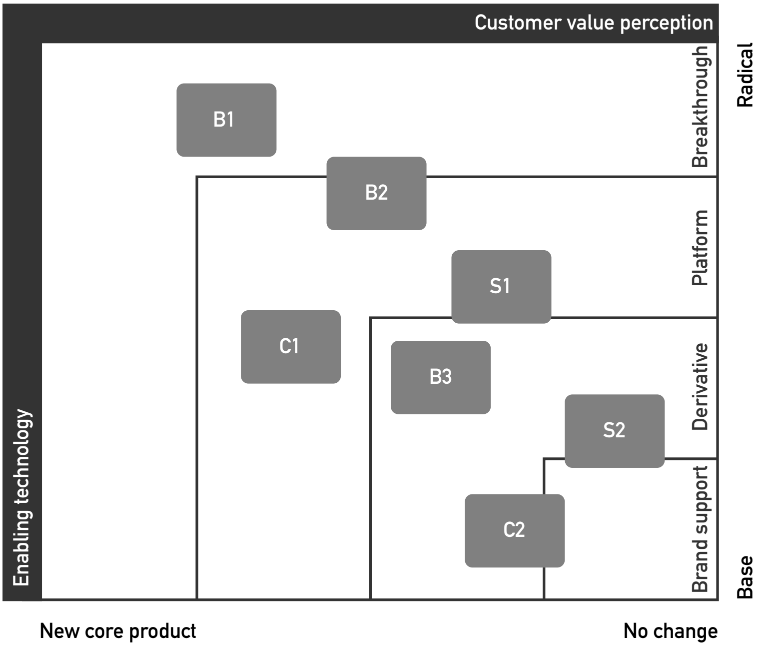

Figure 2.1.8 Product platform for gardening equipment, (B1) blower on hydrogen energy, (B2) blower with noise reduction system, (B3) blower standard, (C1) cutter with flexible drive shaft, (C2) cutter standard, (S1) chainsaw with automatic balancing system, and (S2) chainsaw standard

The creative process of the Delft innovation model is supported by visual collages and written mind maps. Figure 2.1.10 shows a communication device that has been developed by using mind maps. Mind maps of a fuel cell (Figure 2.1.11) and of lead user hikers (Figure 2.1.12) are combined to determine a suitable technology–product–market combination. For more information about this model, see Section 2.3.

2.1.4 TRIZ

TRIZ is a Russian acronym meaning the *theory of inventive problem solving* (Altshuller, 1984). TRIZ can be applied to estimate the probability of technology developments. It is a comprehensive method based on long-term patent research leading to certain basic rules governing problem solving in product development.

Each trend of technology evolution demonstrates a line of a system's structural evolution with regard to changing its physical structure, space, time, energy, supersystem relations, and other parameters. Each trend contains a number of specific patterns, which are transitions that specify how a system should be changed to move from stage A to stage B of evolution. The trends are quite generic in nature, and exploring their applicability requires a combination of modern technologies that reside outside of the industry sector in which a product belongs.

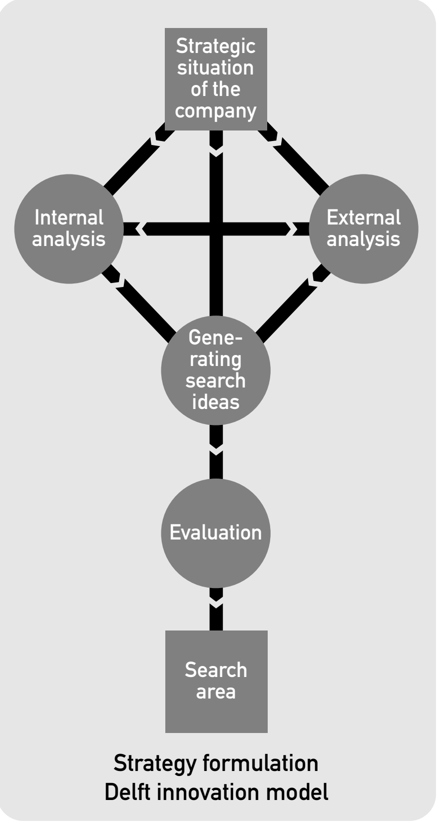

Figure 2.1.9 Scheme representing the strategy formulation stage of the Delft innovation model

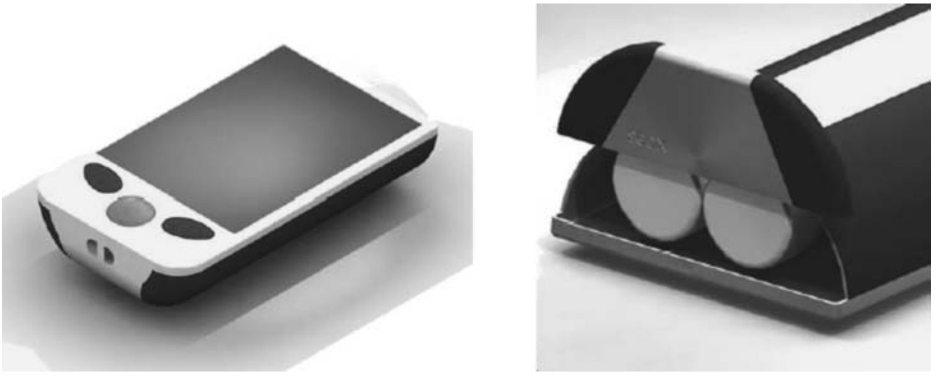

Figure 2.1.10 Communication device for hikers with integrated fuel cells. Left: Front view. Right: Opened back view. Designed by Kyra Adolfsen and Benne Draijer (See Plate 5 for the colour figure)

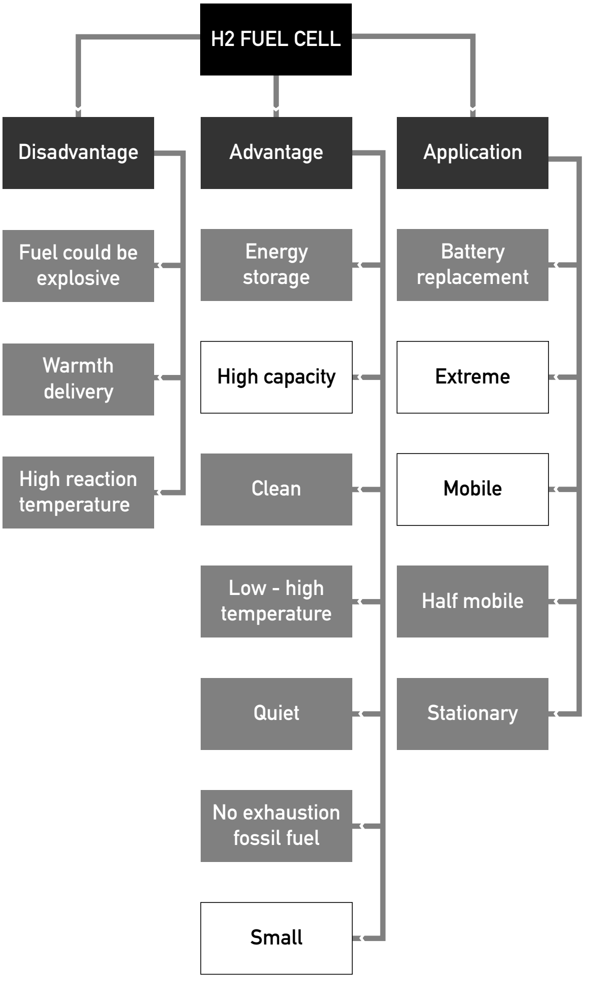

Figure 2.1.11 Mindmap of a fuel cell. Selected search fields in white

Figure 2.1.13 shows in which fields TRIZ could improve product development. Since there are many diverse TRIZ trends, the method becomes complex. Therefore, software has been developed to make it easier to apply TRIZ. Section 2.4 gives an extensive overview of TRIZ.

2.1.5 Technology Roadmapping

A technology roadmap (TRM) establishes a correlation between identified market needs and trends with existing and emerging technologies for a specific industry sector (Souchkov, 2005). Technology roadmaps usually cover 3–10 years and are used in strategic product planning, research planning, and business planning (Phaal, Farrukh, and Probert, 2001).

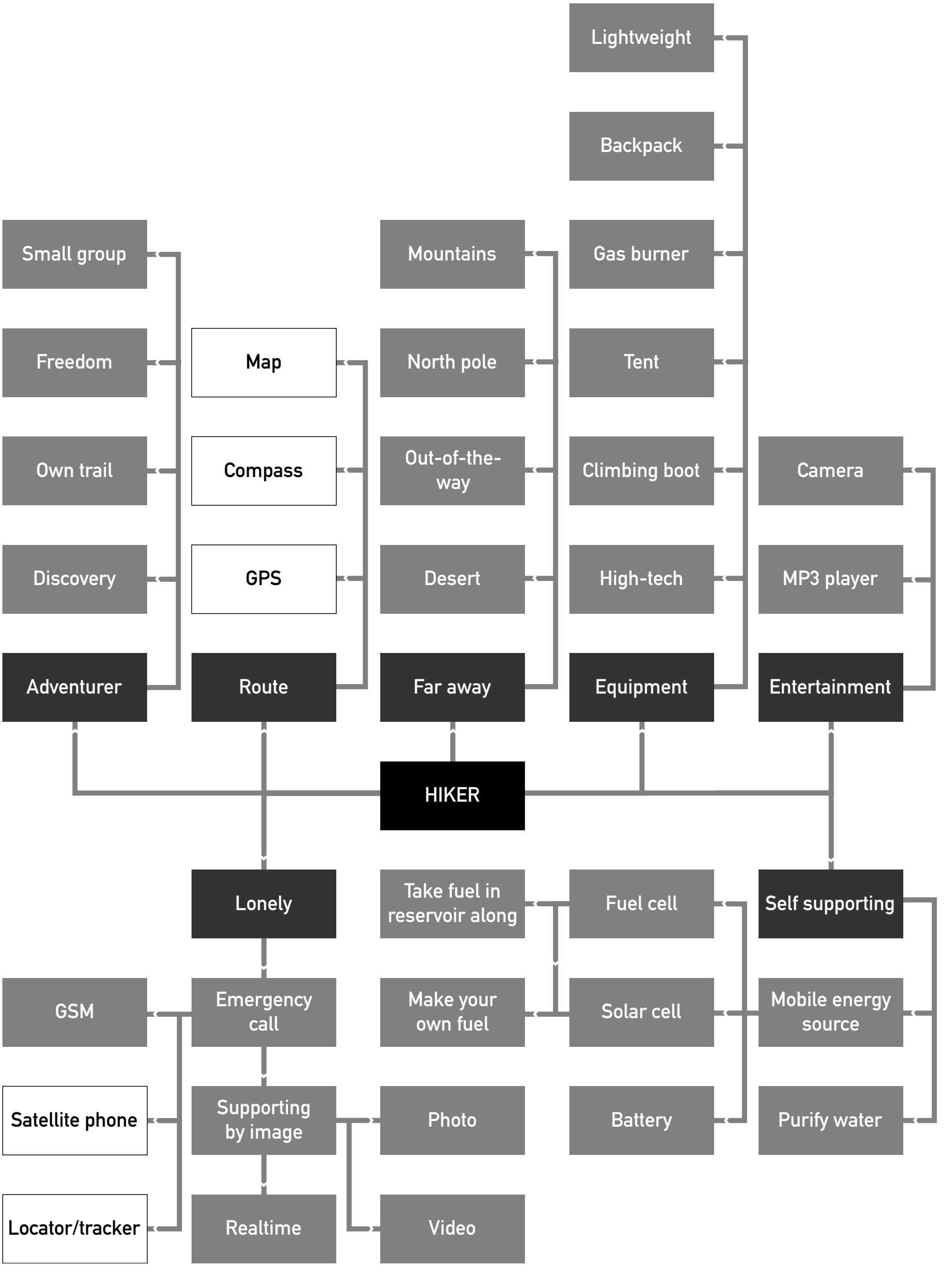

Figure 2.1.12 Mindmap of lead user hikers. Selected search fields in white

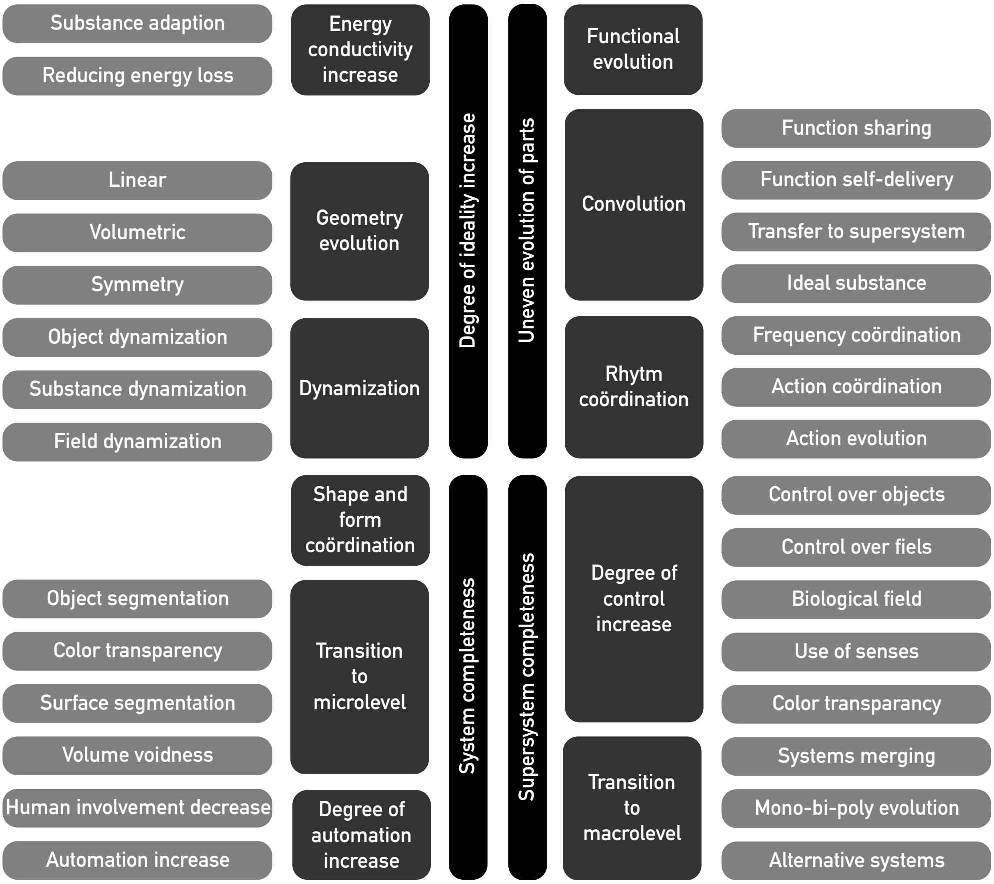

Figure 2.1.13 TRIZ trends of technology evolution, from Souchkov (2005)

Figure 2.1.14 shows an example of a TRM for the furniture industry. Theory and examples of applications of technology roadmapping will be provided by Section 2.5.

2.1.6 Design and Styling of Future Products

Design and styling are assets for technological innovation (Christensen, 1995). More specifically, cars, modern durables, and consumer products require a high degree of integration between functional and aesthetic aspects of design. Design is often regarded as purely aesthetic or superficial. Research by TNO (2005), however, has highlighted the crucial role played by design in the economy of the Netherlands and in product innovation. It was concluded that companies combining technological innovation with new product design increase their market share relative to other companies. It therefore seems likely that industrial designers will provide significant added value to products with new technologies.

A market of products with integrated technologies can be promoted by studying the image that potential users of a proposed product wish to project and designing the product so that it

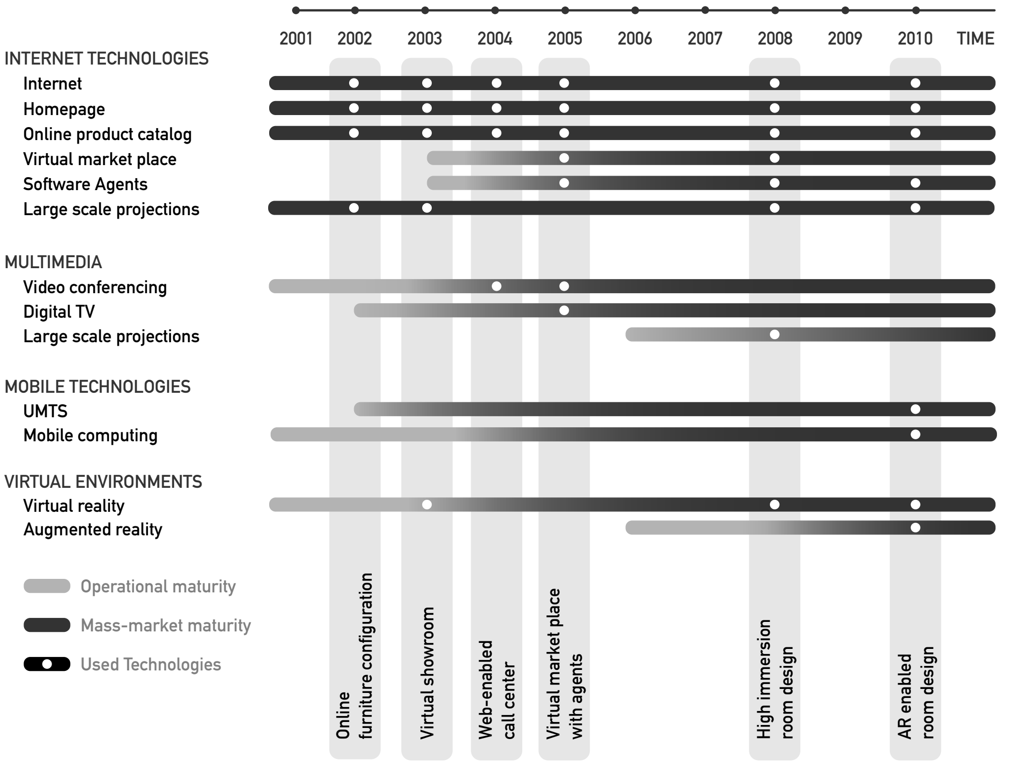

Figure 2.1.14 Technology roadmap for the furniture industry by Valeri Souchkov

meets those aesthetic requirements. A method for developing an appropriate styling for innovative products is shown in Figure 2.1.15. It comprises the use of style elements from both associative and competing products.

Figure 2.1.16 shows a design for a diving lamp with integrated fuel cells. Technology is decisive in the high-end diving market, where users require long burning hours and reliability. In the larger market of so-called family divers, however, design and styling (see Figure 2.1.17) are more important. In Section 2.6, aspects related to the design and styling of future products will be further explained.

2.1.7 Constructive Technology Assessment

In innovation journeys, many actors play a role. New products must be promoted by manufacturers and retailers, must be approved by a competent authority in accordance with industry rules and standards, and must meet with acceptance from consumers. Constructive technology assessment focuses on these processes and how to improve them (Deuten, Rip, and Jelsma, 1997). The dynamics of technological development involve a series of exchanges between technology and society. Social projects such as those shown in Figure 2.1.18 foster the acceptance of new products by teaching people about the benefits of technology for society.

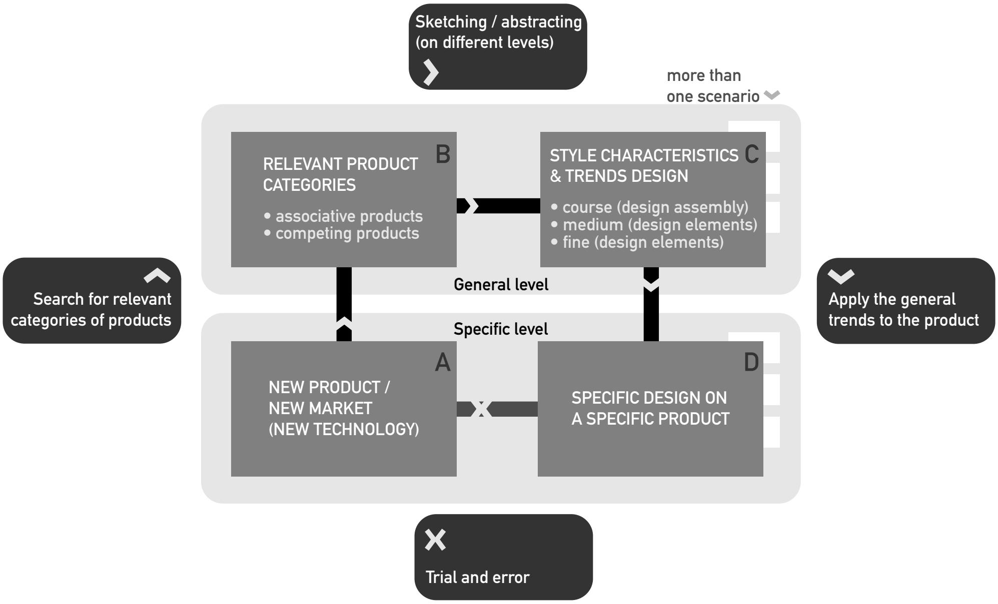

Figure 2.1.15 Method for innovative design and styling based on characteristic style elements from associative and competing product by Stevens (2005)

In Asian metropolises, transportation has always been a difficult problem. Owing to outdated engine technologies, private taxies (referred to locally as *rickshaws*, *tuk-tuks*, *bajajs*, etc.) are a primary source of air pollution and noise. Because they require little power – about 5 kW – rickshaws could be an interesting application for proton exchange membrane (PEM) fuel cells. A positive social impact would result from the decrease of harmful emissions and increased comfort due to decreased noise. As a side benefit, PEM fuel cells could supply the rickshaws with electric power, enabling end users to operate air conditioning, stoves, and refrigerators from them. Moreover the rickshaw, as an icon of transportation cherished by many residents, might serve as a catalyst to accelerate social acceptance of fuel cell technology. In Section 2.7, the theory of CTA will be further explained.

2.1.8 Innovation Journey

In the case of technology-based product design, product development often follows certain patterns. By examining the so-called innovation journeys (Rip, 2005) of products in different fields, one may gain tools for assessing the potential innovation journeys of new products using new technologies or new situations of use; see also Section 2.8.

One pair of students used this approach to design an induction cooking device powered by fuel cells (Figure 2.1.19). They evaluated the evolution of technologies for cooking dinner, starting with plain fire and leading to the principles of electrical cooking. Comparing plain electrical elements, ceramic, halogen, infrared, and induction cooking, they found the last method most suitable in relation to customers' demands for an easy-to-use and

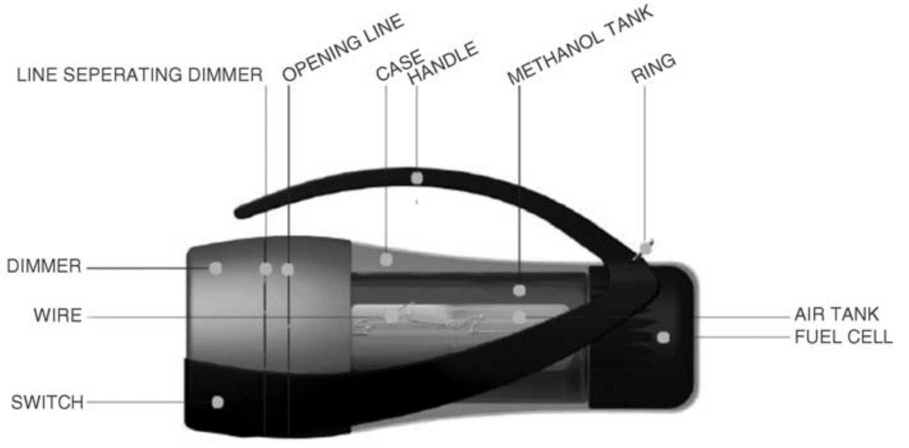

Figure 2.1.16 Diving lamp powered by fuel cells by Julia Garde and Annelies Brummelman (See Plate 6 for the colour figure)

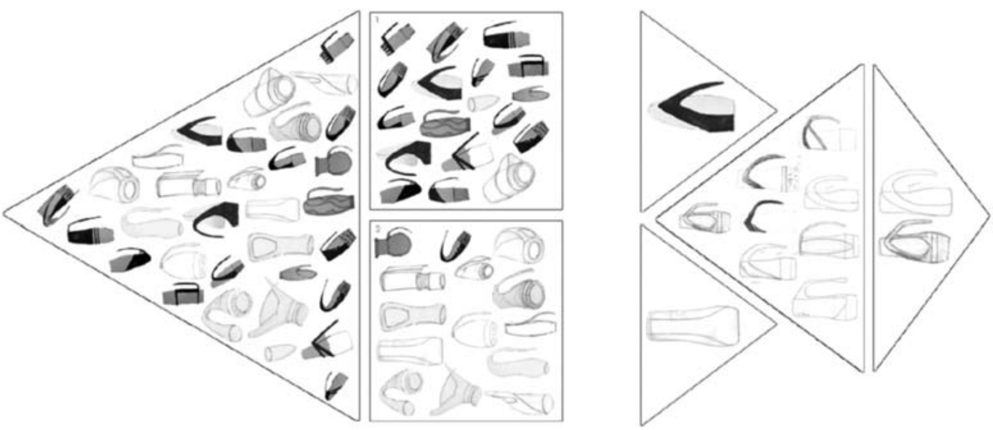

Figure 2.1.17 Design and styling of a diving lamp by diverging, categorizing, and converging associative and competitive style characteristics in two phases (Drawing by Julia Garde and Annelies Brummelman)

lightweight cooking device. The black box in Figure 2.1.19 accommodates all electrical components, including a replaceable hydrogen cartridge, a fuel cell of 500 W, and an induction coil. The black box fits snugly into the cubical case, which serves as a protective shell during transportation. The device is operated by an ergonomic user interface.

2.1.9 Risk-Diagnosing Methodology

Companies must take risks to launch new products speedily and successfully. In this scope, risk-diagnosing methodology (RDM) aims to identify and evaluate technological,

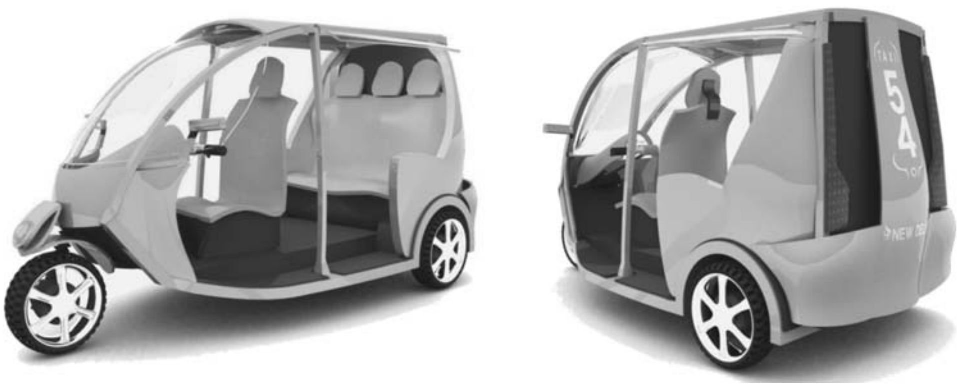

Figure 2.1.18 Fuel cell–powered rickshaw (Designed by Simon Brandenburg and Werner Helmich (2006)) (See Plate 7 for the colour figure)

Figure 2.1.19 Induction cooking device powered by fuel cells. Left: The product in use. Right: In compact carrying case (Designed by Rick Tigchelhoff and Wouter Haanstra) (See Plate 8 for the colour figure)

organizational, and business risk in product innovation (Keizer, Halman, and Song, 2002). This methodology, which will be explained in detail in Section 2.9, has been developed and applied at Philips and Unilever, and is fit for product development in diverse areas such as the automobile industry, printing equipment, landing gear systems, and fast-moving consumer goods such as shampoo and margarine. The risks evaluated by RDM are related to product family and brand positioning, technology, manufacturing, intellectual property, supply chain and sourcing, consumer acceptance, project management, public acceptance, screening and appraisal, trade customers, competitors, and commercial viability.

One pair of students applied RDM to a product platform of fuel cell–powered equipment, and drew the following conclusions:

- The main risk is acceptance of the new, unknown, fuel cell technology by users.
- Most risks related to the production, manufacturing, and distribution of the new product can be mitigated or eliminated by forming a joint venture with several stakeholders.
- A design process that involves the participation of end users can be used to create a higher degree of acceptance for new products.

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2.2 Platform-Driven Product Development

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2.2.1 Introduction

In a global, intense, and dynamic competitive environment, the development of new products and processes has become a focal point of attention for many companies. Shrinking product life cycles, increasing international competition, rapidly changing technologies, and customers demanding high variety options are some of the forces that drive new development processes. More variety will make it more likely that each consumer finds exactly the option he or she desires, and will allow each individual consumer to enjoy a diversity of options over time. In considering the implementation of product variety, companies are challenged to create this desired variety economically. In their quest to manage product variety, firms in most industries are increasingly considering product development approaches that reduce complexity and better leverage investments in product design, manufacturing, and marketing (Krishnan and Gupta, 2001). Platform thinking, the process of identifying and exploiting commonalities among a firm's offerings, its target markets, and the processes for creating and delivering offerings, appears to be a successful strategy to create variety with an efficient use of resources (Halman, Hofer, and van Vuuren, 2003). Key in this approach is the sharing of components, modules, and other assets across a family of products. Historical success stories such as the Sony Walkman, Black and Decker power tools, Hewlett Packard's Deskjet printers, Microsoft's Windows NT, and Minolta's "intelligent lens technology" have shown both the benefits and the logic behind the platform concept. Gupta and Souder (1998) even claim that thinking in terms of platforms for families of products rather than individual products is one of the five key drivers behind the success of short-cycle-time companies.

2.2.2 Definitions

The terms *product families*, *platforms*, and *individual products* are hierarchically different and cannot be used as synonyms. A *product family* is the collection of products that share the same assets (i.e., their platform) (Sawhney, 1998). A *platform* is therefore neither the same as an individual product nor the same as a product family; it is the common basis of all individual products within a product family (McGrath, 1995; Robertson and Ulrich, 1998). As a consequence, a platform is always linked to a product family, while it can serve multiple product lines in the market. The leading principle behind the platform concept is to balance the commonality potential and differentiation needs within a product family. Figure 2.2.1 shows how Skil, a developer of multiple product families (consisting of, e.g., a set of saws, drills, routers, and grinders), utilizes as much as possible the same technical components for its different brand segments even though they have their own styling and perceived worth.

One possibility to build a *platform* is to define it by means of the product architecture. This *product platform* has been defined by McGrath (1995) as a set of subsystems and

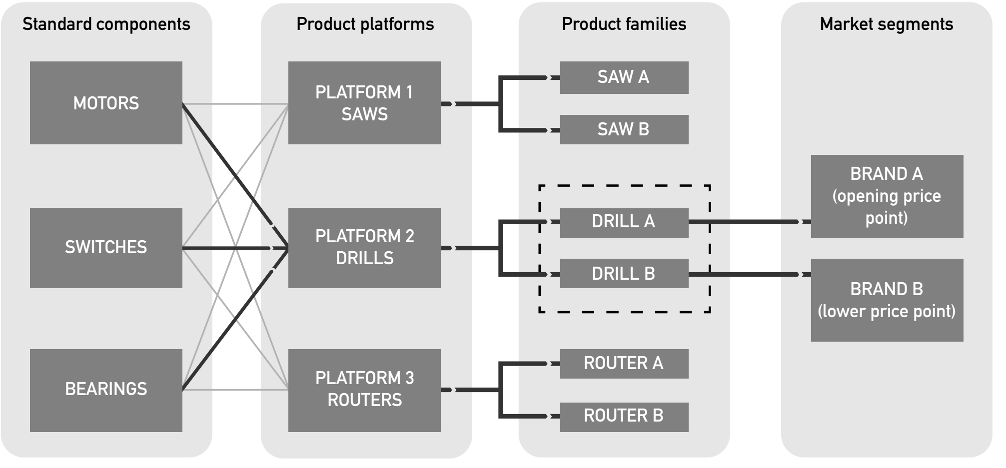

Figure 2.2.1 Platform-based development of product families within Skil

interfaces that form a common structure from which a stream of related products can be efficiently developed and produced. Baldwin and Clark (1999) define three aspects of the underlying logic of a product platform: (1) its modular architecture, (2) the interfaces (the scheme by which the modules interact and communicate), and (3) the standards (the design rules to which the modules conform). The main requirements for building a product family based on a product platform are (1) a certain degree of modularity to allow for the decoupling of elements, and (2) the standardizing of a part of the product architecture (i.e., subsystems and/or interfaces). A modular product architecture in this context is characterized by a high degree of independence between elements (modules) and their interfaces.

The typical inclination is to only think of the product architecture as the basis for a common platform of a product family. In line with discussions in literature (Meyer and Lehnerd, 1997; Robertson and Ulrich, 1998; Sawhney, 1998), we argue that a product family should ideally be built not only on elements of the product architecture (components and interfaces) but also on a multidimensional core of assets that also include processes along the whole value chain (e.g., engineering and manufacturing), customer segmentation, brand positioning, and global supply and distribution.

Process platform refers to the specific setup of the production system to easily produce the desired variety of products. A well-developed production system includes flexible equipment, for example programmable automation or robots, computerized scheduling, flexible supply chains, and carefully designed inventory systems (Kahn, 1998). Sanderson and Uzumeri (1995) refer in this respect to Sony's flexible assembly system and an advanced parts orientation system, designed specifically with flexibility, small-lot production, and ease of model change in mind. Although the costs of this multifunction machine may be twice as much as those of a comparable single-function machine, the greater flexibility possible using manufacturing equipment designed with multiple products and rapid changeover in mind offsets its initial cost. Figure 2.2.2 illustrates how process platforms can be created by

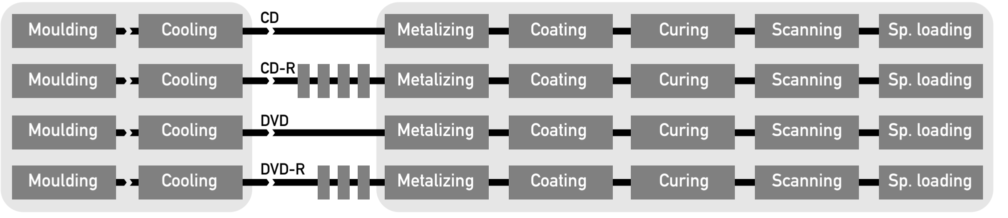

Figure 2.2.2 Process platforms in the production of CDs, CD-Rs, DVDs, and DVD-Rs

searching for potential commonalities in the production process of different product lines of CDs, CD-Rs, DVDs, and DVD-Rs.

Customer platform is the customer segment that a firm chooses as its first point of entry into a new market. This segment is expected to have the most compelling need for the firm's offerings and can serve as a base for expansion into related segments and application markets (Sawhney, 1998). Established customer relationships and knowledge of customer needs are used as a springboard to expand by providing step-up functions for higher price–performance tiers within the same segment or to add new features to appeal different segments (Meyer, 1997).

Brand platform is the core of a specific brand system. It can either be the corporate brand (e.g., Philips, Toyota, and Campbell) or a product brand (e.g., Pampers, Organics, and Nivea). From this brand platform, subbrands can be created, reflecting the same image and perceived worth (e.g., Philishave, Hugo Boss perfumes, and Organics shampoo). With a small set of brand platforms and a relatively large set of subbrands, a firm can leverage its brand equity across a diverse set of offerings (Sawhney, 1998).

Global platform is the core standardized offering of a globally rolled-out product. As an example, designing software for a global market can be a challenge. The goal is to have the application support different locales without modifying the source code. A global rollout plan details the aspects of the product that can be standardized as well as those aspects that should be adapted to country-specific conditions and customer preferences. Customization can involve physical changes in the product, and adaptation in pricing, service, positioning message, or channel (Sawhney, 1998).

2.2.3 *The Creation of Platform-Based Product Families*

Cost and time efficiencies, technological leverage, and market power can be achieved when companies redirect their thinking and resources from single products to families of products built upon robust platforms. Implementing the platform concept can significantly increase the speed of a new product launch. The platform approach further contributes to the reduction of two major resources (i.e., cost and time) in all stages of new product development. By using standardized and pretested components, the accumulated learning and experience in general may also result in higher product performance. Unfortunately, this is not a one-time effort. New platform development must be pursued on a regular basis, embracing technological changes as they occur and making each new generation of a product family more exciting

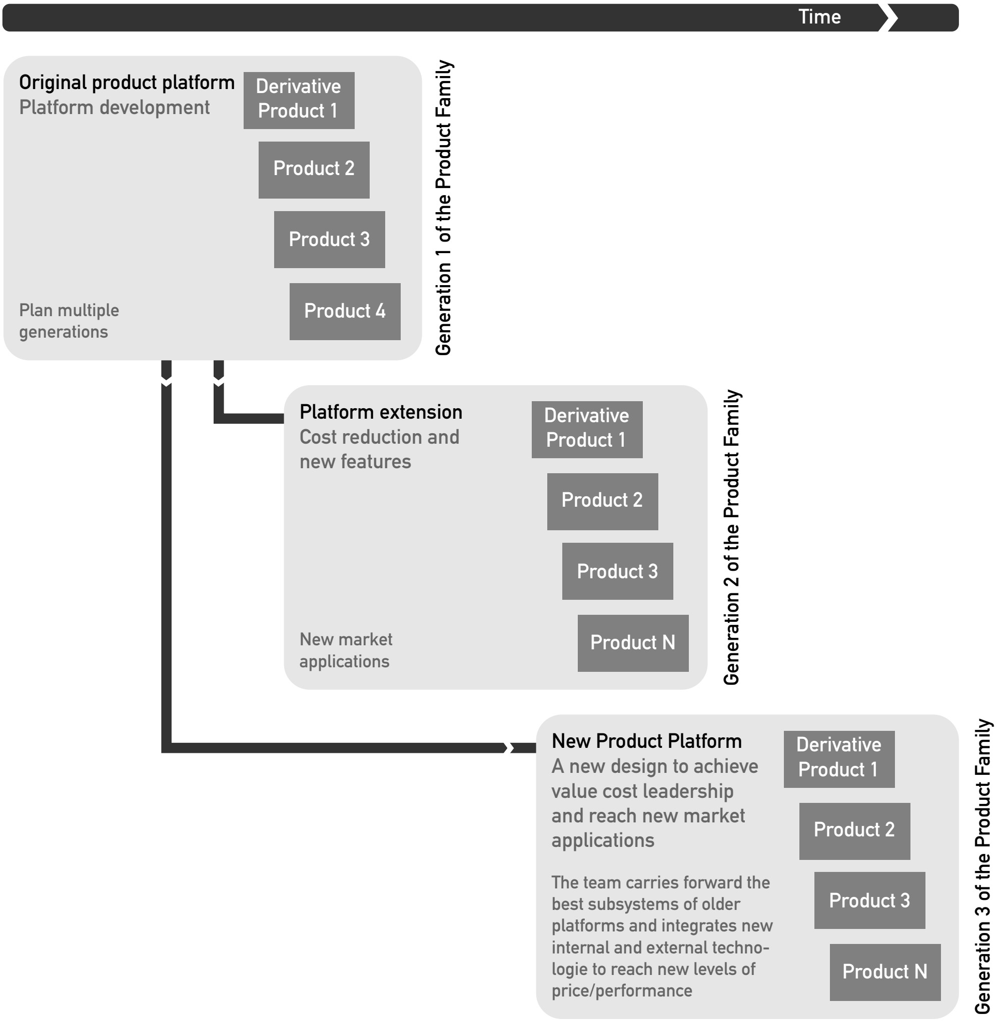

Figure 2.2.3 Product family evolution, platform renewal, and new product creation (adapted from Meyer and Lehnerd, 1997)

and value-rich than its predecessors. Meyer and Lehnerd (1997) propose a general framework for product family development (see Figure 2.2.3).

This framework represents a single product family starting with the initial development of a product platform, followed by successive major enhancements to the core product and process technology of that platform, with derivative product development within each generation. New generations of the product family can be based on either an extension of the product platform or an entirely new product platform. In case of an extension, the constellation of subsystems and interfaces remains constant, but one or more subsystems undergo major revision in order to achieve cost reduction or allow new

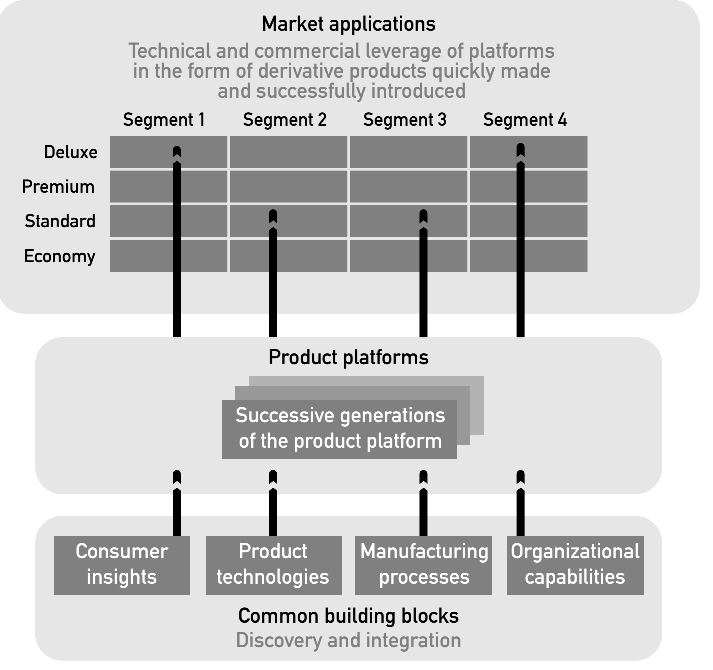

Figure 2.2.4 The evolution of product families (adapted from Meyer and Lehnerd, 1997)

features. An entirely new platform emerges only when its basic architecture changes and aims at value cost leadership and new market applications. Systems and interfaces from prior generations may be carried forward into the new design but are joined by entirely new subsystems and interfaces.

The more consistent a platform concept is defined and implemented in terms of parts, components, processes, customer segmentation, and so on, the more effective a company can operate in terms of tailoring products to the needs of different market segments or customers.

An effective evolution of a product family requires that in collective fashion three essential elements are considered (Figure 2.2.4):

- *Potential market applications*: What type of products can be offered to different market segments? Customers care whether the firm offers a product that closely meets their needs. Closely meeting the needs of different market segments requires distinctive products.
- *Potential commonalities between the distinctive products that can be achieved*: What are the design, manufacturing, and cost benefits that can be achieved by maximizing the extent to which distinctive products share, for example, common components, manufacturing processes, and distribution channels?
- *Platform strategy definition*: This is determined by making trade-off decisions between distinctiveness and commonality. In the ideal case, the platform design represents a relatively high level of commonality that is achieved without much sacrifice in distinctiveness while distinctiveness declines slowly as commonality is increased.

2.2.4 The Platform-Planning Process

Platform planning is a cross-functional activity involving at least the firm's product-marketing, design, and manufacturing functions. Robertson and Ulrich (1998) advocate a loosely structured process for platform planning focused on three information management tools: the *product plan*, the *differentiation plan*, and the *commonality plan*.

The Product Plan

The product plan specifies the distinct marketing offerings over time and usually comes from the company's overall product plan that identifies the portfolio of products to be developed by the organization and the timing of their introduction to the market. The product plan identifies major models but does not show every variant and option. It is linked to other issues and pieces of information:

- Availability of development resources.
- Life cycles of current products.
- Expected life cycles of competitive offerings.
- Timing of major production system changes.
- Availability of product technologies.

The product plan reflects the company's product strategy. Some companies choose to issue several products simultaneously; others choose to launch products in succession.

The Differentiation Plan

The differentiation plan explicitly represents the ways in which multiple versions of a product will be different from the perspective of the customer and the market. The plan consists of a matrix with rows for the differentiating attributes of the product and with columns for the different versions or models of the product, where the last one gives an approximate assessment of the relative importance to the customer of each differentiation attribute. Differentiating attributes (DAs) are those characteristics of the product that are both important to the customer and intended to be different across the products. A common pitfall in platform planning is to become bogged down in detail. The best level of abstraction results in no more than 10–20 DAs.

The team uses the differentiation plan to codify each decision about how the product will be different. On the first pass, the differentiation plan represents the ideal case of each product's differentiation for maximum appeal to customers in the target segments. On subsequent iterations, the ideal case is adjusted to respond to the need for commonality.

The Commonality Plan

The commonality plan describes the extent to which the products in the plan share physical elements. The plan is an explicit accounting of the costs associated with developing and producing each product. It consists of a matrix with rows representing the chunks of the product (listed in the first column). The term *chunk* is used to refer to the major physical elements of a product. A set of products exhibits high levels of commonality if many chunks are shared. To manage complexity, the team should limit the number of chunks to roughly the number of DAs. The remaining columns identify the products in the plan, according to the timing of their development and the metrics used in the commonality plan as number of unique parts, development costs, tooling costs, and manufacturing costs. The values of these metrics are estimated because actual values cannot be determined until the products have been designed and produced.

Managing the Trade-Off between Differentiation and Commonality

The challenge in platform planning is to resolve the tension between the desire to differentiate the products and the desire for these products to share a substantial fraction of their components. For most product contexts, an unconstrained product plan and an unconstrained differentiation plan lead to high costs. For this reason, iterative problem solving is required to balance the need for differentiation with the need for commonality. This iterative activity involves both moving along the distinctiveness–commonality curve and exploring alternate product architectures with different associated trade-off characteristics (Figure 2.2.5).

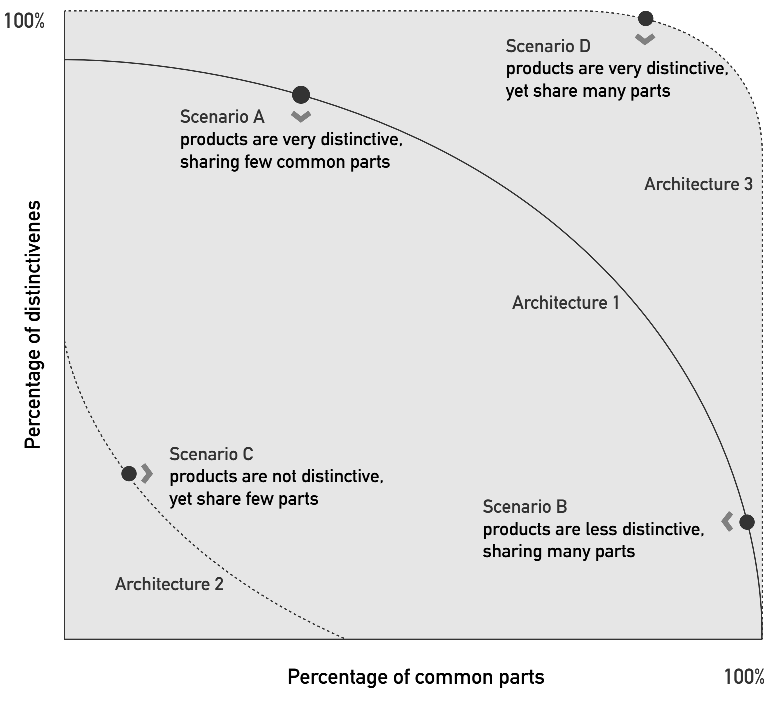

Figure 2.2.5 Trade-off between distinctiveness and commonality (adapted from Robertson and Ulrich, 1998)

2.2.5 Modular versus Integral Product Architectures

Product architecture is defined by Ulrich (1995) as the scheme by which the function of a product is allocated to physical components. The function of a product can be broken down into a number of *functional elements* (sometimes also called *functional requirements*), which are the individual operations that a product performs. The components of a product can be thought of as *physical elements*, which are the parts and subassemblies that realize the function of the product. The components are usually arranged into major building blocks, called *chunks*, made up of a number of components. The mapping between functional elements and components may be one-to-one, many-to-one, or one-to-many. Product architectures can be distinguished into *modular* and *integral* architectures. A modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the products, and specifies decoupled interfaces between components. An integral architecture, on the other hand, includes a complex multirelational mapping from functional elements to physical components and/or coupled interfaces between components. But which one is better?

Product Change

The architecture of a product is closely linked to the ease with which change to a product can be implemented. Products frequently undergo some change during their life due to upgrade, add-ons, adaptation, wear, consumption, and flexibility in use motives. In each of these cases, changes to the product are most easily accommodated through modular architectures. The modular architecture allows the required changes that are typically associated with the product's function to be localized to the minimum possible number of components. However, another popular strategy is to dramatically lower the cost of the entire product, often through an integral architecture, such that the entire product can be discarded or recycled in case of wear and consumption. For example, disposable razors, cameras, and cigarette lighters have all been commercially successful products, and disposable pens dominate the market place.

It is also possible to find change across generations of the product. When a new model of an existing product is introduced to the market place, the product always embodies some functional change relative to the previous product. For products with a modular architecture, desired changes to a functional element can be localized to one component, whereas products with integral architectures require changes to several components in order to implement changes to the product's function.

Product Variety

Ulrich (1995) defines *product variety* as the diversity of products that a production system provides to the marketplace. The ability of a firm to economically create variety resides not only with the flexibility of the equipment in the factory but also with the architecture of the product. A modular-designed camera, for instance, allows the use of different types of lenses (see Figure 2.2.6).

With a modular product architecture, product variety can be achieved with or without flexible component production equipment. In relative terms, in order to economically produce

Figure 2.2.6 Modularity in product design (See Plate 9 for the colour figure)

high variety with an integral architecture, the component production equipment must be flexible. This argument assumes in all cases that the final assembly process itself is somewhat flexible, that is, different combinations of components can be easily assembled to create the final product variety.

Component Standardization

Component standardization is the use of the same component in multiple products. Standardizing parts like axles, steering columns, and most importantly chassis helps the Volkswagen Auto Group to lower its production costs and cut assembly times. Shared parts also allow the Volkswagen Auto Group to produce cars from different brands such as Audi, Seat, Skoda, Scania, and Volkswagen at the same plant. A modular architecture increases the likelihood that a component will be commonly useful and also enables component interfaces to be identical across several products.

A standard interface, for instance, to connect all types of lenses (see Figure 2.2.7) allows the use of a wide variety of lenses for different types of cameras.

Component standardization has implications for the manufacturing firm in the areas of cost, product performance, and product development. Standard components can be less expensive (produced in high volume), exhibit higher performance (learning and experience), and lower the complexity, cost, and lead time of product development (known entity).

Product Performance

Ulrich (1995) defines *product performance* as how well the product implements its functional elements. Modular architectures allow for optimization of local performance characteristics by using a standard component or, when this is not available, modular architectures allow the component to be designed, tested, and refined in a focused way. Architecture also influences the improvement of global performance characteristics usually measured in

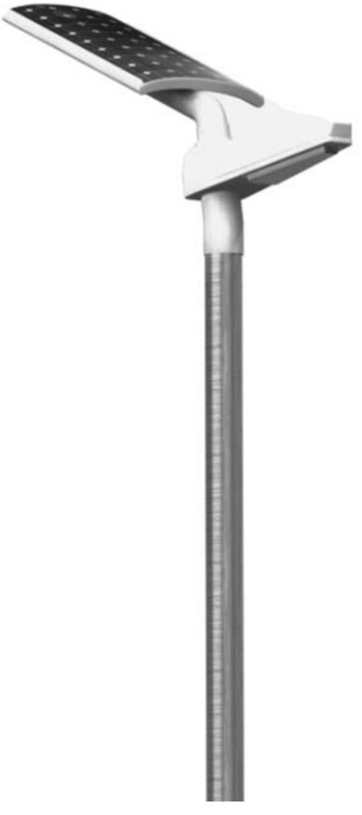

Figure 2.2.7 Outdoor lighting system (See Plate 10 for the colour figure)

such ways as efficiency, size, weight, and speed. An integral architecture facilitates the optimization of holistic performance characteristics and those that are driven by the size, shape, and mass of a product. Such characteristics include acceleration, energy consumption, aerodynamic drag, noise, and aesthetics.

The practice of implementing multiple functions using a single physical element is called *function sharing*. An integral architecture allows for redundancy to be eliminated through function sharing and allows for geometrical nesting of components to minimize the volume a product occupies. Such function sharing and nesting also allow materials to be minimized, potentially reducing the cost of manufacturing the product.

There are no deterministic approaches to choosing optimal product architecture. Ulrich (1995) concludes that in most cases the choice will not be between a completely modular or completely integral product architecture, but rather will be focused on which functional elements should be treated in a modular way (thus enabling the creation of one or more product platforms) and which should be treated in an integral way. And as pointed out by Meyer, Tertzakian, and Utterback (1997), excellence in product platform design is fundamental to the quality and success of a product family, consisting of a basic architecture composed of modules and the interfaces between these modules.

2.2.6 Measuring the Performance of Product Families

In managing product families, there are a number of frequently asked questions: *When should we renew our platform? How much will platform efforts cost, and how long should we expect them to take? What types of engineering and commercial benefits can we expect to gain from these efforts once they are completed? How can we improve our approaches and strategies for product development?*

Meyer, Tertzakian, and Utterback (1997) as well as Meyer and Lehnerd (1997) have developed measures to evaluate a platform's efficiency and effectiveness. To measure platform efficiency and effectiveness, the following data are required:

- *Engineering costs*: These costs comprise the amount of money spent on developing platforms and specific derivative products.
- *Development time*: The time spent from start to finish in platform and derivative product development. For derivative products, the development time cycle starts at the point of specific engineering work for the product itself and ends at the time of release to manufacturing.
- *Manufacturing costs*: These are the costs of upgrading a manufacturing facility to handle new products.
- *Market development costs*: These data may include expenditures on specific promotional campaigns for a new product, channel development expenses, and dealer-training programs.
- *Sales data*: Sales data for each product in a family should be aggregated across its full commercial life cycle.
- *Margins*: These data link profit to specific products.

Platform Efficiency

Platform efficiency is defined as the degree to which a platform allows the economical generation of derivative products.

$$\text{Platform efficiency} = \frac{\text{Derivative Product Engineering Costs}}{\text{Platform Engineering Costs}}$$

This metric can be used to understand development efficiency for an entire generation of derivative products, computing the average R&D costs of the derivative products for a particular platform version and then dividing that amount by that platform version's own development costs. One can also compare the platform efficiency of different platform versions across different product families.

What is a reasonable platform efficiency value? Meyer and Lehnerd (1997), in their study of firms in the electronics industry, indicated that platform efficiency values of 0.10 or less mark the presence of highly leverageable product platforms, meaning that efficient platforms allow the firm to produce derivative products at roughly 10% of the cost of developing associated base platform architectures. However, the desirable benchmark value for a particular company will be industry specific. They recommend studying a successful product family in the company, determining its level of platform efficiency, and then using that as a benchmark for similar groups inside the business.

If resources are being effectively used and learning is taking place, platform efficiency should improve with each successive platform version of a product family. Platform efficiency can be used as an indicator of platform demise. An increase in its value over successive derivative products may indicate weakness in the underlying product architecture. It can also signify a change in management or key resources, human or otherwise. Market factors can also substantially influence the efficiency with which existing platforms can be leveraged into new products, particularly when the market applications are novel to the firm.

Note that the metric, so far, has included only engineering costs. A more comprehensive understanding emerges if one considers the cost ratios for introducing new products into full-scale production.

Platform Effectiveness

Platform effectiveness is defined by Meyer, Tertzakian, and Utterback (1997) as the degree to which product platform–based products produce revenue for the firm relative to the cost of developing those products. Platform effectiveness simply compares the resources used to create products with the revenues derived from them, *over the long term*. The cost of development includes the engineering costs, manufacturing engineering costs, market development costs, and expenditures for plant and equipment. Revenues consist of net sales attributable to each derivative product within the family. Platform effectiveness for a single derivative product is represented as follows (Meyer and Lehnerd, 1997):

$$\text{Platform effectiveness for a single product} = \frac{\text{Net Sales of a Derivative Product}}{\text{Development Costs of a Derivative Product}}$$

The effectiveness measure can be aggregated for an entire generation of products, allowing one to compare the performance of successive generations:

$$\text{Platform effectiveness for a generation of products}$$
$$= \frac{\text{Net Sales of Derivative Products of a Platform Version}}{\text{Development Costs of Derivative Products of a Platform Version} + \text{the Platform Development Costs}}$$

As pointed out by Meyer *et al.*, there are many factors that can lead to declining platform effectiveness. First, the platform itself may have outlived its utility as a basis for creating specific products that are competitive in the market in their features and cost. This would lead to declining sales, affecting the numerator of the effectiveness equations. As for the denominator, R&D costs may be rising due to problems in platform efficiency. Besides, a market either in explosive growth or in free fall will greatly impact the metric.

How is *platform effectiveness* defined for your company's product lines? Meyer and Lehnerd (1997) again suggest that platform effectiveness values will vary from industry to industry and that the most pragmatic way to establish a benchmark for platform effectiveness in the company is through internal study, observing those values associated with the most successful product families.

Taken together, these measures of platform efficiency and effectiveness should be interpreted to evaluate if a specific product platforms needs renewal. When the underlying architectures of major product lines are running out of gas in their ability to (1) facilitate rapid and cost-effective development of derivative products, and (2) deliver the features required by customers at price point that would lead to continued strong sales, it will be necessary to fund and sequence new platform development projects to supersede existing platforms.

2.2.7 Managing Risk in Platform-Based Development

Platform-based development may not be appropriate for all product and market conditions. It still remains difficult to anticipate the consequences of risky platform decisions in advance.

Developing the initial platform in most cases requires more investments and development time than developing a single product, delaying the time to market of the first product and affecting the return on investment time. Also, the failure to develop new platform architectures on a continuous basis subjects the firm to substantial market risk. It stands to reason that if new platform development efforts take longer to complete than derivative products efforts, R&D aimed at platform renewal should be pursued concurrent with derivative products developments on existing platforms. That ensures a continuous stream of products embodying competitive technology (Meyer and Lehnerd, 1997; Meyer, Tertzakian, and Utterback, 1997) Long-term success and survival require continuing innovation and renewal. A potential negative implication of a modular product architecture approach is the risk of creating barriers to architectural innovation. This problem has been identified by Henderson and Clark (1990) in the photolithography industry and may in fact be a concern in many other industries as well.

On top of the fixed investments in developing platforms, platforms may also result in the over-design of low-end variants in a firm's product family to enable subsystem sharing with high-end products (Krishnan and Gupta, 2001). An additional risk concerns the balance between commonality and distinctiveness. A weak common platform will undermine the competitiveness of the entire product family, and therefore a broad array of products will lose competitiveness. Robertson and Ulrich (1998) have pointed out organizational risks related to platform development. Platform development requires multifunctional groups. Problems may arise over different time frames, jargon, goals, and assumptions. In a lot of cases, organizational forces also seem to hinder the ability to balance between commonality and distinctiveness. Engineers, for example, may prepare data showing how expensive it would be to create distinctive products, while people from marketing may argue convincingly that only completely different products will appeal to different markets. One perspective can dominate the debate in the organization.

Finally, the metrics as suggested by Meyer, Tertzakian, and Utterback (1997) can help to monitor, but they do not explicitly say when to create a new platform, and companies can fail to embark in platform renewal in a timely manner.

2.2.8 Application of Platform-Driven Product Development

The student project by Scholder and Friso (2007) comprised the conceptual development of an outdoor LED lighting system for public spaces powered by PV modules (see Figures 2.2.7 and 2.2.8).

During the design process of this project, the students applied platform-driven product development to be able to design suitable solutions for various markets. They were thinking

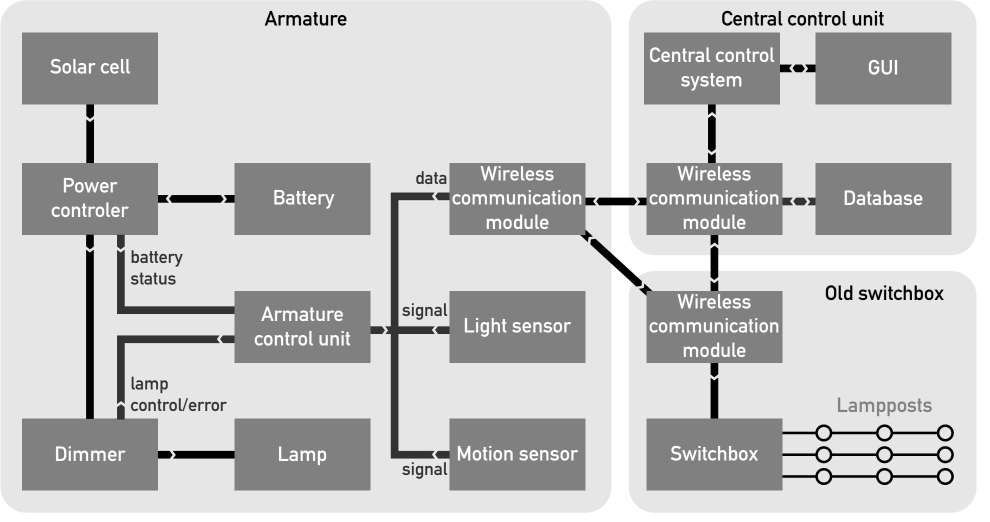

Figure 2.2.8 Scheme representing the technical functioning of this product

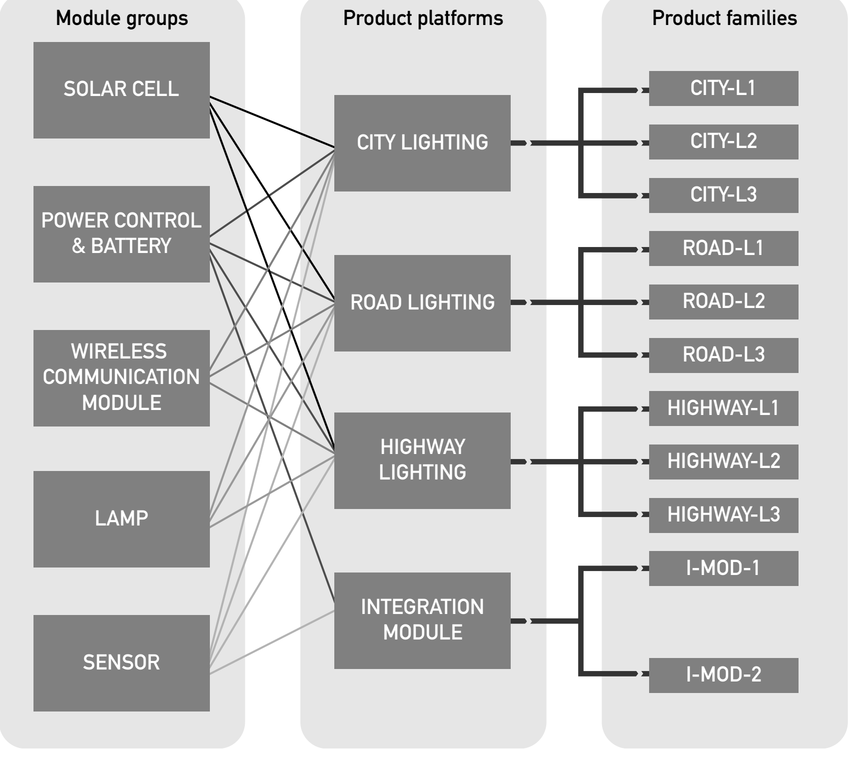

Figure 2.2.9 Product platform for the product shown in Figure 2.2.7

about different types of urban lighting such as city lighting, road lighting, and highway lighting (see Figure 2.2.9). In this way they could ensure a short time to market and guarantee a high reliability. By using a lot of standard modules, the costs for development and production are reduced, and the number of parts in stock can be reduced.

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2.3 Delft Innovation Model in Use

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2.3.1 Introduction

In the use of products and services, the need for new products and services will develop; namely, by using the product, users get good or bad usage experiences. In the case of good usage experiences, they will be loyal to the product and the company or brand that is offering the product; with bad usage experiences, they will look around for better product offerings and maybe change over to other products or brands. However, if a company notices that some of its clients have switched over to the products of innovating competitors, they will probably react by offering better or cheaper products, enabling their former users to switch back to the new offering.

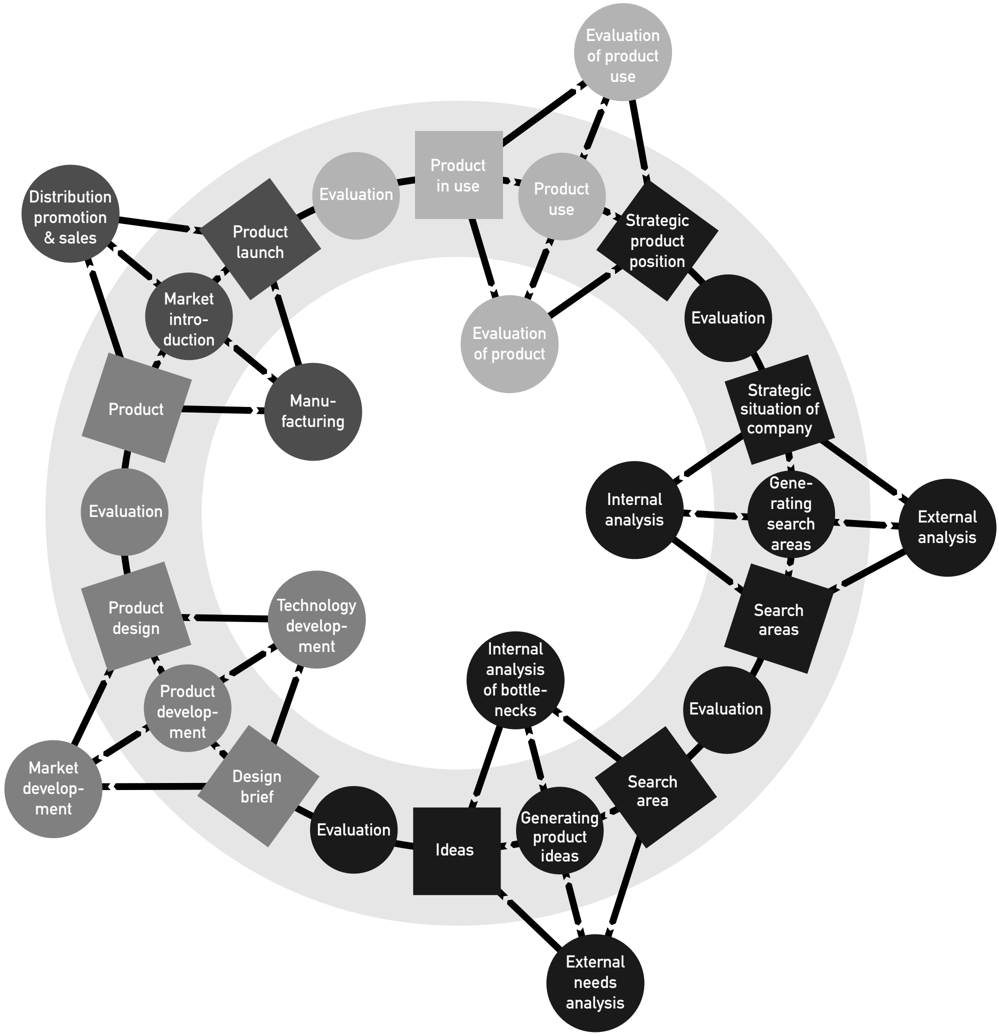

Figure 2.3.1 The Delft innovation model (Buijs and Valkenburg, 2005). Top area: Product use. Black area: Fuzzy front end. Light grey area: Development stage. Dark grey area: Market introduction (See Plate 11 for the colour figure)

To capture the product innovation process, we developed the Delft innovation model (DIM) for educating designers and engineers (Buijs and Valkenburg, 2005; see Figure 2.3.1). For the history and background of the development of this model, we refer to Buijs (2003). This model of the innovation process is one of the elements of the Delft innovation method. For more details about the overall method, we refer to Buijs (2012). In the circular representation of the Delft innovation model in Figure 2.3.1, it can be seen that the product innovation process bites itself in the tail. It shows the five stages (starting from the top and moving clockwise): (1) *product use*, then (2) *strategy formulation*, followed by (3) *design brief formulation*, then on the 8 o'clock position is the (4) *development* stage, and finally at 11 o'clock is (5) *market introduction*.

Section 2.3 is structured as follows: In Sections 2.3.2 and 2.3.3, an explication is given about the conceptual model of the innovation process within a company that was built to help practitioners in the field to structure and organize their innovation process. This is followed by Section 2.3.4, which features two practical cases in which master students of the University of Twente show their abilities to apply the model in real-life product innovation cases. Special attention is paid to their struggling with the model: They have to tweak and adjust the model for each specific case, without dumping the main message of the model. This chapter is closed by a meta-reflection by the builder of the model about their playing with his ideas (Section 2.3.5).

2.3.2 Stages of the Delft Innovation Model

The Product Use Stage

The starting point of the *product use* stage is the *product in use* (see Figure 2.3.2). This means that the consumers can buy and use the product. Now the product has to fulfill its promises. Does it do what the company, the brand image, and the nice advertisements have been promising? The new product is tested against the real-world competition.

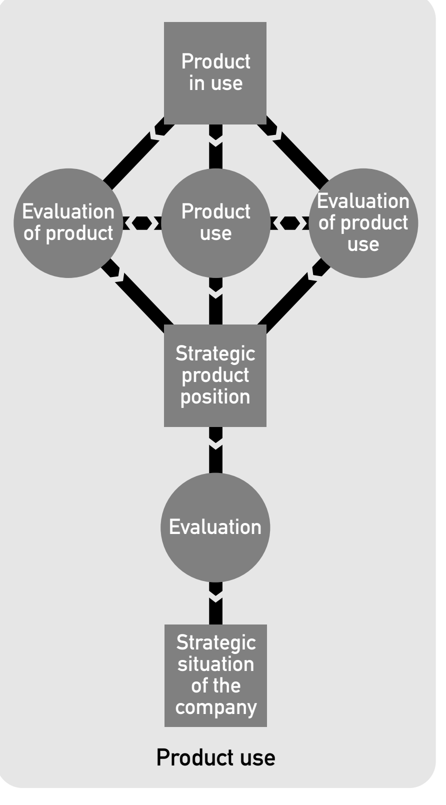

Figure 2.3.2 The *product use* stage

This *product Use* stage is the most important stage of the product innovation process, but it is also the stage the company has the least influence on. Of course they discovered the original need, they designed the product, and they are responsible for the manufacturing, distribution, and sales, but now the product has to fly for itself. Now it is up to the user to verify all the assumptions and ideas that the company has put into the new product's specifications.

Product use of a new product will lead to a change in the strategic position of the company that is offering the product. The *strategic position* is the position of the company within its competitive arena.

The *strategic position* is dependent not only on the company's strategic actions but also on the competition's actions and reactions. Evaluating this change will reveal a new *strategic situation of the company*, and must ultimately lead to the decision to start a new product innovation process. Figure 2.3.2 summarizes the *product use* stage.

The Strategy Formulation Stage

The *strategy formulation* stage should start with external investigations to check and validate the earlier recognized need for innovation in the *product use* stage. An *external analysis* cannot be executed from behind your desk. You have to go outside, into the real world. Observe clients, visit shops, talk to consumers, read journals, watch television, be at cool and hot places, and buy and use competitive products.

The reason we have put the three subprocesses parallel to each other is because they are mutually interdependent. What is relevant in the external environment depends on what the company is. The *internal analysis* influences the *external analysis*. One of the results of the *internal analysis* is a judgment about strengths and weaknesses. During the *internal analysis*, we discover what makes this company unique, what are the strategic strengths, and what are the core competences. Innovating is risky; therefore, it is better to build the innovation on the company's strategic differentiating strengths rather than on resources every company has.

The results of the *external analysis* and *internal analysis* are fed into the central process of generating search areas. A *search area* is a tool to handle the bulkiness of the relevant external world. Up front, we are not able to discriminate what external trends and developments are relevant for a given company. *Search areas* are combinations of internal company (strategic) strengths with external opportunities. We like to talk about SWOT synthesis because it is a creative activity (Buijs, 1992). It is not just about analyzing objective data; no, it is about formulating data, giving sets of data a new name, and changing the meaning of data by giving them another name.

After the evaluation step, in which the interesting potential *search areas* are selected, and in which it is checked whether the execution of this stage has been up to expectations, the company can decide to go to the next stage of the innovation process. For a summary of the *strategy formulation* stage, see Figure 2.3.3.

The Design Brief Formulation Stage

In this stage the raw ideas from the chosen *search areas* have to be transformed into concrete product ideas. Product ideas must be formulated in such a way that a new product development department can start designing the new product.

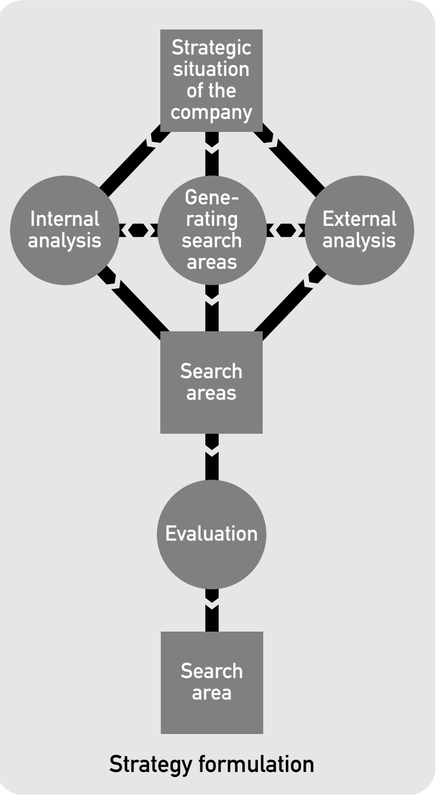

Figure 2.3.3 The *strategy formulation* stage

First we have to find out what internal bottlenecks could prohibit the company from going on with the chosen *search area*. *Internal bottlenecks* can be other strategic priorities, conflicting projects, missing knowledge, or other resources. If these bottlenecks look too big, the *search area* has to be put in the refrigerator, and probably the earlier *strategy formulation* stage has to be redone (or one of the other chosen *search areas* has to be investigated).

During the *external needs analysis*, we are really diving deep into the needs of targeted potential consumers. We are going to visit and talk to our potential clients. We have to find out what really drives people, what needs and wants they have, what they think about competing products, and why they want to spend money on substituting offerings. This is a reality check of the proposed *search area*.

Based on this external information, the third process can be started: *generating product ideas*. All kinds of creativity techniques can be used to come up with ideas for new products (see creativity gurus like De Bono, 1985; Gordon, 1961; Osborn, 1957; Rickards, 1974). You need hundreds of ideas to get one implemented. Generating ideas is the core of this stage, and all rules about creativity should be applied.

In the evaluation step, a couple of product ideas will be considered to become the future champions. They have to be formulated in the *design brief*.

For a summary of the design brief formulation stage, see Figure 2.3.4.

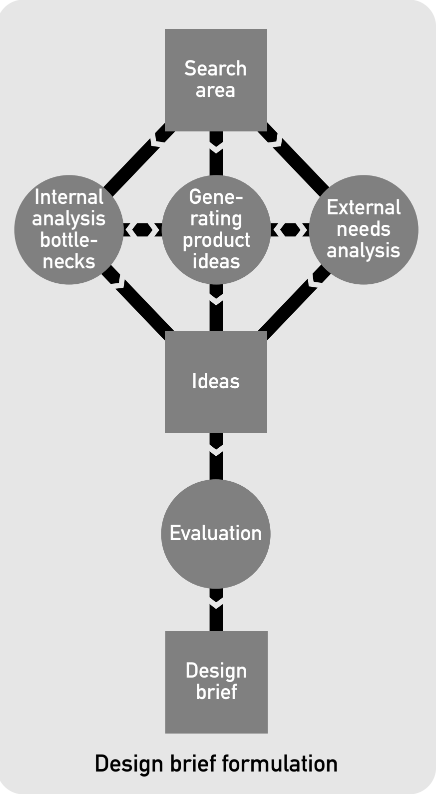

Figure 2.3.4 The *design brief formulation* stage

The Development Stage

This is the stage of all traditional product design and engineering activities. The *design brief* is a starting point, followed by three parallel processes: development process of the product, development of the market, and development of the technology.

The core is product design. Do not forget to wake up the targeted market. It is a new product, so nobody in the marketplace knows anything about it. Great emphasis on marketing and promotion activities is essential for successful innovating companies. The *development* stage ends with at least working prototypes that probably even have been tested with the potential clients.

Figure 2.3.5 represents the *development* stage of the DIM.

The Market Introduction Stage

This is the final stage of the DIM. This is the last opportunity for the innovating company to actively do something to ensure the wanted qualities of the new product. The core result is the *product launch*. We refer to this moment as "Steve Jobs in concert," because Apple has been famous for its new product introduction parties where Steve Jobs used to talk about and show the new product. In Figure 2.3.6 the *market introduction* stage is summarized.

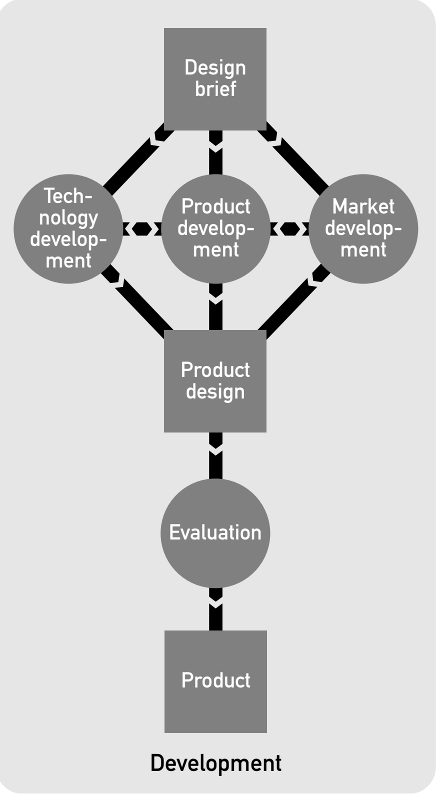

Figure 2.3.5 The *development* stage

Now the new product is for sale, and next the *product use* stage (see Figure 2.3.2) can begin, which will close the innovation cycle. This will probably cause a future change of the *strategic position* of the innovating company and its competitors. The competitive environment is also influenced and changing. The next innovation game will soon be on!

2.3.3 Concluding Remarks on the Delft Innovation Model

As we all know, models are just abstract representations of reality. They mimic only parts of reality, not all of it. With the introduction of the DIM, we want to help companies to improve their innovation activities, but it is not a cookbook. You have to translate our ideas about the innovation process to your own world.

In real life the five stages of the innovation process have different duration times. *Product use* can be as long as decades, *market introduction* can be as short as one day, *development* runs from a couple of weeks to 2–3 years, and *design brief formulation* and *strategy formulation* both last a couple of months, but sometimes it can take years to realize and experience the need for innovation. In our model we visualize them as five equal stages, and we suggest that all subprocesses within each stage should be executed jointly, but in reality that is not true.

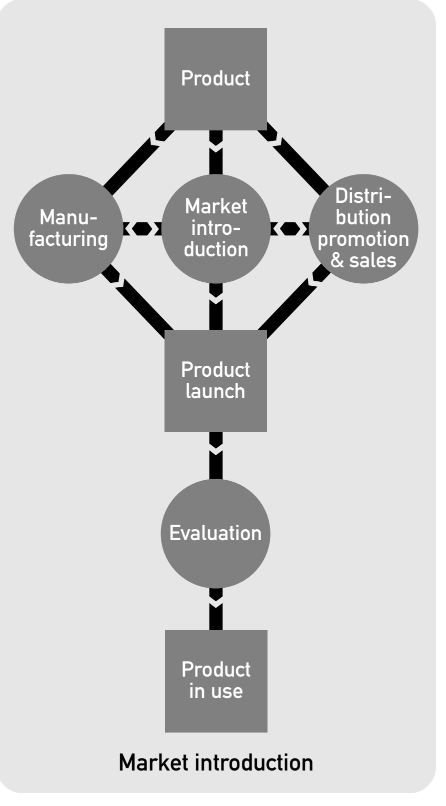

Figure 2.3.6 The *market introduction* stage

We want to conclude with some insights based on empirical studies about the product innovation process and relate them to the DIM model. About 30 years ago Cooper tried to get grip on the differences of innovation processes in the real world compared to in theory (Cooper, 1983). He discovered that not all theoretical innovation activities had been used during all innovation processes (apparently you can sometimes skip certain actions). Also he noticed different time patterns within the innovation process. From 1980 to 1987, we executed a large empirical study (the so-called *Pii study*) inside companies using an earlier version of the DIM model (Buijs, 1984, 1987). We also revealed different time patterns over the different stages of the innovation process. In 2008 we published another empirical study on different innovation patterns (Buijs, 2008). Complex projects (e.g., with new technology and/or a new client) need more activities in the first stages, and also different activities than in noncomplex projects. We also found that innovation leaders adapt an opportunistic attitude toward carrying out activities in parallel in order to gain time. It appears that project-specific circumstances lead toward skipping steps and adopting different time patterns in various product innovation projects. A possible explanation for these differences between the theoretical way innovation process should be run, and the practical way they are run, is that the theory considers innovation *processes*, while in practice companies run innovation *projects*. This could mean, for instance, that in innovation project Q the *external analysis* is skipped, because the marketing department had just finished a report about changes in the outside world. And the project leader of innovation project Q just grabs this report and uses it. So in the project there was no time spend on the *external analysis*, although the necessary information became available from another source. Another example could be a company that just acquired a small company because it developed an interesting new technology. Once again in innovation project Z there is no time spent on *technology development* (see the left-hand circle in Figure 2.3.5), but inside that acquired company other people have spent a lot of time on it. So be aware about this discrepancy between innovation projects in real life and innovation processes according to theory.

2.3.4 Applying the Delft Innovation Model in Real Life

Knowing what to do in the innovation process is one thing, but executing it is another. This section describes two applications of the method by master's-level students in the Industrial Design Engineering faculty of the University of Twente. These projects were done for the Sources of Innovation course, where students were instructed to use a variety of innovation methods in the design of a product.

UV Light for Food Preservation

Van Ettinger and Jansma (2008) applied the DIM to a student design project that required the design of a product using LED technology. This resulted in the design of an ultraviolet (UV)–LED light for food preservation in refrigerators. The DIM was used together with other design methods (innovation journey, platform-driven product development, and innovative design and styling), and the authors describe how they applied various models to their process:

> By following this path of innovation methodology, the whole industrial design process is covered. By beginning with the journey, the supporting technology will be examined and the historical aspect of the product becomes clear. *With the help of the DIM model, the clarification of the task will be sorted out and also the optimization of the elements.*

It appears that they used the DIM for task clarification, once the decision was made to explore food preservation as an outcome of the innovation journey method of the previous phase. This resulted in initial product ideas, for example the use of UV radiation to damage bacteria, and color coding to categorize food types, which were incorporated in the final design. This loosely corresponds to the strategy formulation stage of the DIM, whose starting point in the theoretical model is the strategic situation of the company. There are some differences between the DIM-in-theory and the application by these students in practice. One of the most basic is that there is no "company" for which to conduct an internal analysis in this project. Rather, the students have chosen to analyze the possibilities (strengths) of the technological possibilities and initial concept ideas: "the strength of the idea is the dual effect of controlling the e-coli bacteria (and) . . . color LEDs (to give) an indication to the customer of separating different types of food . . . minimal size . . . low energy consumption." In

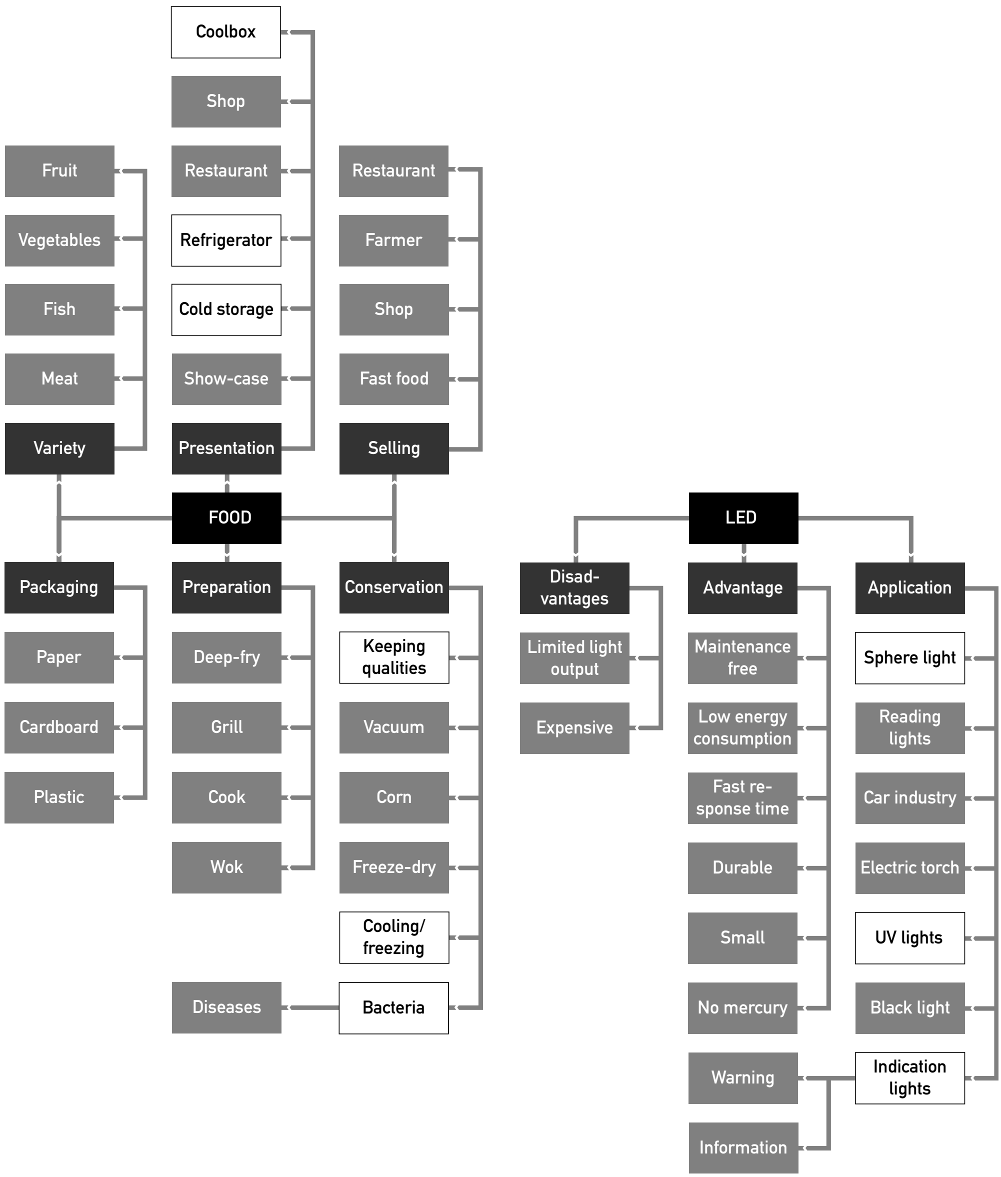

Figure 2.3.7 DIM mind maps (Van Ettinger and Jansma, 2008)

contrast to the theoretical model, challenges and weaknesses were given little consideration (although the potential psychological barriers to using UV light with food were noted). Mind maps were used to structure and visualize their DIM approach. These were in two areas, LED lighting and food, and are shown in Figure 2.3.7.

Analysis of these gave the authors the following search areas: sphere and indication light sources, ultraviolet light and radiation, specific cooling systems, and keeping the qualities of

Figure 2.3.8 Final product (Van Ettinger and Jansma, 2008) (See Plate 12 for the colour figure)

food. In the theoretical model, search areas are an input to the design brief stage. In these students' work, it is an input for the platform-driven product development method, where the components needed to implement loose concepts based on the search areas are evaluated.

The resulting product after use of the DIM and other innovation methods is shown in Figure 2.3.8. Details regarding form were developed in later stages, but the fundamental decisions made while applying DIM regarding product function and use were retained.

T-Spider Fuel Cell Vehicle

Similarly, students Damkot and de Groot (2006) use the DIM early in the design process for a fuel cell–powered vehicle. The students chose to apply the method "because of its possibilities. . . . In this project, there is a new technology in a market with opportunities. The DIM Model has the capacity to combine the intrinsic values of technology with opportunities in the market." Guidelines resulting from their use of the DIM were used as inputs for platform-driven product development.

They used the innovation phase model "to optimally combine the technology with the opportunities in the city." Two mindmaps were used – one for technology, and another for cities – to visualize and structure their use of DIM.

The authors describe the mind maps shown in Figure 2.3.9 as follows: "Technology contains 4 subgroups; disadvantages, advantages, applications and Design and Styling. City contains 5 subgroups; environment, infrastructure, transportation, opportunities and problems. Transportation is split up into public transport and individual transportation. The used points for the search fields are marked green. There are six market fields and five technical fields" (see Figure 2.3.10).

After creation of the individual mind maps, a cross comparison of these technical and market-oriented search fields was made, as shown in Figure 2.3.10. A principal result of this comparison is the decision to design a small vehicle (Figure 2.3.11). As with Van Ettinger and Jansma (2008), the design here is split into different components for consideration in the next stage of platform-driven product development.

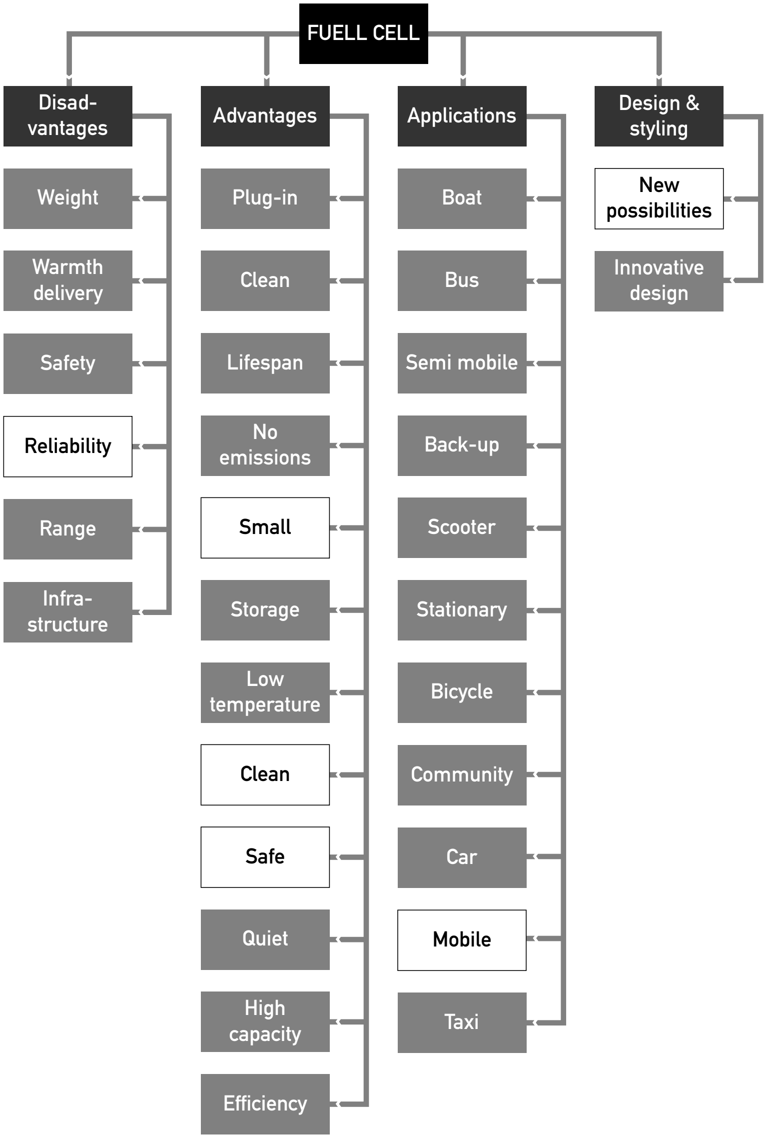

Figure 2.3.9 Search field selection using mind maps (Damkot and de Groot, 2006)

2.3.5 Reflections on the Delft Innovation Model in Practice

It should be noted that there are important differences between the DIM-in-theory and in practice. The student cases described here deal with a speculative situation where both constraints and additional resources are not present or are artificially given.

In a real-world setting, DIM is meant to provide a general approach to the design process rather than strictly prescribe a step-by-step approach. The metaphor of a recipe is given: It is

		Market fields					
		Improve mobility	Scooter	Bikeways	Roads / highways	Parking space	Router restrictions
Technical fields	Small	1	2			3	
	Clean		4				
	Safe			5			
	Mobile						
	Reliability	6					

Figure 2.3.10 Search field comparison (Damkot and de Groot, 2006)

Figure 2.3.11 Final product (See Plate 13 for the colour figure)

not so much a rigid application of the process that is intended, but rather an understanding of ingredients and their essential qualities, how they interact with each other, what can be substituted or skipped, and how to work with available resources. It is this deeper level of understanding that allows not only for improvisation, but also for greater possibilities for arriving at original outcomes.

The external environment within which innovation takes place is an important consideration. The natural inertia of organizations is to continue with the status quo. Change requires energy and is often disruptive. This places the main driving force for innovation in the external environment: such as the activities of competitors, technological developments, or access to new markets. This external location for the stimulus to innovate is another source of differentiation between applying the DIM in education and in practice. One of the educational implications is that while the real world cannot be perfectly modeled, it is important for instructors to try to approximate some of its critical elements in developing cases, and for students to be clear about assumptions they make regarding the context of their projects.

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2.4 TRIZ: A Theory of Solving Inventive Problems

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2.4.1 Introduction

TRIZ (a Russian acronym for the "theory of solving inventive problems") was originated in 1946 by Russian military patent examiner Genrich Altshuller. His main focus of interest was to understand how inventors came up with creative solutions. To reach his goal, he studied more than 400,000 patents intentionally drawn from different areas of industries. Such massive studies helped Altshuller to capture the nature of the creative process behind producing inventions. He identified a relatively small number of high-order patterns and principles that complied with the majority of inventions and that were general for most industries (Altshuller, 1969). Another important TRIZ discovery was that technology, like any other type of human activity, does not evolve randomly. Each product in every area of technology follows a certain sequence of "inventive transformations" to meet continuously evolving market demands and requirements. Long-term studies of technology evolution revealed common patterns and trends, according to which seemingly different systems evolve. Studies of these trends and patterns form a large part of TRIZ that is known as a *theory of technical systems evolution*.

By now in total, more than 1.5 million patents and technological solutions were studied to create modern TRIZ. Although previously relatively little known outside of the former Soviet Union, TRIZ is gradually becoming a key component for supporting invention and innovation since it helps organizations and individuals to establish innovation as a scientifically based, structured, and predictable process. In short, TRIZ enables one to create new value on demand. Modern TRIZ is a result of research efforts of more than 50 years in Soviet Union, and lately in Europe and the Unites States. It offers both a theory of invention and a number of practical techniques, which help to perform the complete "idea cycle": from analysis of a given situation to generation and evaluation of new ideas.

2.4.2 Components of TRIZ

Modern TRIZ includes different methods and techniques to support different stages of the ideas generation process:

- *Analytical techniques*: A group of techniques that help to manage the complexity of problem situations, look at problems from different angles, understand real problem causes and formulate problems correctly, and extract and predict future problems.
- *Ideas generation and inventive problem-solving techniques* that define methods for solving inventive problems.
- *TRIZ knowledge bases*, which contain generic patterns and guidelines of solution strategies and patterns of "strong" solutions, which can be applied to virtually any new problem to quickly come up with new solution ideas. TRIZ also includes a unique database of scientific effects structured according to technological functions.
- *Theory of technology evolution*: Models of evolution of technical systems and techniques for forecasting future product and technology evolution; tools to explore innovative potential of systems and generate new ideas on the basis of technical systems evolution trends.
- *Psychological techniques to enhance creativity*: A group of techniques to overcome mental inertia and further develop creative imagination.
- *Evaluation and ranking techniques*: A group of techniques that help to select problems and rank generated ideas.

The use of TRIZ is organized within the systematic innovation process (Figure 2.4.1), which structures the use of different TRIZ techniques and tools according to the desired outcome. In the following subsections, we present some most important concepts and tools of TRIZ.

2.4.3 Contradiction as a Driving Force of Invention

Existing technical systems are usually improved incrementally to achieve the most optimal values of their parameters. However, when incremental improvements do not lead to a desired result, a radical improvement takes place. We usually call such radical improvements

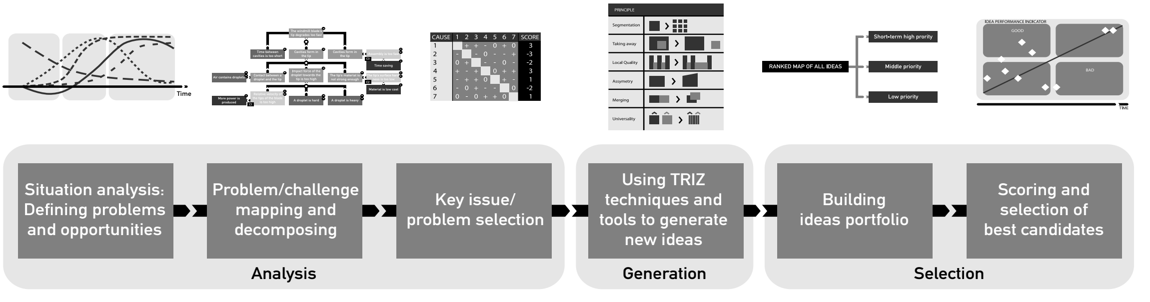


Figure 2.4.1 The systematic innovation process with TRIZ

inventions, which are new, non-obvious solutions unknown in the past. Altshuller found that in most cases, an inventive solution results from resolving a contradiction, which arises when an existing product or system is not capable of meeting new or growing market demands any longer, but known improvements of product features would cause an unacceptable change of some other product features. For instance, to increase a car's stability on a road, one of the known solutions is to increase the weight of the car. But this would require greater fuel consumption. Finding a totally novel way of improving the car's stability without increasing its weight consumption will result in a patentable invention.

TRIZ states that to obtain inventive solutions, contradictions must be eliminated without compromising. With a new solution, we should be able to achieve the desired effect in full without diminishing other advantages of a product or technology, and without causing negative side effects. For instance, coffee in a cup gets cold over time due to its contact with the much colder air. An obvious solution would be to cover a cup with a lid. But did we solve a contradiction? Not completely, because to drink coffee we will have to remove the lid, and this increases our discomfort. Therefore we have a contradiction between two parameters: the desired temperature of coffee and the degree of our comfort. According to TRIZ, the best solution will keep coffee hot without introducing any discomfort during drinking. In addition, this best solution should eliminate the contradiction without introducing new negative effects and, very importantly, without increasing costs. A good example of resolving this contradiction is cappuccino: a milk foam layer insulates coffee from the air without introducing obstacles for drinking. But, what about those who prefer other types of coffee? This contradiction is still to be solved.

With TRIZ, contradictions are solved at the abstract level by following certain generic principles rather than by numerous trials and errors. Instead of directly jumping to a solution, a problem is analyzed and formulated as a contradiction, and then a number of relevant heuristic *inventive principles* are proposed that contain the best solution strategies from previous inventors' experience (Figure 2.4.2). Each inventive principle suggests a number of

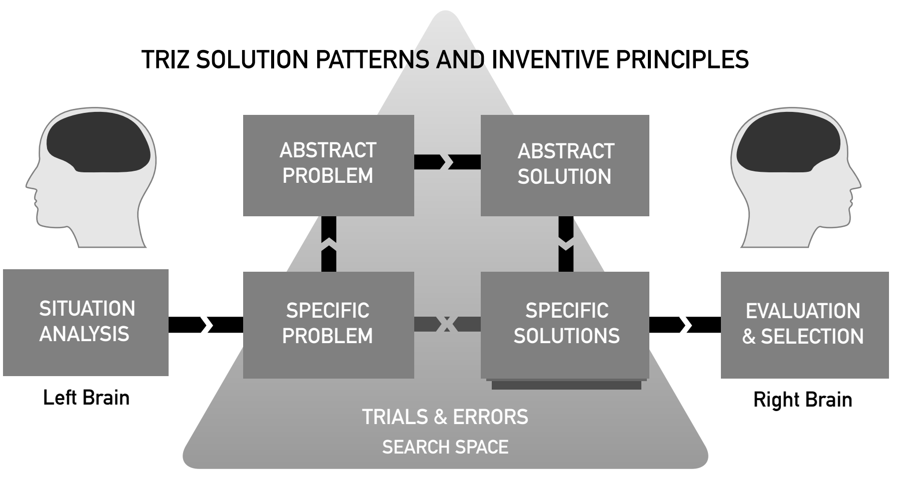


Figure 2.4.2 Solving problems with TRIZ

recommendations that can be used to solve a given problem (Altshuller and Fedoseev, 1998). Examples of such inventive principles are as follows:

Principle of Nesting

- Place one object inside another.
- Increase the number of objects nested.
- Make one object pass through a cavity of another object.
- Introduce a new process inside of an existing process.
- Increase the number of "nested" processes.
- Make process activities dynamically appear when needed and disappear when not needed.

Principle of Spheroidality

- Instead of linear parts of an object, use curved parts.
- Use rollers, balls, and spirals.
- Use rotary motion.
- Use centrifugal forces.
- If a process is nonlinear, consider increasing the degree of nonlinearity.
- Use circular flow instead of linear flow.
- Use roundabout solutions in a process.

This knowledge-based approach drastically reduces amount of time needed to find a specific solution. One of the best-known TRIZ techniques is called *40 inventive principles*. The principles are used through the so-called *contradiction matrix*, which contains references to specific inventive principles according to over 1,000 types of generic technical contradictions.

2.4.4 Five Levels of Solutions

Not all inventions are equal. Some inventions result in truly new, breakthrough technologies that require relatively a long research and development time and have to pass through all stages of technology development as discussed in Section 2.5.3, "Technology Readiness Levels." But some inventions are rather simple and do not require extensive research and development to be implemented. For instance, it would be difficult to compare the invention of a laser with the invention of adding an extra thermal insulation layer to a coffee maker.

Figure 2.4.3 shows how TRIZ distinguishes between different levels of solutions. Level 1 includes solutions that do not really require invention: These are standard solutions that can be obtained by optimization. Level 2 requires innovative thinking, but the resulting solutions are still rather simple modifications of existing products and systems. Level 3 is where "real" innovation takes off: A certain system, product, or principle finds a radically new application area. Level 4 includes so-called "pioneering" inventions: A radically new combination "function or principle" is created (usually drawn from scientific studies at level 5). And level 5 is formed by scientific discoveries that can be implemented in new pioneering inventions. Sometimes levels 4 and 5 coincide.

As is clear from this description, the total number of solutions drops with each next level. There are many more level-2 solutions than level-4 ones. Level-4 solutions represent only a fraction of all known technical solutions.

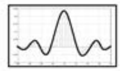
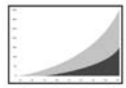
Level	Features	Examples	Example Illustration
Level 5: **Discovery**	Discovering a new scientific principle	X-ray discovery, (or radio waves discovery, coherent light discovery, etc.)	
Level 4: **Pioneering Invention**	Creating a radically new Function/Principle combination	X-Ray radiation (principle) is used to "see through" (function) a human body, thus launching a new technology area: X-Ray medical machines	
Level 3: **Concept Transfer**	The use of a known Function/Principle combination in a new application area (market)	X-Ray technology is brought to other areas: non -destructive testing of constructions; X-Ray security systems in airports, etc.	
Level 2: **Non - linear System Change**	Reconfiguring and improving an existing system (or adding new functions, etc) within the same Function/Principle/Market combination	"Pulsating" mode of an X-Ray security device to decrease energy consumption	
Level 1: **Linear System Change**	Solution method is known and applicable within existing Function/Principle/Market combination , only parameter value change is required	Increasing the power of X-Ray generator for testing larger objects	

Figure 2.4.3 Levels of technical solutions

2.4.5 Evolution of Technical Systems

In general, every technical system (product or technology) follows three general phases of evolution before it is replaced by a more effective system based on a new principle: birth, growth, and maturity (Figure 2.4.4).

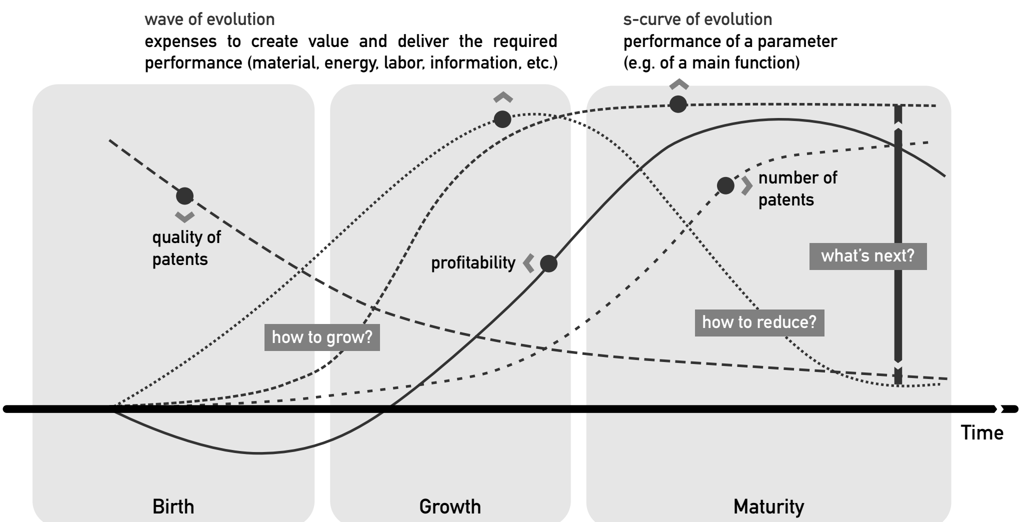


Figure 2.4.4 Evolution stages of technical systems

The curves in the figure represent the following:

- The *S curve of evolution* shows how performance of a main system parameter (of a certain function delivered by a system) changes over time provided a basic principle of function delivery is not changed. When a system is just created, the parameter's performance is usually rather low. However, the function became possible and that matters above all at this stage.
- The *wave of evolution curve* shows how a typical technical system evolves respectively its physical dimensions, energy consumptions, and costs. At the stages of birth and growth, the system tends to become more massive, energy consuming, and expensive. However, at the stage of maturity, specific values representing these parameters tend to decrease. The first electronic tape recorders that used semiconductors were bulky and costly. Later they were transformed into inexpensive small cassette recorders.
- The *quality of patents curve* shows that high-level inventions (level-3 and level-4 solutions) are usually made when a system is just created. When the system becomes mature and commercially successful, most of the patents filled protect solutions of level 2 and sometimes 1.
- The *profitability curve* indicates that during the stages of birth and grows, financial investments are usually made without any profit. Return of investments starts only when a technical system is successfully distributed at the market.
- The *number of patents curve* indicates an increase in the number of patents filled to reduce competition when a system becomes commercially successful.

Let us take, for instance, digital photography, where one of the main parameters of value is image quality. The first generation of digital cameras produced very low quality. In addition, these first cameras were bulky and costly. However, a new function was created, capturing images digitally, and it was a breakthrough invention. Then the next phase (growth) started: All efforts were put into making digital cameras produce high-quality images. With each innovation, the image quality grew rapidly. After 10 years of further evolution, even small pocket cameras reached the quality of good "old" film cameras. Now this parameter is in the "maturity" stage: We really do not need to invest extra money to increase the quality of images (at least for the mass market), thus the S Curve becomes flat and now camera manufacturers pay attention to improving other parts of a digital camera or reducing the costs of delivering its functions.

What happens when we exhaust the resources of evolution within a given working principle? The same as what happened with film cameras: They were replaced by digital ones. Such transition usually means that we considerably boost the functionality and performance of a system or product by replacing a working principle behind delivering its main function, which prevents a technical system from developing further. The evolution of each technical system can be represented as a timeline of S curves, where each S curve is based on a certain working principle.

2.4.6 Ideality

One of the first discoveries made by Altshuller was that evolution of a vast majority of technical systems follows a so-called *trend of ideality growth*. In other words, with each

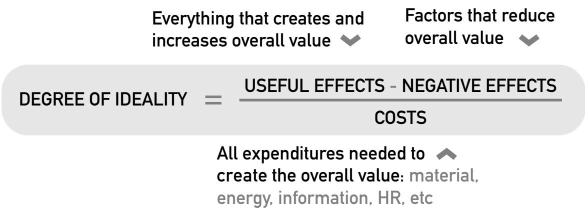


Figure 2.4.5 A system's degree of ideality expressed as a formula

successful innovative improvement, technical systems tend to become more "ideal": They increase their performance, quality, and robustness, whereas the material, energy, labor, and other types of resources needed to manufacture and provide the life cycles of these systems tend to decrease.

The trend of ideality growth plays a very important role in helping us understand how and why systems and products evolve, and define strategies for further improvements of these systems and products.

As seen in Figure 2.4.5, the overall degree of a system's ideality can be increased by increasing the overall value of the system (functionality, performance, etc.), by reducing negative effects that reduce the overall system's value (to improve quality), or by decreasing the resources needed to create and maintain the system's life cycle. Really successful innovations affect all three components in a positive way.

Increasing the degree of ideality does not always means reducing complexity. Just compare a mainframe computer 30 years ago and a modern desktop PC. The price of the desktop PC today cannot be even compared to what organizations had to pay 30 years ago for the mainframe, while the performance and functionality of a modern desktop PC are many times higher (positive effects). It is more reliable, generates less heat and noise, is easier to recycle (negative effects), and costs much less to manufacture and maintain (costs).

2.4.7 Trends of Technical Systems Evolution

During studies of the history of many technical systems, TRIZ researchers discovered that technology evolution is not a random process. Many years of TRIZ studies resulted in extracting a number of general trends governing technology evolution no matter what area technical products belong to. The practical use of these trends is possible through so-called *lines of technical systems evolution*. Each line of evolution describes patterns of transitions between old and new structures of a system.

One of the evolutionary trends of systems by transitions to more dynamic structures (*dynamization*) is shown in Table 2.4.1.

Knowing the lines and trends of technology evolution is very important to estimate what evolutionary phases a system has already passed. As a consequence, it is possible to foresee what changes the system might experience in the future and directly generate new ideas.

Table 2.4.1 TRIZ trend of dynamization applied to the case of mobile phones

1. Monolithic solid object	Traditional mobile phone.	
2. Monolithic object divided into two segments with nonflexible link	Mobile phone with a sliding part that contains a microphone.	
3. Two segments with a flexible link	Flip-flop phone of two parts.	
4. Many segments with flexible links	Phone that is made as a wristwatch: Its bracelet is made of segments that contain different parts of the phone.	
5. Completely flexible, elastic object	A completely flexible phone that can be used as a wrist band.	
6. A field replaces function of a solid object	A phone without a screen. The function of a screen is delivered by a field-visible light produced by a pico-projector.	

Currently the TRIZ trends of technical systems evolution are organized in a system (Figure 2.4.6). The trends can be used as an independent tool to reveal evolutionary potential of technical systems and produce ideas for next generations of solutions.

2.4.8 Science for Inventors

New breakthrough products often result from using the latest scientific advances. One of the TRIZ techniques, known as *databases of effects*, suggests searching for new basic principles by defining what technical function is needed and then finding a scientific principle that can deliver the function.

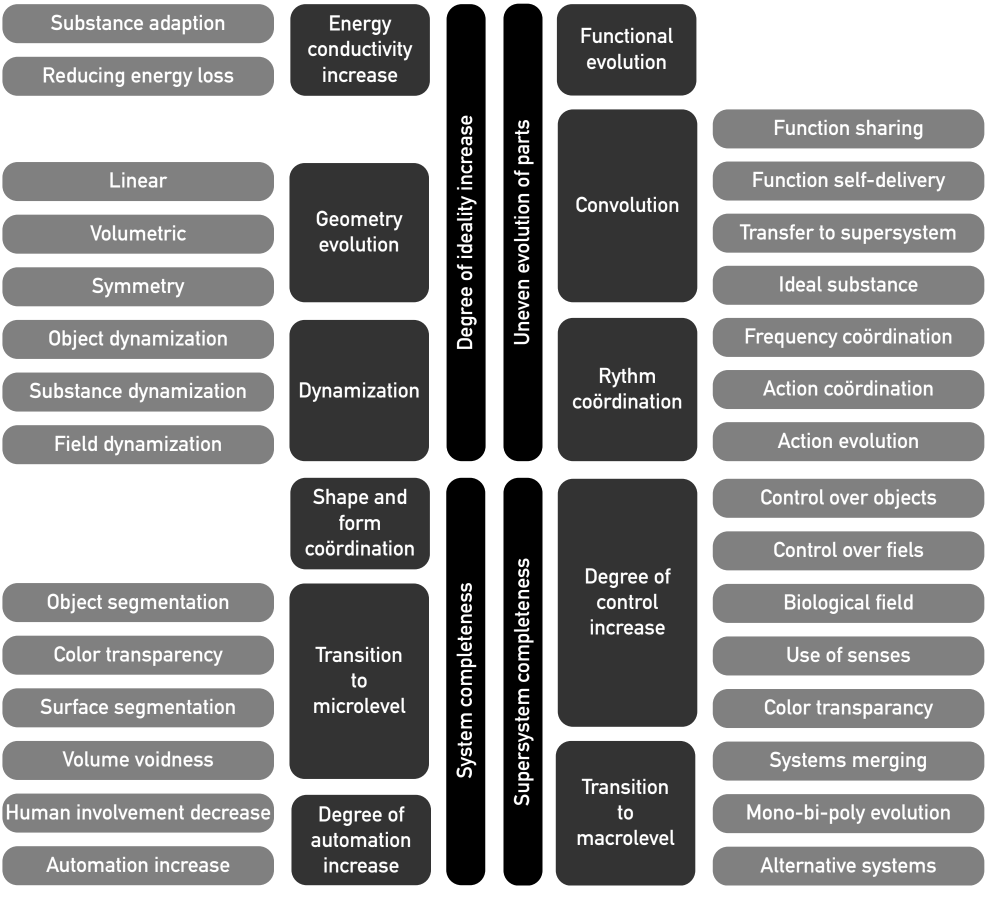


Figure 2.4.6 TRIZ trends of technical systems evolution

Studies of patent collections indicated that inventive solutions are often obtained by utilizing physical effects not used previously in a particular area of technology. Knowledge of scientific phenomena often makes it possible to avoid developing complex and unreliable solutions. For instance, instead of a mechanical design including many parts for precise displacement of an object for a short distance, it is possible to apply the effect of thermal expansion to control the displacement.

Finding a physical principle that would be capable of meeting a new requirement is one of the most important tasks in the early phases of design. However, it is nearly impossible to use handbooks on physics or chemistry to search for principles for new products. Descriptions of natural phenomena available in such texts present information on specific properties of the effects from a scientific point of view, and it is not clear how these properties can be used to deliver particular technical functions.

The TRIZ databases of effects bridge a gap between technology and science. In the databases, each general technical function is identified with a group of scientific effects

Table 2.4.2 Fragment of the TRIZ database of scientific effects

Function	Effects
To separate mixtures	Electrical and magnetic separation. Centrifugal forces. Adsorption. Diffusion. Osmosis. Electro-osmosis. Electrophoresis.
To stabilize object	Electrical and magnetic fields. Fixation in fluids that change their density or viscosity when subjected to magnetic or electric fields (magnetic and electrorheological liquids). Jet motion. Gyroscopic effect.

that can deliver the function. The databases consist of three categories of effects: physical, chemical, and geometric. A search for a needed effect or a group of effects is possible through formulation of a technical function (see Table 2.4.2). Examples of technical functions are “move a loose body” or “change density,” “generate heat field,” and “accumulate energy.”

One of the first patents obtained with the use of TRIZ outside of the former ex-USSR was issued to Eastman Kodak. Engineers used the TRIZ databases of effects to develop a new solution for precise linear displacement of a high-end camera’s flash. A traditional design includes a motor, a mechanical transmission, and an actuator to convert rotary motion to linear motion. A new patented solution uses piezoelectric effect and involves a piezoelectric linear motor, which is more reliable, cheaper, and easier to control.

Currently, the database of Goldfire Innovator^{TM}, a leading software tool that supports TRIZ, contains over 8,000 physical, chemical, and geometrical effects with examples of their applications (Invention Machine, 2011).

2.4.9 Analytical Techniques

It is well known that solving inventive problems is difficult since in most cases they are not formulated correctly. In addition, in many cases it is not clear what problem to solve. In order to deal with ill-defined initial situations, TRIZ introduces a group of tools that help us to perform the needed analysis.

One such tool is *function analysis* (see Figure 2.4.7), which decomposes systems and products to components and identifies problems in terms of undesired, insufficient, poorly controllable, or harmful functional interactions between both system components and components of a so-called *supersystem*, which is formed by everything that does not belong to the system but interacts with it. For instance, if a person takes a cup with hot coffee, the cup might be too hot and can burn his or her hand. In this case, a hand of a person is included to a function model and belongs to a supersystem of the system “cup with coffee.”

TRIZ-based function analysis helps to identify a range of function-related problems within a system and rank them according to their importance. It can be used not only for finding existing problems but also for identifying resources to increase the degree of ideality of systems and products.

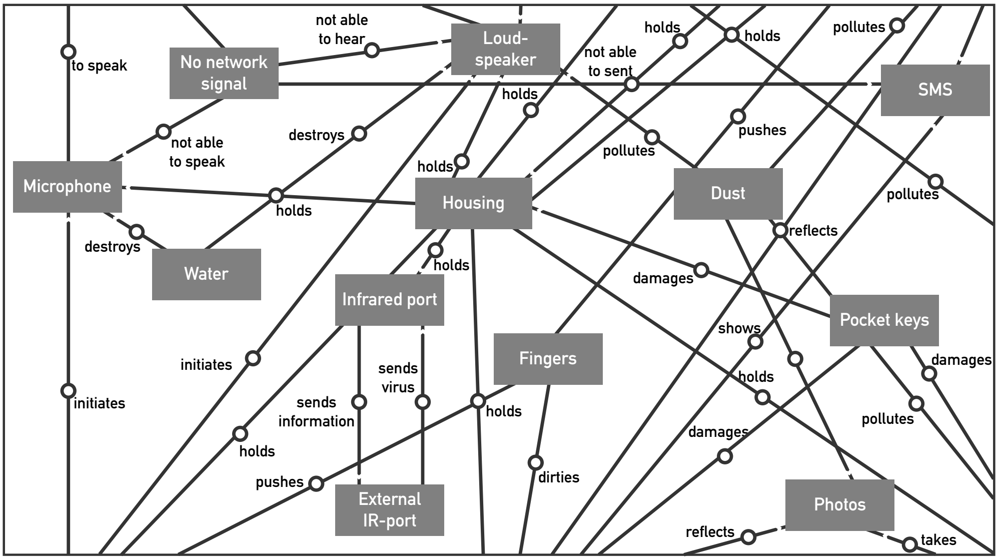


Figure 2.4.7 A fragment of the function analysis diagram

Another tool, recently introduced to TRIZ, is called root conflict analysis (RCA+) (see Figure 2.4.8). Based on a combination of classical RCA and TRIZ philosophy, RCA+ helps to "dissect" a problem formulated as an undesired effect to a tree of causally related underlying negative causes and contradictions. Such a process helps one to understand factors that contribute to the main negative effect and visualize all contradictions that create barriers preventing us from solving a problem in a straightforward way. Later, these contradictions can be directly solved with other TRIZ techniques.

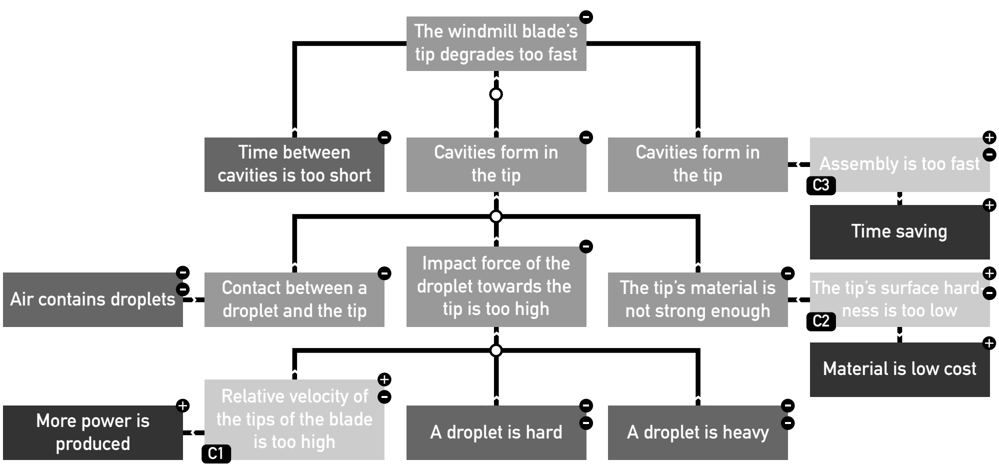


Figure 2.4.8 A fragment of the root conflict analysis (RCA+) diagram

2.4.10 Psychological Inertia and Creativity

Sometimes it is stated that TRIZ reduces creativity. This is not correct. Creativity is one of the crucial factors of successful invention. TRIZ operates at an abstract level, and creativity is very important to translate TRIZ recommendations to real and feasible solution ideas. It is possible to say that TRIZ provides guidelines for the most effective use of creativity and guides our creative search.

Modern innovation demands thinking out of the box and exploiting diverse knowledge. Many innovative challenges, especially the most difficult ones, require a huge number of trials and errors. As pointed by the Industrial Research Institute in Washington, DC, on average, one successful project requires 5,000 raw ideas to be generated. American Management Association reports that 94% of all innovative projects today fail to return investments.

When we start exploring a solution search space, how many directions should we explore to find a right direction? The more difficult a problem is, the more trials we have to make without any guarantee that a desired idea will be found. When Altshuller started to work on TRIZ, his primary goal was to overcome this major disadvantage of chaotic and random idea generation. TRIZ provides navigation within the solution search space, thus directing a problem solver toward an area where a chance to find a desired solution is highest.

Creativity is important to fight psychological inertia, which keeps us locked within existing solutions and ideas and does not let us see things differently. These barriers are difficult to overcome. TRIZ includes a section called *creative imagination development* that consists of techniques to help with developing our creative skills. Altshuller strongly believed that creative imagination can and must be developed to enable the most effective use of TRIZ. In addition, special psychological "operators" were incorporated to some TRIZ techniques to reduce our mental inertia. For instance, one TRIZ tool, the *algorithm of inventive problem solving* (ARIZ), introduced a stepwise algorithm of reformulating an initial problem by executing a number of procedures that reduce our psychological inertia and help us to recognize "hidden" resources to solve the problem.

2.4.11 Practical Value of TRIZ

TRIZ is not a magic wand that solves problems all by itself. Creative solutions are always found by people. But TRIZ eliminates a painful process of generating hundreds or even thousands of trials and errors and waiting many years for a new insight.

As reported, today TRIZ and TRIZ software tools are used in about 5,000 companies and government organizations across the globe. In 2006, Samsung Electronics officially stated that within 2004–2006, the use of TRIZ provided the company with total economic benefits of €1.5 billion. Thanks to TRIZ, Boeing Corporation designed a better refueling tanker on the basis of 767 aircraft than similar aircraft of a competitor, and it helped the company to win a contract totaling more than €1 billion. Intel Corp. recently named TRIZ as "Intel's innovation platform of the twenty first century."

In general, the use of TRIZ provides the following benefits:

- Considerably increases productivity when searching for new ideas and concepts to create new products or to solve existing inventive problems.

- Increases the ratio of useful ideas to useless ideas during the ideas generation process by providing immediate access to hundreds of unique innovative principles and thousands of scientific and technological principles stored in TRIZ knowledge bases.
- Reduces the risk of missing an important solution to a specific problem due to a broad range of generic patterns of inventive solutions offered by TRIZ.
- Uses scientifically based trends of technology evolution to identify evolutionary potential of a technology or product and select the right direction of evolution.
- Leverages the intellectual capital of organizations via increasing a number of patented solutions of high quality.
- Raises the degree of personal creativity by training individuals and groups to approach and solve inventive and innovative problems in a systematic way.
- Structures and organizes the creative phases of the innovation process.
- Supports patents strategies (circumvention, umbrellas, etc.).
- Introduces a common "innovation" language to improve communication.

TRIZ is the most powerful and effective practical methodology of creating new ideas available today. TRIZ does not replace human creativity. Instead, it amplifies it and helps to move

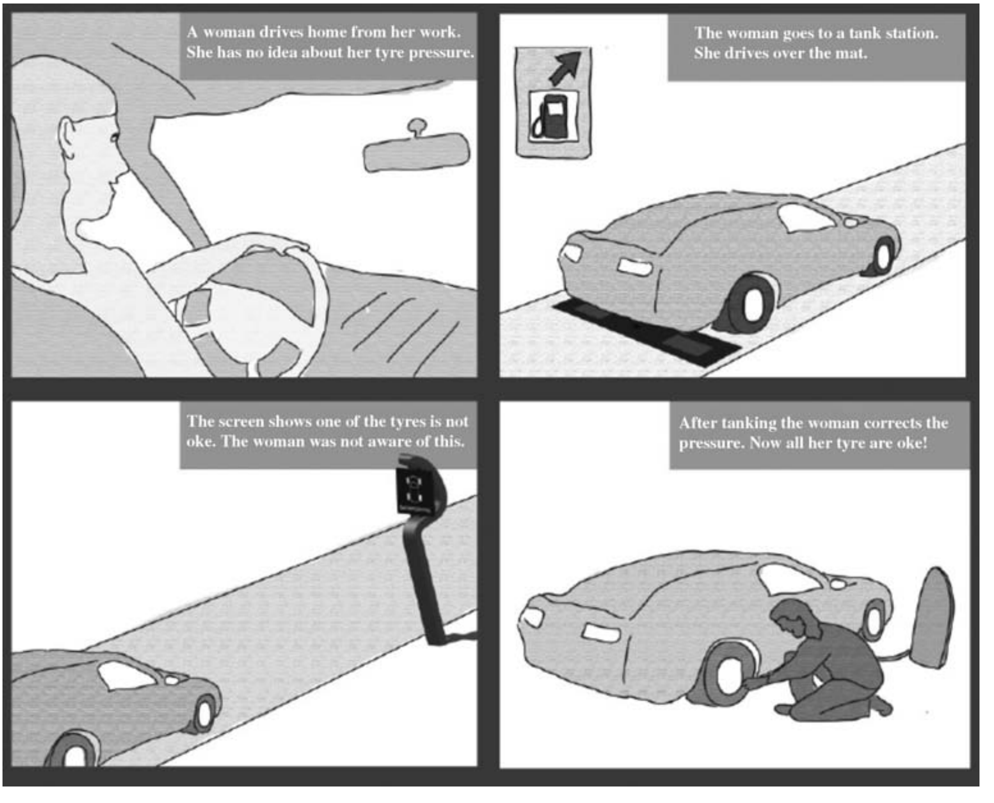


Figure 2.4.9 User scenario of the BandOK product by Geurds and Van der Molen (2011)

it in the right direction. As proven during long-term studies, virtually everyone can invent and solve nontrivial problems with TRIZ. However, modern TRIZ is a complex discipline; therefore, to learn and master skills with it demands time and effort. But thanks to recent advancements in TRIZ education and the development of new software and engineering support tools of systematic innovation, this process is not as difficult as in the past. Recently, TRIZ was included as a supporting tool for Six Sigma to solve problems that cannot be solved with traditional methods. TRIZ conferences and congresses are conducted annually in many countries.

2.4.12 Application of TRIZ

In 2011 Geurds and Van der Molen developed a product concept based on the use of piezo-electric sensors. The concept, called the BandOK system, measures the pressure of car tires while driving and gives feedback to car drivers on the pressure, because well-maintained tire pressure makes it safer to drive and saves fuel, money, and exhaust. During their design process, students applied TRIZ during concept selection and final design of the product, whose use is shown in Figure 2.4.9 and whose technical principles are illustrated in Figure 2.4.10.

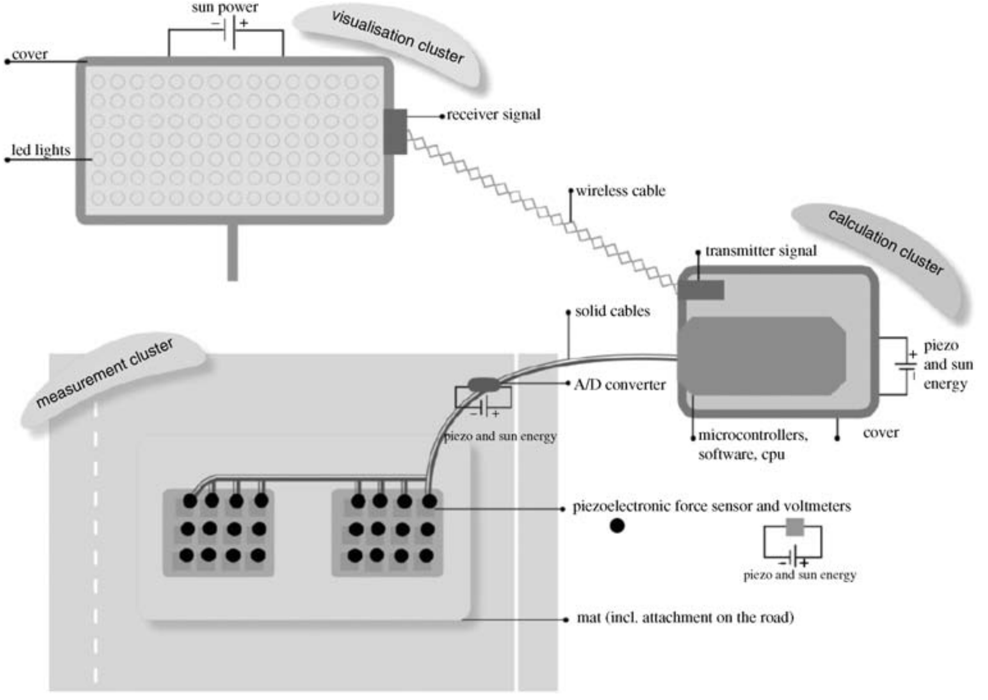


Figure 2.4.10 Scheme of the technical functioning of the BandOK product concept (Geurds and Van der Molen, 2011) (See Plate 14 for the colour figure)

Table 2.4.3 TRIZ principles applied to the BandOK concept

TRIZ principle	Ideation BandOK
Segmentation	Two measuring units on each side of the road
	Two measuring units, one for left wheels and one for right wheels
Merge	iPhone app or TomTom device instead of separate display unit
	Combine with other measuring and information devices (e.g., a check for your lights)
	Integrate speeding flash pole
Prior (anti-) action	Weather resistant
	Vandal proof
Other way around	Make display unit moveable: projection on asphalt, car screen
	Pump the tire before you see if it is flat
Dynamization	Moveable service station (e.g., ANWB Service Centrum, the Netherlands)
	Field measuring instead of physical product
Periodical	Only take a picture when a car passes
	Only give feedback when a car passes
	Only measure or be active when a car passes
High speed	Communication between camera, sensors, and display
Intermediary	Get feedback later, by e-mail or by logging into website
Replacement	Modules, platform-driven development
	Easy to repair, update
Composite	PV unit integrate in shell or pole
	Extra light source to take picture in the dark

In the embodiment design phase, the TRIZ principles shown in Table 2.4.3 were applied to their product concept with a focus on tire pressure. The ideas that were generated in this way were evaluated and partially applied in their final product concept.

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2.5 Technology Roadmapping

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2.5.1 Introduction

An organization involved in product development faces a number of challenges related to its future. One of the most critical tasks is to define short-term and long-term product strategies that can be transformed into specific plans. To understand which products and technologies have to be planned for future development, especially within the long term, organizations need to forecast the evolution of their products. Any product or technology is created to meet certain needs and demands of the person or system for which it is to be developed. No technical product is developed to exist independently of the context in which it is supposed to be used: A product always delivers a function or a number of functions requested by its surrounding systems or environment. For instance, a battery is developed to provide electronic and electric devices with energy, and a flashlight's purpose is to deliver a function targeted at a higher system: a human being who wants to use the flashlight to illuminate a certain area of space.

To stay innovative, a company that produces flashlights has to therefore continuously follow the evolution of three areas: the (1) evolution of human or societal needs with respect to the functionality of devices producing light, (2) evolution of technologies that make it possible to create flashlights to meet these particular needs better, and (3) evolution of all competitive businesses that produce flashlights. In a modern global economy, ignoring just one of these areas will undoubtedly reduce the company's chances to survive and grow.

Understanding evolution means comprehending interrelations that exist between three large categories of knowledge related to a specific product: evolution of market, evolution of technology, and evolution of business. None of these areas is static; they are in continuous development.

It is also important to understand a difference between a technology and a product. A product is a technical system composed of a number of components that deliver specific functionality. A technology is a process that enables producing this functionality. For instance, a lamp can be considered a product, and a process of generating light on the basis of passing electric current through a metal wire that heats the wire and thus produces light can be considered a technology. It is obvious that a product might integrate many different subsystems that are built upon different technologies. A process of creating electric current and a process of generating light are two separate technologies. If we look at a mobile phone, we will see hundreds of enabling technologies that make it possible to create the needed functionality of its parts and components.

In turn, each subsystem of a mobile phone can be considered a separate product. However, the same functionality can be achieved on the basis of different technologies. For instance, a function of generating light can be obtained through heating metal wire, through laser radiation, or through the effect of electroluminescence in semiconductors. A particular type of technology can be described by a more general term, for example *virtual reality*. Sometimes the name of a technology can coincide with the name of a product if this product is used as a subsystem. For example, the term *photo sensor* might indicate a technology of capturing images by a light-sensitive matrix and converting captured information to digital form.

2.5.2 Technology Roadmaps

There are two major groups of factors that drive product evolution:

1. *Technology push:* Development of new technologies and, therefore, products based on scientific and technological research; and
2. *Market pull:* Market needs that should be satisfied by new- or next-generation products and technologies, and requests to create and develop these technologies.

Both technology and market are spaces with many variables. How does one successfully identify what comes next? What products will be successful? And, more importantly, what products will these be? To plan feasibly, one should be aware of the current level of market needs and business developments. However, that is not enough. To make a long-term forecast that can result in a specific product development plan, we need to know what technologies can be used to improve existing products or develop new ones. Technology roadmapping addresses this issue.

The technology roadmap (TRM) introduces connections between identified market needs and trends with existing and emerging technologies for a specific industry sector to improve existing and develop new products. Technology roadmaps provide a graphical framework for exploring and communicating strategic plans. They comprise a multilayered, time-based chart that visually links market, product, and technology information and represents their evolutions within a selected time interval, enabling market opportunities and technology gaps to be identified. Originally, technology roadmapping was introduced by Motorola in the 1980s (Willyard and McClees, 1987).

TRMs can be used in various contexts (Garcia and Bray, 1997). Primarily, they are used in strategic product planning, research planning, business planning, intellectual property creation, and protection. Typically organizations create and use TRMs in two cases:

1. *Product-planning TRMs*, where roadmaps cover the nearest future (1–3 years ahead) and are based on already available and mature technologies.
2. *Strategic emerging TRMs*, where roadmaps cover a more extended time interval (typically up to 7, sometimes up to 10 years).

A typical TRM chart for both cases is shown in Figure 2.5.1. It consists of four layers:

1. *Timeline*: This is a line that starts at the moment of creating TRM and extends to a final year selected for products planning.
2. *Business and Markets*: This box shows specific market goals and objectives that will be fulfilled by future products. For example, it can be *Mobile Internet access* or *supersonic flight*. Such goals do not define a specific product but a general objective. A product that should deliver functionality to reach the objective is defined in a lower box.
3. *Products*: This box specifies products that will meet the business and market objectives. For instance, "a camera phone" means developing a mobile phone with integrated photo or video camera. It is not necessary to define a single line of products replacing each other in time. Several products can co-exist or be launched in parallel. In addition, different products defined in TRM can utilize the same key technology. A number of different

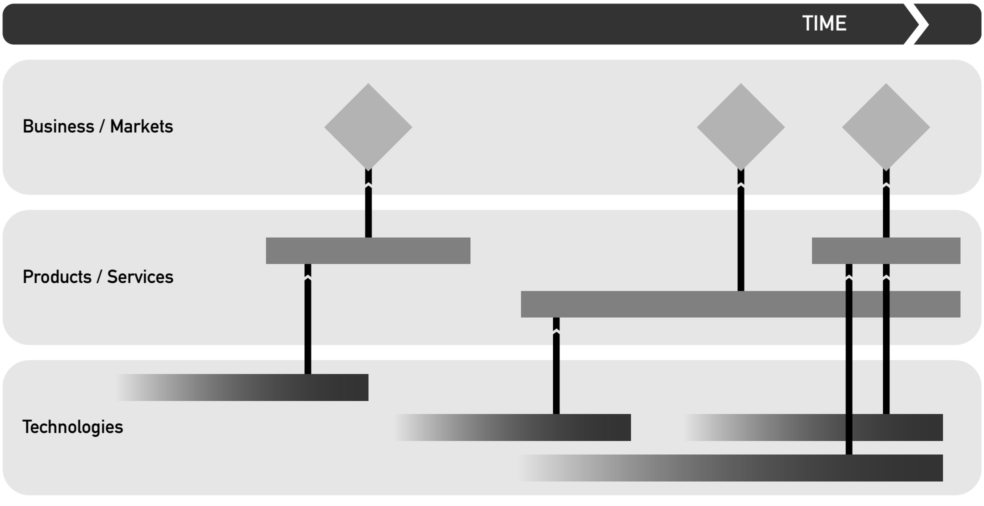

Figure 2.5.1 Time-based layered chart in a typical TRM

products can be identified by the same company that would provide mobile Internet access and that are based on the same key ultrafast wireless data communication technology.

4. *Technologies*: This box contains specific *key* technologies that are needed to build the desired products. It focuses on mature technologies that are currently not used in the existing products at all or at emerging technologies, or both. For instance, developing a camera phone requires a technology of a photo sensor. If this technology has not reached yet maturity level, we have to estimate when the technology becomes mature and thus define when a product based on that technology can be launched at the market. For this reason each emerging technology in TRM can be represented by a rectangle with a gradient that specifies the expected time of transition from immature technology to mature.

For example, if a strategic emerging TRM for mobile wireless communication were created in 1991, its simplified version could look like the one shown in Figure 2.5.2. Such a roadmap was never created at that time; the purpose of this example is to better explain the paradigm of technology roadmapping and show what the final roadmap representing a long-term plan can look like. The gradient of the bars representing technology maturity is shown in an arbitrary form for illustrative purposes only.

Note that it is extremely difficult to plan for almost 20 years ahead because certain technologies might not be available yet and new inventions that would influence the development of new products or their features are still to be created.

The diagrams shown in Figures 2.5.1 and 2.5.2 are the most simplified examples of TRM. TRM can include different layers in addition to these four layers. For instance, the following layers can be added:

- The *vision layer* represents change or updates of the vision of the organization.
- *Market niches* identify application areas for each product.

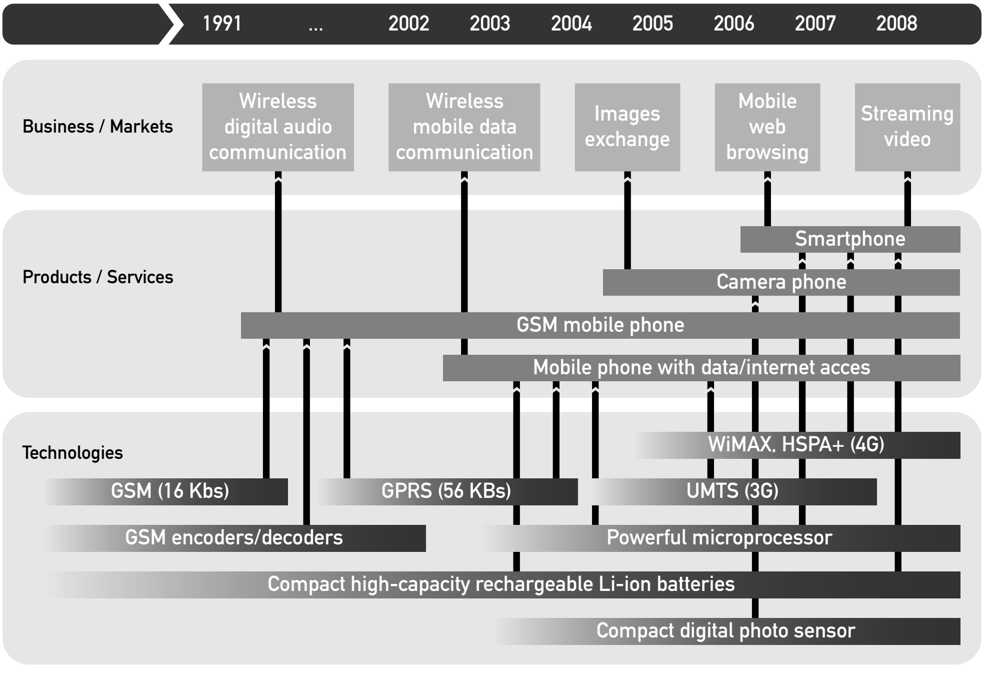

Figure 2.5.2 A TRM for a wireless mobile communication. Please note that this TRM has been made in 1991

- *Internal and external resources* are needed to achieve each step of the plan for both technology and product development. This layer might comprise financial, technical, labor, and any other type of resources.
- *R&D programs* are needed to mature the needed technologies and integrate technologies to products.
- *Integration activities* are done with partners, suppliers, and customers.

There is no unified approach to developing roadmaps. Instead, each organization that develops TRMs uses the best practices and methods available in the organization or outside and can be highly customizable (Phaal, Farrukh, and Probert, 2004).

TRMs are very flexible, and any important information that can influence the proper planning of future products, technologies, and activities might be added. In addition, each bar representing a technology or a product can be further decomposed to more specific components. For instance, a camera phone (mentioned in Figure 2.5.2) might be referred to a broader list of technologies, such as image-processing software, data storage, lens, shooting parameters control, and so forth. For this reason, to avoid the growth of complexity of a TRM, a subsystem of a more complex system can be separated into another TRM. For instance, the evolution of data storage for mobile wireless communication might require a separate TRM. However, this separate TRM must still be connected with the main TRM.

2.5.3 Technology Readiness Levels

One of the major challenges in strategic emerging roadmapping is to recognize and identify emerging technologies in a timely way. *Emerging technologies* are those technologies that are still under development and have not reached a point yet when they can be used for creating new products or new product features. The only viable way to know what technologies might be used in the future is to continuously monitor these technologies in fields that might be related to a specific product category (or family). In the 1990s, NASA adopted a scale with nine levels that gained widespread acceptance across industry and remains in use today (Mankins, 1995). The scale includes the following technology readiness levels (TRLs):

- *TRL 1:* Basic scientific principles observed and reported. This is the lowest level of technology maturity.
- *TRL 2:* Basic technology concept and/or application formulated. At this level, the future application of the technology is still speculative.
- *TRL 3:* Analytical and experimental critical function and/or characteristic proof-of-concept. This step includes physical validation of the technology concept, primarily in the laboratory environment.
- *TRL 4:* Component and/or breadboard validation in the laboratory environment. This step extends checking against the physical validity of a concept, but is still in the laboratory environment.
- *TRL 5:* Component and/or breadboard validation in a relevant environment. This step provides validation of the technology concept in a realistic environment.
- *TRL 6:* System or subsystem model or prototype demonstration in a relevant environment. This step requires the development of a prototype of a future product and proof of its feasibility in a realistic environment.
- *TRL 7:* System prototype demonstration in a space environment. This step is specific to space missions.
- *TRL 8:* Actual system completed and "flight-qualified" through test and demonstration.
- *TRL 9:* Actual system "flight proven" through successful mission operations. This step involves the elimination of all errors in a product found at the previous step.

These TRLs can be used to evaluate the readiness and maturity of any technology and its degree of applicability in forecasted products. TRLs do not depend on financial, business, or market data used in TRM; they only focus on evaluating the physical and practical validity of a technology concept.

It is obvious that for a short-term product-planning TRM, only those technologies that are already proven in a realistic environment have to be chosen (TRLs 6–9). For a long-term strategic emerging TRM, lower TRLs can be considered too.

It is also crucial to estimate properly a current technology readiness level and how much time it might take to reach TRL 9, when the technology becomes mature and can be used in a new product. Such estimations are often performed by independent science and technology experts. Large companies that have extensive R&D divisions often prefer to develop such core technologies in-house (Figure 2.5.3). Many large industrial companies invest to groups performing basic research and cooperate with universities and various academic organizations.

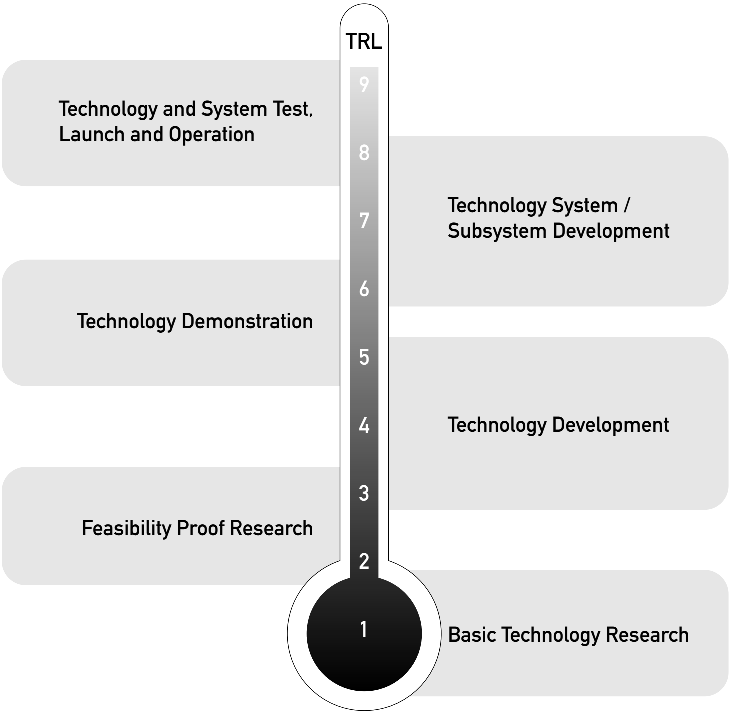

Figure 2.5.3 A "thermometer" of technology readiness levels (TRLs) mapped to technology development phases

2.5.4 TRM Process

There are three phases of the TRM process identifying the following:

1. *Market evolution:* The study of current unfulfilled and evolving market requirements and demands within a certain time frame; developing vision, and identifying the marketing objectives and time intervals needed to reach these objectives.
2. *Product evolution:* Studying what changes will be necessary in the existing products that would meet the identified market objectives, and identifying what new products can be created on the basis of the mature and emerging technologies within the defined time frame.
3. *Technology evolution:* Examining key and critical technologies (both existing and emerging) that would support the development of products identified at phase 2.

The process of creating TRM is highly iterative. It is performed in both top-down and bottom-up manners. A TRM process integrates both technology push and technology pull; therefore, after each phase of the TRM process is completed as a "first draft," information gathered during the next phase can be used to introduce changes and modifications to the information gathered during the previous phase. Often, completely new information can be

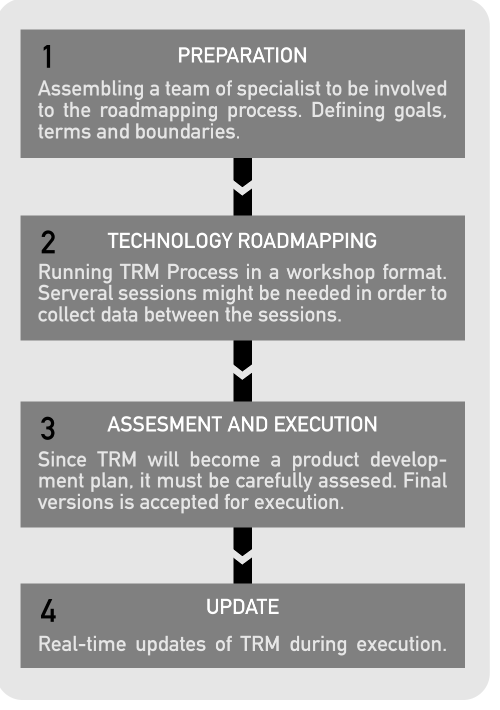

Figure 2.5.4 A general process including TRM

introduced; for instance, finding a new technology can lead to identifying a new market opportunity by creating a new product.

To properly prepare and finalize TRM, preparation and assessment activities are required. Once created and approved, TRM must be reassessed and updated regularly to avoid wrong investments, or add new technologies or the results of market studies that were omitted in the original and follow-up versions. Figure 2.5.4 represents all these activities, including a TRM process (stage 2).

Preparation and analytical studies (phases 1 and 2 of the process described in Figure 2.5.3) can take time before one starts the first workshop on visualizing TRM. All findings during these stages are recorded in a document or in a number of documents that will accompany a created visual TRM. This document usually contains detailed descriptions of the follows:

- Results of market studies and vision.
- Future expected product features.
- Emerging technology readiness levels.
- Argumentations of decisions.
- Risks.
- Future collaborations.
- Estimated investments.

Today a number of software tools exist to support TRM. However, large organizations often prefer to develop their own tools adapted to their needs and goals. These tools can be integrated with other documents created by an organization for different purposes.

2.5.5 *Benefits from TRM*

In summary, TRM:

- Provides a visual framework for integrated product and technology planning.
- Helps with establishing the monitoring of key and critical technologies.
- Establishes a plan of key activities within a relatively long term.
- Visualizes critical information along a timeline.
- Identifies technology gaps.
- Helps with defining innovation strategies.
- Improves communication among different parties involved in business, technology, and product development.
- Improves decision making by bringing together critical issues along different activities.
- Identifies needed collaboration and cooperation activities organization-wide and with third parties that will be needed to realize technology and product plans.
- Helps with identifying resources, cost, and time targets.
- Helps to reduce short- and long-term risks.

TRM can be considered a part of technology foresight activities. It is a useful tool to identify business opportunities and to plan diverse joint activities across different units and groups in an organization.

2.5.6 *Application of TRM*

In 2008, master's-level students Erkel and Reilink developed the living cubes concept shown in Figure 2.5.5. *Living cubes* is a modular lighting system with interactive tiles that react to

Figure 2.5.5 An impression of living cubes by Erkel and Reilink (2008) (See Plate 15 for the colour figure)

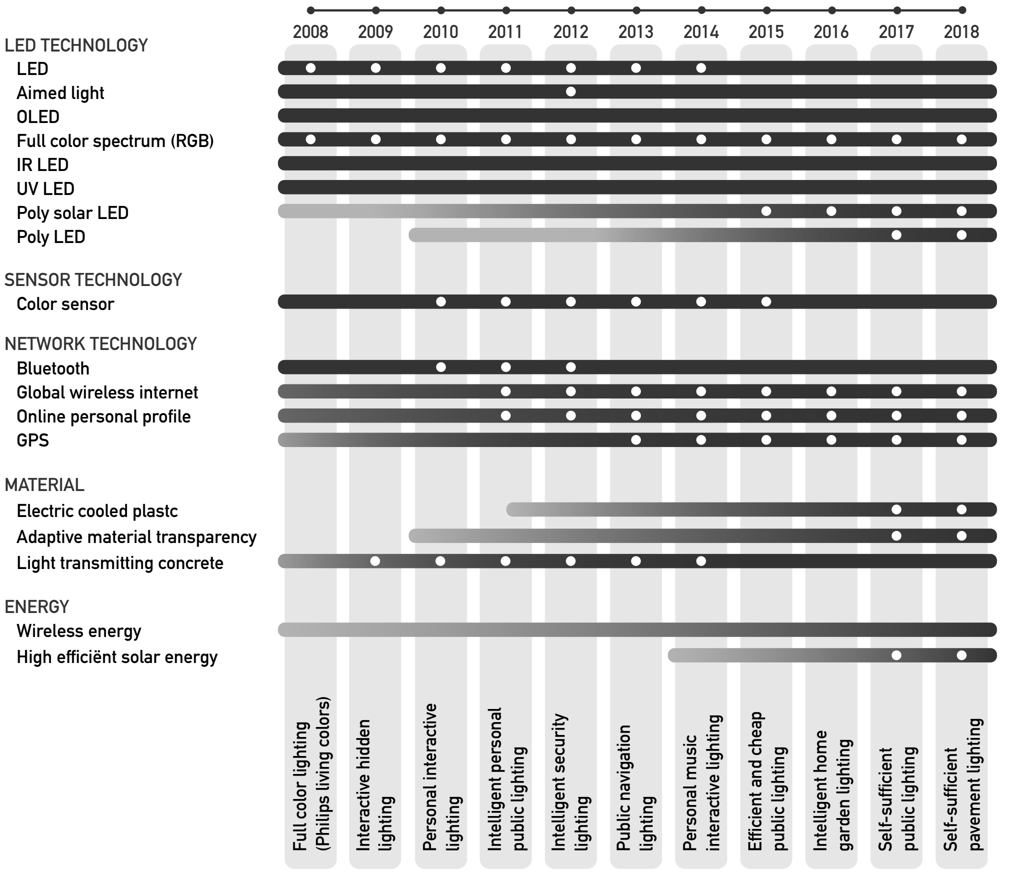

Figure 2.5.6 A technology roadmap made in the framework of living cubes by Erkel and Reilink (2008)

the environment in public spaces like, for instance, parks or shopping malls. In this project a TRM was developed for various technologies that could be applied in lighting products. This TRM is shown in Figure 2.5.6.

The interactive tiles with LED lights are all connected with each other to one central central processing unit (CPU) tile that processes all data to decide which tiles emit a certain color of light with a certain intensity. The living cubes concept has different functionalities during day and night. During day, the only functionality is decoration: making a public space interactive and personal. During night, the decorative functions remain and additionally lighting and security functions become active.

All light-emitting tiles have one or more light sensors (depending on the size of a tile) that can detect an object or person standing on top of the tile. When a tile detects a person, it sends a signal to the CPU tile that decides the appropriate reaction. All kinds of configurations can be created with different interactions. The following interactions are integrated in this concept:

Personal color: As soon as an individual person is standing on a light-emitting tile, the tile will emit a certain color of light. This light is chosen based on the person's preference.

This preference is detected by the information on the person's mobile phone using a Bluetooth connection. This technology will be integrated into the concept in the near future. When this technology is not yet integrated or if the person doesn't has a mobile profile, a random color is chosen.

Fading colors: The light-emitting tiles on which a person is standing have a special individual color. When a person walks over these tiles and is no longer standing on a certain tile, this tile still emits the person's individual color of light. After some time, the color fades (lower intensity) until it does not emit that color of light anymore. This system shows when a person has been sitting on a bench and it also shows from where person is coming. The purpose of this feature is to create an interactive personal and dynamic atmosphere in a public space like a park.

Blending colors: When two persons are standing close to each other, they both have their individual colors of light surrounding them. The tiles between those two persons blend the two colors. When, for example, a couple is sitting on a bench the bench blends the two colors. This creates a special atmosphere.

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2.6 The Design and Styling of Future Things

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2.6.1 Introduction

Design and styling of new products used to be easy. Modernism depicted that the new product should be designed to fit the utility function of the object efficiently, and that the shape should be geometric and clean. Postmodernism of the 1980s, however, re-introduced the idea of cultural reference and emotion in product design. From then on, products had to communicate not only a utility function but also cultural context and moral values (Krippendorff, 2007). Increased interest in the perception of these products by their intended users added a role for psychology and emotion in product design in the late 1990s (Desmet, 2002). Finally, the idea of product experience, introduced in the beginning of the twenty-first century, added an important role for the use of products (Green, 2002). From then on, using products should also be pleasurable and provide a memorable experience (Schifferstein and Hekkert, 2007). A lot of work has been done on mastering this increasing complexity, mostly relying on step-by-step methodology.

The design and styling of innovative products are even more complicated, depending on their innovativeness. When incremental innovation is applied, the characteristics of relating products can provide a reference for the design of new ones. One can think of the classic example of the first generation of cars, which looked like "carriages without horses." However, in the case of breakthrough innovations, the intended new objects have no real "predecessor" in their existence, in other words, there is no reference to determine how they should look. To match the example of the introduction of the car, one can think of the first successful airplane by the Wright brothers, which showed little resemblance to birds (or anything else).

This newness is best suited with an umbrella methodology based on insights from creativity. Our design educational practice shows that the search for suitable product concepts beyond the obvious can be facilitated by bringing the design challenge to a higher level of abstraction (Eggink, 2009b), as for instance depicted by TRIZ, and more recently also adopted by the Vision in Product Design (ViP) method (Hekkert and Dijk, 2001). To stay with our example of the car as a carriage without a horse, one should not try to design the next generation of carriages, but rather "a means of individual people transport with the use of combustion engine technology."

With regard to the development of innovative aesthetics in particular, in our post-modern twenty-first-century society, the image of products has sometimes become more important than the product itself (Baudrillard, 1994; Jameson, 1991). Then it is not the physical product, but the perception of the product by the user, that determines its existence (Crilly, Moultrie, and Clarkson, 2004). Bernhard Bürdek argued as early as 1991 that the functionalist idea of "form follows function" cannot play its central role in the development of aesthetics anymore, because of the increased importance of "visually anonymous" electronics and information technology (Bürdek, 1996). Electronics and interfaces simply do not have a particular shape, like steam engines or bicycles used to have. Naylor and Ball (2005) illustrated this ambiguity effectively with the supposedly functional shape of a neutral box that could be "anything" (Figure 2.6.1). This abstract nature of technology even increases when considering developments in bio- and nanotechnology (Drukker, 2009). Interestingly, in contrast, developments in materials and computerized production techniques enable us to make nearly any shape we want (Figure 2.6.2). In this context, the communication function of aesthetics – telling the user what the product is and how to use it – is therefore very important. It is this combination of circumstances that provides the designer with a powerful influence on the recognition and acceptance of innovative product concepts by their intended users.

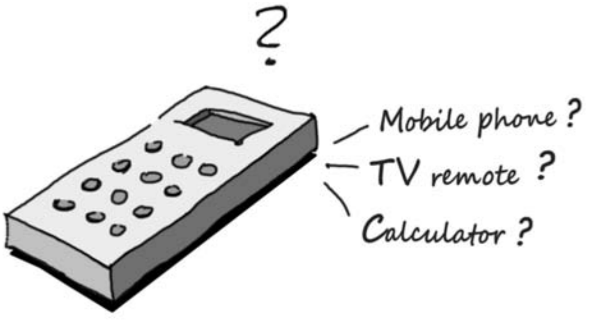

Figure 2.6.1 The Generic Keypad by Naylor and Ball (2005, p. 62) illustrates the problem of product ambiguity

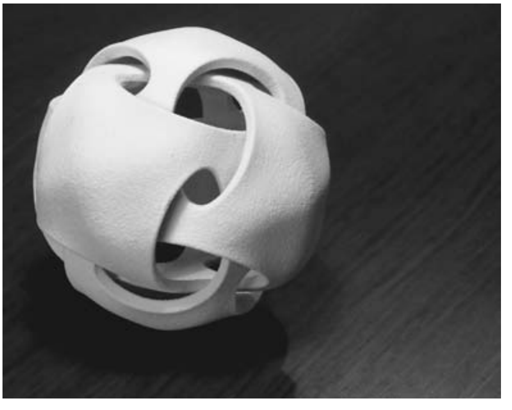

Figure 2.6.2 Example of a complex shape that is produced with the use of rapid prototyping techniques

2.6.2 Communication

The communication function of design is easily understood, following the communication model of Crilly, Moultrie, and Clarkson (2004) (Figure 2.6.3). The consumer response at the right side of Figure 2.6.3 is steered by the information that is received through the senses.

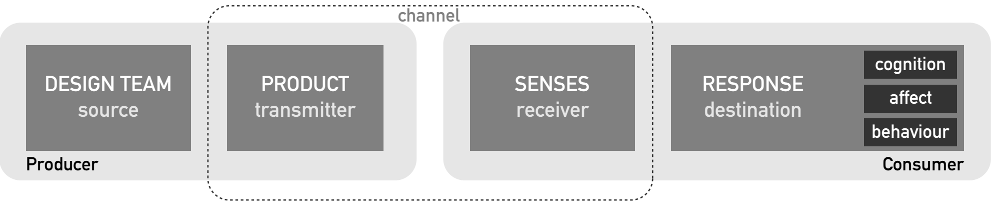

Figure 2.6.3 Basic model of product communication by Crilly, Moultrie, and Clarkson (2004, p. 551)

Figure 2.6.4 Products that communicate how to hold and use them (left and middle), and an example that does not (right)

The interpretation of that information leads to (re)cognition, a certain level of affect (like or dislike), and a particular behavior. To evoke the desired recognition, liking, and behavior, the product has to transmit the right information. Therefore, the design team has to put the right idea into the styling of the product. For example, a sustainable car concept has to transmit the idea of environmental friendliness. If the intended consumer associates the styling of the concept with spoiling fuel instead, he or she will not show the desired behavior (using and liking the car).

The communicated idea can support the usability of the product. The do-it-yourself cordless drill and jigsaw in Figure 2.6.4 are clear about where the user should put his or her hands to hold and manipulate the objects. The rather smoothly curved handlebar sections reflect the form-language of the human body. Especially with the jigsaw, this is in sharp contrast with the rather technical expression of the 'dangerous' part of the device, surrounding the saw blade. The cordless drill also has a shape that literally points towards the hole that is to be drilled. In contrast to that, the styling of the "white box" design of the little iPod on the right, does not provide such a clue how to hold and manipulate it.

The idea that the product transmits does not necessarily have to do with the primary functionality of the object. The iPod Nano in Figure 2.6.5 expresses the idea of "simplicity,"

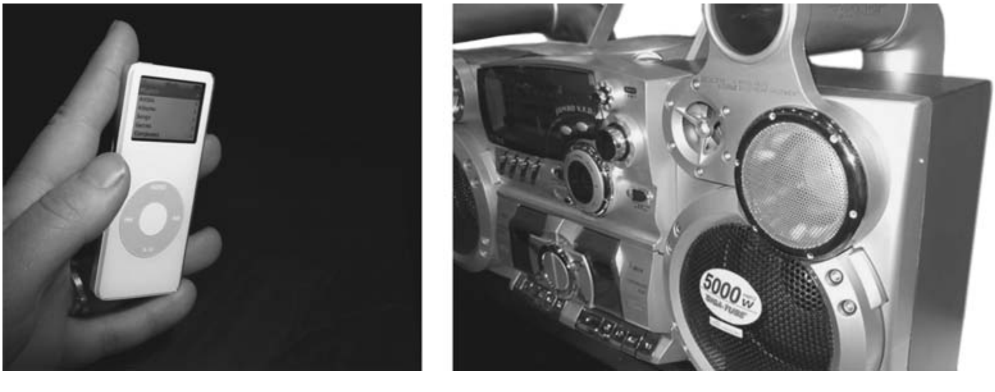

Figure 2.6.5 The iPod Nano from 2005 successfully communicates "simplicity" (left), whereas the music device on the right communicates the opposite

which is a metaphor for the interface's ease of use. The rather chaotic styling of the ghetto blaster on the right is expressing "complexity" as a metaphor for *value for money*; the consumer gets a lot of options when purchasing the device. Especially with the design of innovative products, where the perception of the consumer is already challenged by a lack of reference from predecessors, the central message to communicate should not be too complex. When the central idea of the product is clear, the shape and functionality of the product can be designed in a focused way, with the result that the consumer will recognize the benefits easier (Eggink, 2009a).

The iPod, for example, was one of the greatest recent successes in handheld devices. But its shape was not very pleasant to hold in your hand, and successors with better functionality. However, the central idea of "simplicity" was very dominantly implemented, stressing the problem that often occurred when introducing new consumer electronics: people being afraid that they could not cope with the new product's complexity.

This communication of the design idea should be regarded as a cultural phenomenon; the response of the consumer is determined by his or her cultural context or so-called *cultural capital*. In fact, the message is best understood when the sender and receiver share a common frame of reference. A red car, for instance, connotes "fastness" and "danger," because people learn that red depicts danger as in traffic lights. They can also associate the color with the fast cars of the Ferrari brand.

The designer has to constantly search for the right cultural references that contain the desired message, then transform the characteristics of these cultural references into the styling of the new object. This transformation of cultural meanings can be executed on different levels of abstraction (Nijkamp and Garde, 2010), from the simple use of the color red for "danger" to the implementation of form complexity as a metaphor for advanced technology that can be seen in the object of Figure 2.6.2, which was issued to promote the possibilities of rapid prototyping.

2.6.3 Acceptance

New products have to build an "audience." Early industrial designer Raymond Loewy said in his autobiography, "A lot of people are open to new things, as long as they look like the old ones" (Loewy, 1951). Loewy translated this in the famous MAYA (most advanced yet acceptable) principle, which suggests that things should look new, but not too much. This is unfortunately a relative and therefore very subjective guideline, because it is never clear what is "too much." This MAYA principle has a background in social studies on people's aesthetic preferences, where it is argued that people long for both ease of recognition and the excitement of newness (Armstrong and Detweiler-Bedell, 2008). In other words, it is the ever-existing paradox of comfort versus thrill. However, in their illustrative research on typicality, novelty, and aesthetic preference, Hekkert, Snelders, and van Wieringen (2003) conclude that people have aesthetic preference for objects that are both typical *and* novel:

> In sum, it seems that our results provide an empirical basis for the industrial design principle coined MAYA by Raymond Loewy. . . . In order to create a successful design, the designer should strike a balance between novelty and typicality in trying to

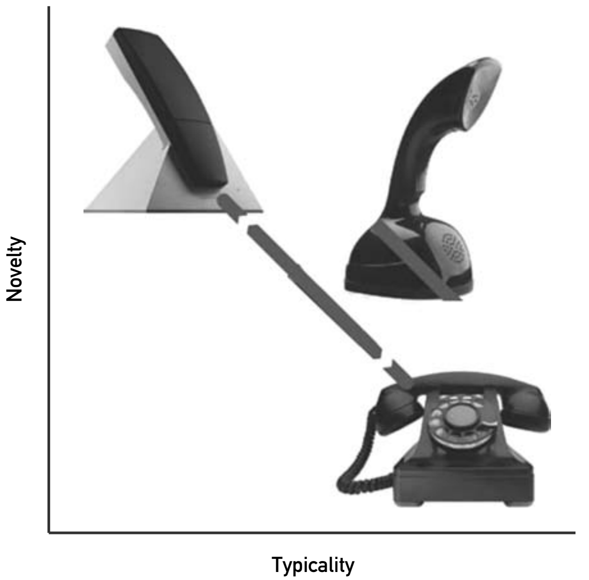

Figure 2.6.6 Example of the relationship between novelty and typicality in telephone designs. The gray arrow depicts the (normal) highly negative correlation

> be as innovative as possible while preserving, as much as possible, the typicality of the design. The fact that this is feasible is due to the fact that the correlation between novelty and typicality, although highly negative, falls short from being perfect. (p. 122)

In fact, the interpretation by Hekkert, Snelders, and van Wieringen (2003) turns the MAYA principle into a very useful tool. The transformation of terms puts an end to the endless discussions on whether an advanced design is still acceptable or too advanced, because now a new design should be both advanced (novel) *and* acceptable (typical). This is, of course, only possible when typicality and novelty are considered two different variables, and not each other's opposites. This is best understood when the opposite of typical is seen as *different*, and the opposite of novel is seen as *expected* (Eggink, 2010). The historic example of the red Ericophone in Figure 2.6.6 is a telephone design where both typicality and novelty score high. The Ericophone is novel because of the upright position of the handset (with the dial at the bottom of the base) and typical because of the familiar shape and form language of the handset, which is copied from the traditional black model.

This principle can be implemented in many different ways. In the Gina concept car by German car manufacturer BMW, for example, the bodywork is innovatively executed in fabric, covering a tubular frame. Because the fabric was made in one continuous piece covering the whole body, this solution resulted in a form of wrinkling of the bodywork when the doors were opened. This wrinkling of body coverings is very new within the styling of cars, but at the same time very recognizable for the user because it associates with skin. Master student Industrial Design Engineering Jan Willem Peters explored the principle in his master graduation project and came up with a range of other examples. Amongst others he designed a

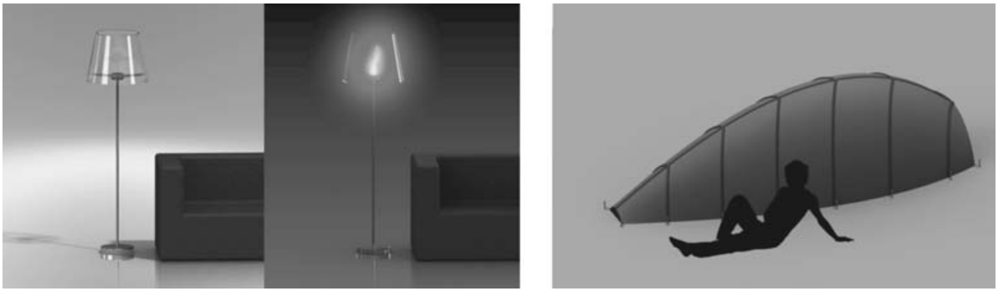

Figure 2.6.7 *Lampshade-Fireplace* and *Tent* concept by Jan Willem Peters, combining familiar shapes in a new context (tent) and combining a new functionality with a familiar context (fireplace)

lampshade-fireplace, and a tent with the shape of a leaf (Figure 2.6.7). The lampshade-slash-fireplace looks very familiar in a living room context, but is new because of the gel burner that is providing a real fire, situated somewhere one does not expect. The tent concept transforms the shape of a leaf into a small shelter. The familiar structure of the veins of the leaf is combined with the structural support for the tent.

So the combination of newness and recognition is typically achieved when something widely known is presented or applied in a new, unfamiliar context (Eggink, 2011b). This principle can be traced back to the practice of "displacement" by the early twentieth-century Surrealists, and is still a powerful mechanism for cultural meaning making (Figure 2.6.8).

2.6.4 Method

When the novelty–typicality principle is combined with the outline for stimulating creative solutions on a higher level of abstraction as was derived from TRIZ, we can put this in a

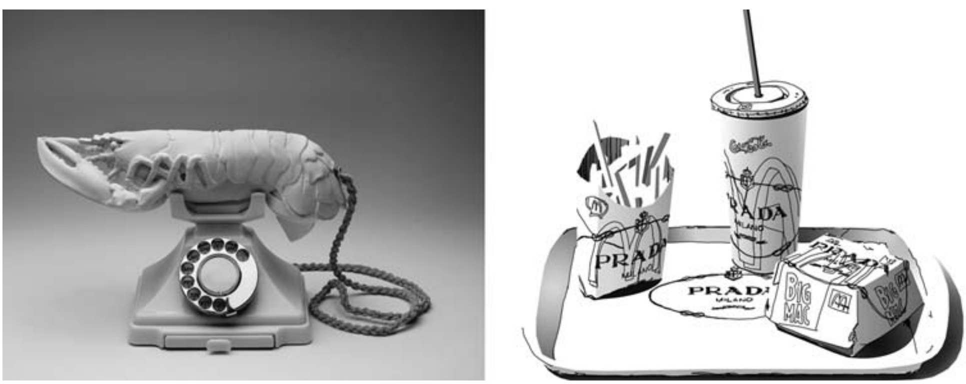

Figure 2.6.8 *Aphrodisiac Telephone* by Salvador Dalí, from 1936 (1936, courtesy Museum Boymans-van Beuningen, Rotterdam; photo Tom Haartsen) and *Prada Value Meal* by Tom Sachs (1997) share the same principle of meaning making

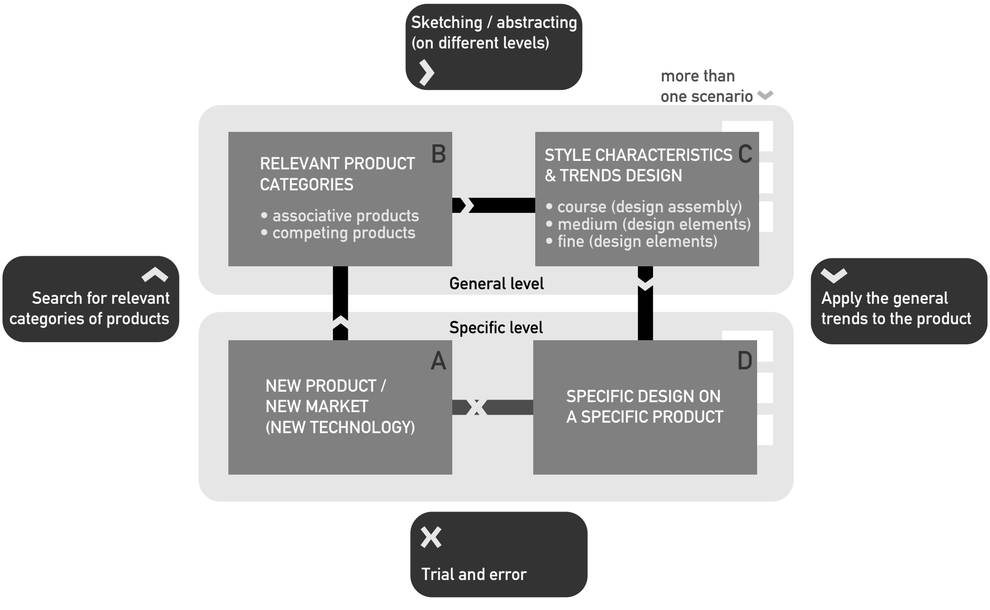

Figure 2.6.9 Basic model of innovative design and styling, by Stevens (2008–2010)

scheme as depicted in Figure 2.6.9. The design challenge of the new product is elevated to a general level on the left. Here the central idea to be communicated should be established from relevant product categories and related cultural references. From there, the implementation of newness and typicality on an abstract level can be facilitated by associative and competing products or imagery.

On the right side of the model in Figure 2.6.9, the insights should be applied to the specific product design, resulting in a concrete object that incorporates the abstract product idea. Within this process, an exploration of different design possibilities, based on future trends and scenario development, could ensure that the specific design fits the desired future context.

2.6.5 Examples

Two examples will be given of the actual development of the styling of future concepts. Both originate from the teaching practice at the Industrial Design Engineering curriculum of the University of Twente in the Netherlands.

The first example is from a design course in cooperation with Dutch sports car manufacturer Donkervoort. The assignment was to develop future concepts for a genuine sports car experience in a society context that has more and more traffic restrictions. Leendert Verduijn, Bernd Worm, and Frank Scholder approached the problem by first visualizing the intrinsic contradiction of the assignment (Figure 2.6.10).

The visualized argument is that developments in electronic driver assistance, in combination with road safety and increased density, will put the driver in a stringent harness

Figure 2.6.10 Visuals depicting the central problem statement and the desired solution for the design: combining the racing car with the intrinsic freedom of city running

(Figure 2.6.10, left), leading to illusionary freedom (Figure 2.6.10, middle). The solution for a true sports car experience has to lie in substantially less car instead of more car (Figure 2.6.10, right). Presented in this way, the visualizations stimulate the designer to look for creative solutions that lie behind the obvious, and they also support the evaluation of design ideas (Eggink, 2011a).

The implementation of this abstract idea is shown in Figure 2.6.11. Instead of a sports car, the students designed a minimalistic construction that stays as close to the body as possible, reminiscent of the inspiration source from popular youth culture, city running or Parkour. The eventual concept is a clear combination of novelty and typicality (Figure 2.6.11, right). The back half looks like a lightweight motorcycle, and the front half like a skateboard (the associative and competing products as mentioned in the upper-left corner of the basic model in Figure 2.6.9). The posture of the driver resembles that on a reclining bicycle, but the absence of the driving train renders a different effect. The sense of freedom for the user is established by minimizing the parts in the front. Because no part of the construction is in the sight of the user, the shape reflects an urge forward and there is no visible protection that blocks the user's idea of freedom.

The second example is from a master course named Create the Future, where student groups first have to create a future context for their designs through systematic scenario development (Eggink, Reinders, and van der Meulen, 2009). Within this future context, the groups have to develop a product concept, and in this particular example the group created a future electric mobility concept named *Amplified Walking*. The central idea is that the

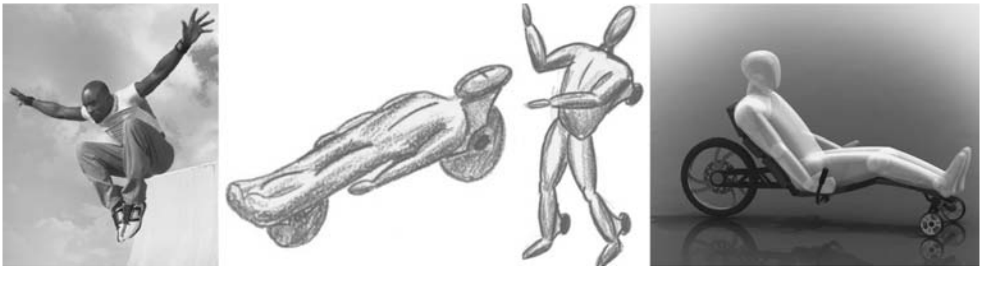

Figure 2.6.11 From central idea to design concept: The electric driven tricycle can be folded into the shape of a wheeled suitcase so that the fun can be combined with public transport before or after use

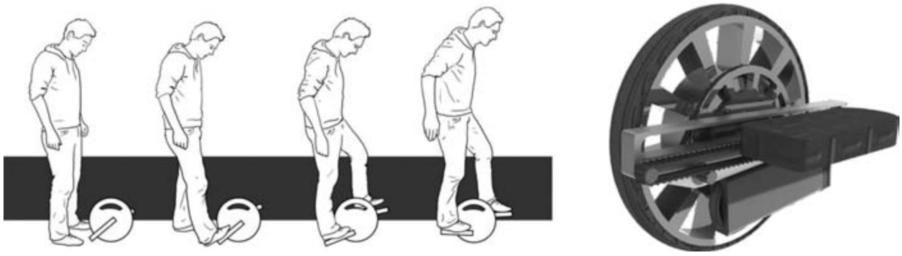

Figure 2.6.12 The amplified walking concept, by Alfred Doppenberg, Ronald van Galen, Mark Grob, and Elias van Hoek

electrically driven device amplifies the movements that you normally make when you are walking, stepping, or running (Figure 2.6.12). Ingenious electronic feedback will keep the user stabilized in the same manner as the two-wheeled Segway does.

The amplified walking concept was developed for a future scenario context where consumer involvement with new developments was very high. This resulted in a product architecture based on building blocks that should be possible to construct in endless combinations, like a form of mass customization. The group presented three different product architectures, likely to be built by different user groups. All three also combined a form of newness with recognition of the typical features of the user group's main inspiration sources (Figure 2.6.13). The first one combines the appearance of a unicycle with the styling of a white iPad. The second one is a mix of skateboard and mountain bike. The third concept resembles a typical fitness device, targeted on elderly people.

2.6.6 Conclusions

Design and styling have major influences on perceptions of innovative product concepts. The right styling depends on a profound mix of both novel and typical styling items. This combination of items has to communicate the desired attributes of the product, by means of association with the cultural background of the intended user. For clear acceptance of the communicated message, it should be not too complicated. One central idea is easier to communicate and can at the same time perform a guiding role in the design's detailed development. Two example projects have shown how styling features and product architecture can go hand in hand to express the desired feelings around future product concepts.

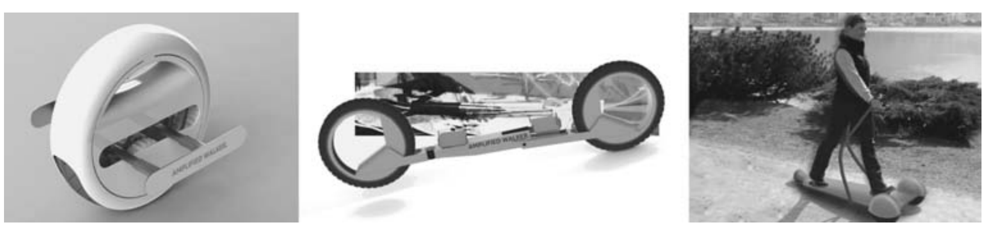

Figure 2.6.13 Three possible implementations of the amplified walking concept

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2.7 Constructive Technology Assessment

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2.7.1 Introduction

Technology assessment (TA) aims to support the designing and shaping of technology in society. TA is supposed "to reduce the human costs of trial and error learning in society's handling of new technologies, and to do so by anticipating potential impacts and feeding these insights back into decision making, and into actors' strategies" (Schot and Rip, 1997, p. 251). TA practices are intended to create, communicate, and apply knowledge about and reflection on the potential and actual interaction of (new) technology and societal actors and forces.[1] An overarching definition is offered by the TAMI project, a joint effort of European TA agents, to summarize the state of the art of TA: "Technology assessment is a scientific, interactive and communicative process which aims to contribute to the formation of public and political opinion on societal aspects of science and technology" (TAMI project, 2003, p. 4).

The first concepts of TA were developed in the United States at the end of the 1960s. At that time a need to assess the potential, normally unexpected negative effects of new technologies was perceived that led in 1972 to the creation of the Office of Technology Assessment (OTA) as a research-based service and early warning mechanism of the US Congress; OTA worked for more than 20 years with quite some success, but in it was closed down by a Republican majority in Congress (Smits *et al.*, 2010; Smits and Leyten, 1991). The OTA served as a model for various forms of parliamentary TA services established in European countries, directly or indirectly linked to parliamentarian decision making (such as in the United Kingdom, Germany, Denmark, the Netherlands, and Switzerland).

Since the late 1990s, TA concepts have increasingly adopted a *dedicated design ambition*. In the meantime, there is a considerable variety of TA approaches such as *expert TA*, *participatory TA*, *interactive TA*, *rational TA*, *real-time TA*, and constructive TA (CTA).

In particular, CTA aims to understand social issues arising from new technologies and to influence design practices. This development has been driven by three independent but interrelated forces:

1. After the nuclear and computer technologies of the twentieth century, today *new and emerging technologies* are again attracting our attention, such as nanoscience, nanotechnology, and life sciences (e.g., genomics). These new technologies are characterized

[1] Since the early days of TA, experts have uttered a dedicated design ambition; see, for example, Coates (1975); Bimber and Guston (1997); Rip, Misa, and Schot (1995); and Smits, Leyten, and den Hertog (1995). This holds even more for most recent TA works such as Robinson (2010) or Te Kulve (2011).

by a considerable heterogeneity of related knowledge bases, new forms of interdisciplinary exchange (e.g., *translational research* in biomedicine), as well as generic fields of application with potentially far-reaching effects on economies and societies.

2. More than in earlier days, TA experts feel confident about being able to cope with the *Collingridge dilemma* (Collingridge, 1980), that is, they see a good chance to effectively *shape technological development* at early stages, before design and societal embedding have become irreversible. This hope draws not a small amount on the insights of international interdisciplinary science, technology, and innovation studies (STIS): Today we have at our disposal a good socioeconomic understanding of innovation processes (e.g., Dosi, 1982), framed by long-term specific technological, economic, social, political, and cultural "regimes" (Nelson and Winter, (1977, 1982); Rip and Kemp, 1998); stretching across multilevel systems (e.g., Geels and Schot, 2007); and shaped by specific forms of grown *de facto* governance. The better one understands these interrelations, the more likely and robust a prospective "modulation" of technological developments will become (Rip, 2006).
3. As a third force we have seen since the late 1990s, at least in Europe, a growing interest in TA concepts drawing on *participatory* elements in the design of new technologies, now conceptualized as a process of innovation. "Users" are interfering in innovation (e.g., Oudshoorn and Pinch, 2003; van Oost, Verhaegh, and Oudshoorn, 2008; Von Hippel, 2005) – think of the enthusiasm of Linux-based open-domain software communities, or of the dedication of voluntary contributors to the various Wiki databases.

On such grounds, a "realistic," (i.e., modest though dedicated) design ambition toward technologies can emerge: If in today's polyvalent society literally "everything goes," why shouldn't it be possible to design and shape technology in an explicit and at the same time reflexive way?

The present chapter[2] will sketch a dynamic concept of TA – with a focus on CTA – and its contribution to the governance of technological innovation. A constructivist and reflexive TA concept will be suggested: Informed by heuristics-based analyses, CTA will be presented as modulating ferment in the social process of technological innovation and as a building brick of its emerging *de facto* governance. Finally we will suggest the metaphor of TA as a dance of three elements:[3] The "practice" of technological innovation; the "theory" of science, technology, and innovation studies; and the "policy," that is, public and private governance ambitions.

2.7.2 New Attention for the Design and Governance of Science, Technology, and Innovation

Increasingly politicians, industrial actors, societal groups, and technology experts are concerned about inappropriate attempts at steering technological development and thus hampering the realization of desired innovation effects. In the past, all too often

[2] The text draws partially on Kuhlmann (2007, 2010) and Rip (2008).

[3] See also Kuhlmann (2007) and Smits and Kuhlmann (2004). The dancing metaphor was used earlier by Arie Rip (1992) with respect to the relation of science and technology, inspired by Derek de Solla Price's discussion of this relation (1963).

development followed the model of the "economics of technoscientific promise" (Felt *et al.*, 2007): Promises to industry and society, often far reaching, are a general feature of technological change and innovation, and are particularly visible in the mode of governance of emerging technosciences (biotechnologies and genomics, nanotechnologies, neurosciences, or ambient intelligence), all with typical characteristics. They require the creation of a fictitious, uncertain future in order to attract resources: financial, human, political, and so on. They come along with a diagnosis that we are in a world competition and that we (Europe, the United States, etc.) will not be able to afford our social model if we don't participate in the race and become leaders in understanding, fueling, and exploiting the potential of technosciences. The model

> works with a specific governance assumption: a division of labor between technology promoters and enactors, and civil society. Let us (= promoters) work on the promises without too much interference from civil society, so that you can be happy customers as well as citizens profiting from the European social model. (Felt *et al.*, 2007, p. 25)

Under this model of techno-economic promises politics, science and industry take the lead, while the innovation needs and expectations represented in the society appear to remain in a rather passive consumer role.

Felt *et al.* (2007) suggest as an alternative model the "economics and socio-politics of collective experimentation," which are characterized by emerging or created situations that allow people to try out things and learn from them. The main difference with the other model is that "experimentation does not derive from promoting a particular technological promise, but from goals constructed around matters of concerns and that may be achieved at the collective level. Such goals will often be further articulated in the course of the experimentation" (Felt *et al.*, 2007, p. 26f). This model requires a specific division of labor in terms of participation of a variety of actors, who are investing because they are concerned about a specific issue (see also Callon, 2005). "Users matter" in innovation – that has been shown not in the least by our UT colleague Nelly Oudshoorn and her team (Oudshoorn and Pinch, 2003). Examples of such demand- and user-driven innovation regimes include the information and communication sector (where the distinction between developers and users is not sharp), sports (e.g., von Lüthje, Herstatt, and von Hippel, 2005), or the involvement of patient associations in health research (e.g., Rabeharisoa and Callon, 2004) and pharmacogenomics (e.g., Boon *et al.*, 2008). The concept of "open innovation" debated around the user-driven development of nonpatented open-source software, and more generally in Hank Chesbrough's influential book (2003) is largely overlapping with the collective experimentation concept. The governance of such regimes is precarious since they require the long-term commitment of actors who are not always equipped with strong organizational and other relevant means, and there is always some room for opportunistic behavior. Nevertheless, the promise is innovation with sustainable effects.

2.7.3 Constructive Technology Assessment

So we are in need of a governance of technological innovation that builds on exchange, debate, negotiations, and cooperation between companies, science, civil society, and political systems. Which role can TA adopt in this setting?

Which TA? Smits *et al.* (2010; see also Smits and Leyten, 1991) differentiate "Watchdog TA" and "Tracker TA." Watchdog TA is supposed to fulfill an early-warning function for political decision makers. Related projects are often conducted by centralized (parliamentary) TA agencies. Actors in the innovation process do not play an active role in Watchdog TA. In contrast, Tracker TA, or CTA, aims to proactively and constructively interfere in the process of technology development and design.

TA Methods (Source: TAMI project, 2003, pp. 48–49)

Scientific methods include the "Delphi method, expert interviews for collecting expert knowledge, modeling and simulation, cost/benefit-analysis, systems analysis, risk analysis, material flow analysis, trend extrapolation, scenario technique for creating knowledge to think about the future . . . discourse analysis, value research, ethical analyzes, value tree analysis."

Interactive methods include "consensus conferences, co-operative discourses, public expert hearings, focus groups, [and] citizens' juries are belonging, currently in part supported by using electronic media."

Communication methods include "newsletters, opinion articles, science theater, (interactive) websites and various types of networking."

CTA as a constructive design process starts from the assumption that actors involved in technology development can find themselves in two basically different positions: as insiders or outsiders to the development process. Garud and Ahlstrom (1997) suggested differentiating the positions of enactors and comparative selectors: *Enactors* are technology developers and promoters aiming to enact new technology; they "construct scenarios of progress, and identify obstacles to be overcome. They thus work and think in 'enactment cycles' which emphasize positive aspects" (Te Kulve, 2011, p. 31). *Comparative selectors*, in contrast, observe technological development process from the outside and may be in a situation to compare the enactors' offers and performance with other, parallel developments. There are professional comparative selectors (such as regulatory bodies like the US Food and Drug Administration) using professional tools for their assessments, and amateur comparative selectors (such as critical consumers and nongovernmental organizations [NGOs], the latter increasingly turning professional) (Te Kulve, 2011, p. 32). Enactment cycles and comparative selection cycles come together in *bridging events* (Garud and Ahlstrom, 1997), with insiders and outsiders interacting. Such interaction may lead to variations in the technological design process and can have an impact on the direction of selection decisions. Such bridging events "can be constructed on purpose, by actors from enactor or selector positions, and by more disinterested actors such as Constructive Technology Assessment (CTA) agents" (Te Kulve, 2011, p. 33).

CTA agents start from the assumption that enactors and selectors of new technology make assessments all the time, so rather than making assessments (by TA agents) CTA aims to create and orchestrate bridging events as dedicated "spaces" for interaction, learning, and reflection (Rip and te Kulve, 2008). Both enactors and selectors can undergo *first-order* or *second-order learning processes*: According to Argyris and Schön (1978), first-order learning links outcomes of action to organizational strategies and assumptions that are modified so as to keep organizational performance within the range set by accepted organizational norms. The norms themselves remain unchanged. Second-order learning concerns inquiries that resolve incompatible organizational norms by setting new priorities and relevance of norms, or by restructuring the norms themselves together with associated strategies and assumptions, hence escaping tunnel vision and crossing borders.

CTA agents, in order to create dedicated spaces for first- and second-order learning, organize *interactive workshops*, often enriched by the elaboration of alternative *sociotechnical scenarios*, stimulating the debate of participants (see the "TA Methods" in this section). Such scenarios "capture ongoing dynamics and develop assessments of future developments. They show the effects of interactions between enactors and selectors which provides more substance to interactions in workshops as actors can draw upon the scenarios for inspiration" (Te Kulve, 2011, p. 34).

The interfering character of CTA requires an explicit understanding of the room for maneuver of the involved actors – up to now, still a weak point of CTA concepts. To which extent can the participants effectively manage or steer the development, variation, and selection processes? The *governance context* of CTA-supported design processes needs to be explored and understood. *Governance* means the coordination and control of autonomous but interdependent actors either by external authority or by internal mechanisms of self-regulation or self-control (Benz, 2007, p. 3). This is of particular relevance when it comes to the development and design of new and emerging technology: The potential areas of application, markets, concerned actors and audiences, and dimensions of potential effects are still in flux; and political arenas, decision criteria, and policy means are not yet determined.

2.7.4 Governance: CTA and Design in an Institutional Context

CTA and technological design are taking place in "inherited" economic and institutional environments. Any realistic attempt to shape technological development effectively has to understand the driving forces and hampering factors of governing this institutional context.

A useful heuristic for this purpose is offered by the school of evolutionary-economic analyses of technology dynamics. It is built on the findings of "innovation studies," in particular on the seminal work of Nelson and Winter (1977, 1982): In their "search of a useful theory of innovation" and convinced of the stochastic, evolutionary, and organizationally complex and diverse character of innovation, the authors observed different technological "regime*s*" characterized by longstanding specific "search strategies" of engineers, determining to some extent the development trajectory of a given regime. Drawing on this basic observation, other authors have defined *technological regimes* as "the complex of scientific knowledge, engineering practices, production process technologies, product characteristics, user practices, skills and procedures, and institutions and infrastructures that make up the totality of a technology" (Van den Ende and Kemp, 1999, 835). Rip and Kemp (1998) explicitly added to the "grammar" of a regime the public and private strategies and *policies* of relevant actors: Technology is conceptually and as an artifact socially constructed, including the governance of a regime.

Finally, these conceptual elements were combined in the heuristic of a *multilevel perspective* on sociotechnical transitions (e.g., Geels and Schot, 2007), characterized by niche

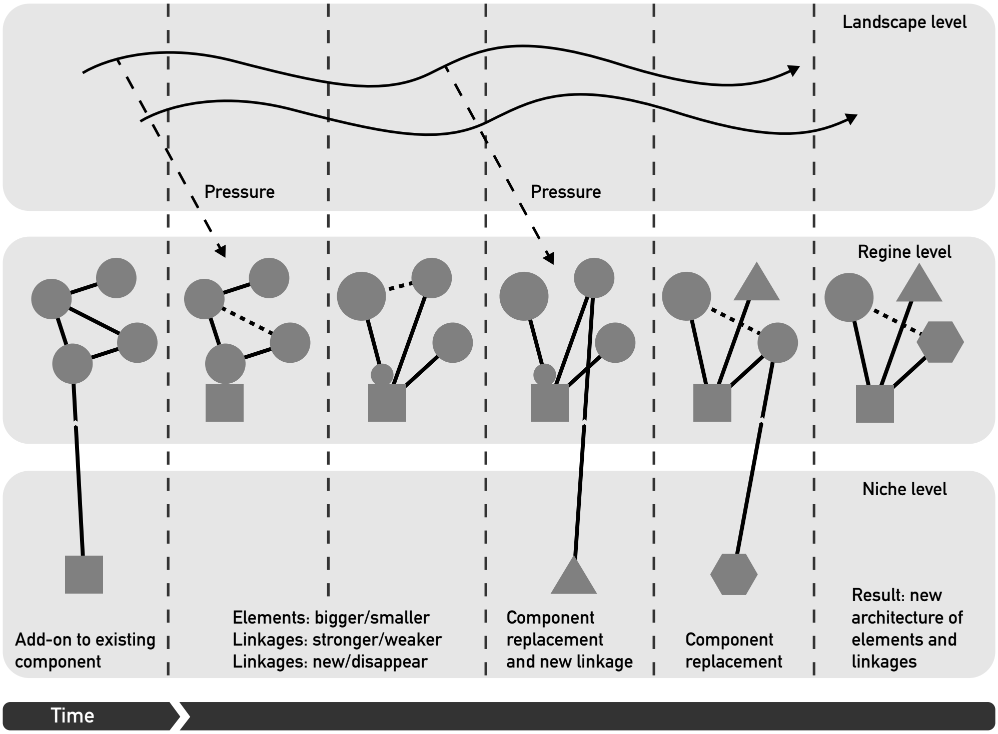

Figure 2.7.1 Schematic presentation of reconfiguration of a technological regime (Geels and Schot, 2007, p. 412)

innovations on a micro level (developing in emerging or created and protected incubation spaces), sociotechnical regimes on the meso level, and wider sociotechnical landscapes on the macro level (macroeconomic, cultural, and macropolitical developments). Studied with the help of this heuristic, one can see *regime transitions*, sometimes incremental and sometimes radical, sometimes driven by basic changes in the overarching landscape or stimulated through niche innovations undermining dominant regimes (see Figure 2.7.1).

Such transition processes are fueled by promises and expectations about technological options and innovation (Van Lente, 1993). Actors anticipate and assess their options *vis-à-vis* changing regimes and create *de facto* new patterns (Rip, 2001) that can trigger "irreversibilities" (Callon, 1991) resulting in "endogeneous futures" (Rip, 2001). In other words, the analysis of the transition of sociotechnical regimes offers a heuristic help to open up the allegedly fatal transition point of the Collingridge dilemma for empirical research. This holds also for the governance of technological developments in a regime context: We can better understand the options and limitations for dedicated shaping.

Here it is useful to clarify the underlying concept of *governance*: The concept is used here as a heuristic, borrowed from political science, denoting the dynamic interrelation of involved (mostly organized) actors; their resources, interests, and power; the fora for debate and arenas for negotiation between actors; the rules of the game; and the policy instruments applied (e.g., Benz, 2007; Kuhlmann, 2001). Governance profiles and their quality and direction are reflected not a small amount in the character of public debates between stakeholders, policy makers, and experts. Think of the debates on genetically modified organisms (GMOs), or – still more in *status nascendi* – debates on the governance of an emerging, cross-cutting science, technology, and innovation (STI) field like nanotechnology (e.g., Joly and Rip, 2007).

How much leeway do actors in a given regime actually have? One has to understand the *de facto governance* of a given social context. Conceptually we can draw here upon the "actor-centered institutionalism" of Mayntz and Scharpf (1995) and Scharpf (2000). The *de facto* governance of sociotechnical regimes can be analyzed as a web of cognitive, normative, and regulatory rules. Actors have to cope with these rules; while inevitably reproducing them, they are also incrementally changing them through deviating behavior. In the context of emerging sociotechnical regimes, actors cannot achieve more (but also cannot achieve less) than to shape what will happen anyway, while at the same time rules are being transformed (Rip, 2008).

Against this background TA, in particular CTA, can be understood as a *modulating factor* of the *de facto* governance and of the co-evolutionary development of a regime. The better we understand the *de facto* governance in a given regime, the more CTA can in a realistic and constructive manner modulate technological development and design. CTA as a means of *reflexive governance* is aware of the limits of dedicated governance; this awareness is even a strategic underpinning of its ambition (Rip, 2006; Voss *et al.*, 2006).

2.7.5 CTA as a Dance: Strategic Intelligence

CTA as a means of reflexive governance aims to make the diverging perspectives and interests of relevant actors visible and debatable aiming to increase the learning capacity. Here we suggest the metaphor of a *dance* of "practice," "policy," and "theory" (see Figure 2.7.2); they can be seen as partners on a dancing floor, moving to varying music and exposing different configurations.

"Theory" is represented by the arsenal of dedicated and methodologically rich STIS.[4] The multilevel analysis of regime transitions sketched out in this section is of particular value for the application of CTA as a means of reflexive governance (e.g., Konrad, Truffer, and Voss, 2008; Markard and Truffer, 2008). As a dancing partner, STIS (theory) would move about in the worlds of technology designers in a constructivist and reflexive manner (Robinson, 2010), analyzing the perspectives and interests of the other dance partners and reflecting on its own position (sometimes even changing its own beliefs): in other words, CTA becomes a means of reflexive governance.

The "dance floor" for CTA can be conceptualized as a "forum," defined as institutionalized space specifically designed for deliberation or other interaction between heterogeneous actors with the purpose of informing and conditioning the form and direction of strategic social choices in the design and governance of science and technology (see Figure 2.7.3; Edler *et al.*, 2006). The debates on a forum can be supported with insights from strategic

[4] For an overview, see Silbey (2006), Hackett *et al.* (2007), and Fagerberg *et al.* (2006). Scientific journals such as *Research Policy* (rather economics oriented) and *Science, Technology, and Human Values* (rather sociologically oriented) enjoy a high reputation.

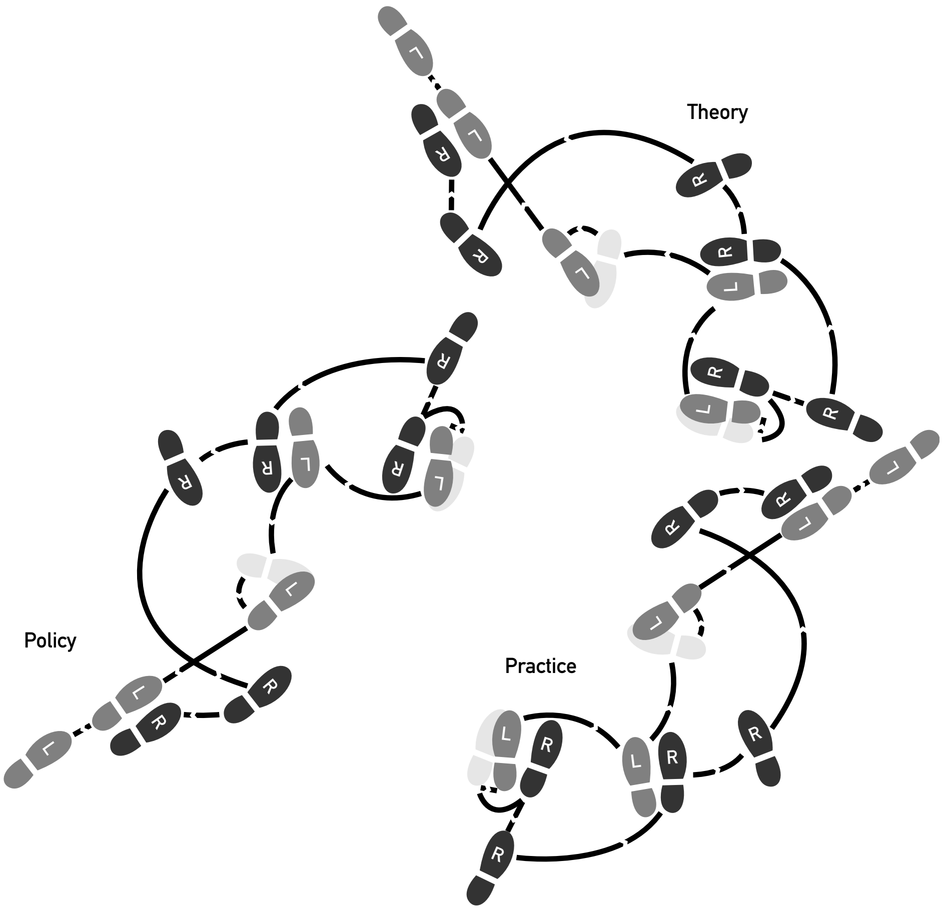

Figure 2.7.2 Dance of "practice," "policy," and "theory" (Kuhlmann, 2007)

intelligence (SI). SI has been defined as a set of sources of information and explorative as well as analytical (theoretical, heuristic, and methodological) tools – often distributed across organizations and countries – employed to produce useful insight in the actual or potential costs and effects of public or private policy and management (Kuhlmann *et al.*, 1999). Strategic intelligence is "injected" and "digested" in fora, with the potential of enlightening the debate. SI can draw on semipublic intelligence services (such as TA agencies or statistical offices), on "folk" intelligence provided by practitioners or NGOs, and in particular on research-based statistical STIS.

2.7.6 Limits to CTA and Reflexive Governance of Technology Design

Today constructive TA is using a broad spectrum of scientific, interactive, and communicative methodologies and SI instruments in order to modulate on various fora, the *de facto* governance of technological development and design, aiming to increase the learning

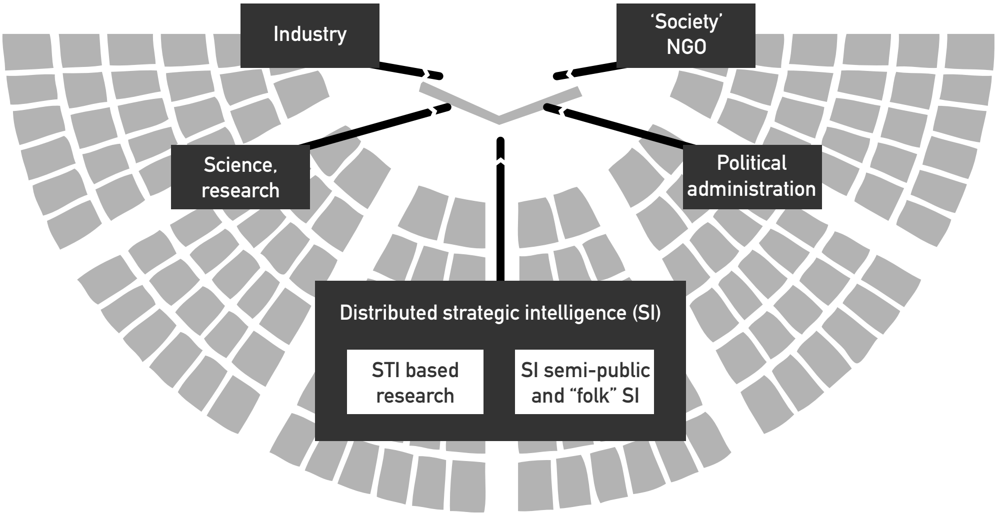

Figure 2.7.3 Forum for the deliberation of sociotechnical themes (Kuhlmann, 2007)

capacity and reflexivity of involved actors (enactors and comparative selectors). Examples include the targeted mobilization of users and the creation of niches as protected space for experimentation (e.g., Kemp, Schot, and Hoogma, 1998), using *inter alia* consultation processes and scenario workshops (Elzen *et al.*, 2004; Robinson, 2010; Stemerding and Swierstra, 2006; Te Kulve, 2011).

Still, one can question the practical relevance of CTA, understood as a dance of practice, policy, and theory in the daily life of industrial design practices. Is this in the end more than just a dream of concerned idealists? After all, CTA is just *one among many factors* driving actual sociotechnical development, and finally TA may play just a symbolic role in the games of interested parties. There is still no final answer to such questions; but without the dedicated *political will* of leading actors in science, technology, industry, politics, and society, there will be no reflexive TA as constructive design practice and governance.

2.7.7 Application of CTA

Researchers executed a constructive TA for the introduction and use of a new type of asphalt comprising phase change materials that would reduce the freezing of road surfaces and hence the use of salt in winter. Goals of the CTA were to obtain information about the acceptance of the new product by society, which will be done by looking into political, social, environmental, economic, and cultural effects, starting with mapping the actors that play a role. These actors are shown in Figure 2.7.4. In the rest of this subsection, the roles of the actors will be explained by the students.

Road-Building Companies

Road-building companies play a big role in the implementation of new road surface material, because they have to build the new roads with it. If production requires new techniques and

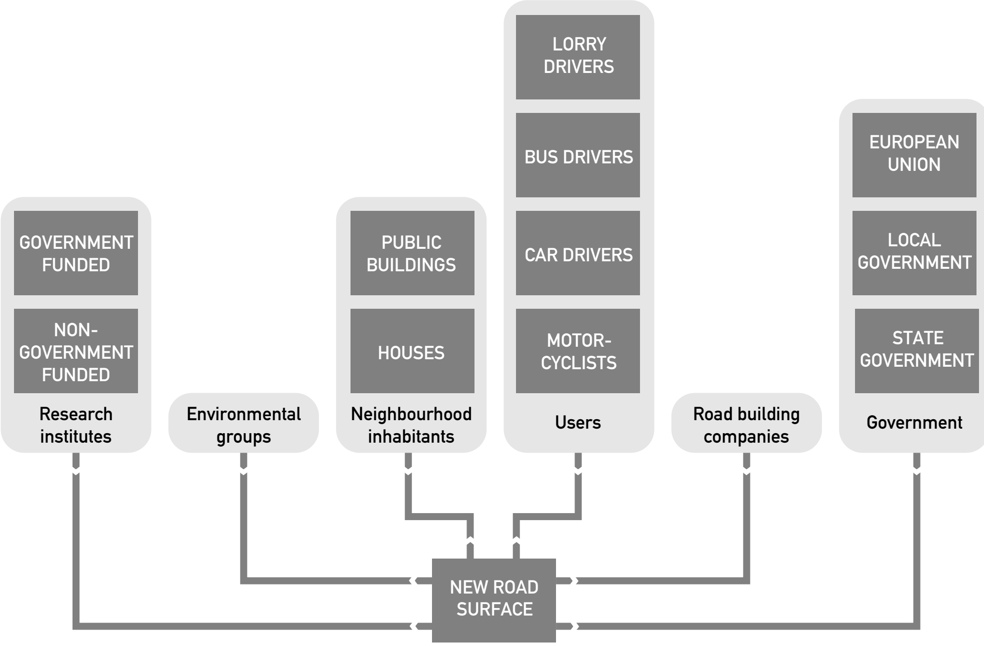

Figure 2.7.4 Scheme representing the interfaces between various actors and a new type of asphalt

perhaps also higher costs, the companies might not be pleased. However, the use of advanced and sustainable techniques could also work to their advantage if it fits with an image the company would like to depict. New supplier contracting is probably necessary, because the needed phase change materials are produced by specialized companies.

Government

The government has an important voice in the implementation of a new highway product, because a lot of planning is involved. When can the new roads be built? How much will it cost? How long will it take, and what kind of impact will it have on traffic flow? How much maintenance will be needed in the future? What is the product lifetime of the new material? These are just a few of the questions that can be asked about the long- and short-term influence of new highways.

Vehicle Drivers

This group consists of car owners as well as motorcyclists, bus drivers, and lorry drivers. Their interests have to do with costs and safety. If the new highways come with higher road taxes, they will not be happy about it. But perhaps if safety can be improved and is in balance with the higher costs, they might be willing to concede.

Neighborhood Inhabitants

Though this group is called *inhabitants*, it can also be people who work in the area of a highway or schools in the area. The way in which a new highway product may affect them is, for example, sound generation of the new material or pollution effects.

Environment Activists

Environmental groups want the world to be more sustainable. This includes using fewer resources. If the sustainable asphalt has noticeable advantages for the environment, environmental activists will promote is use.

Research Institutes

These groups will probably encourage a more sustainable highway, but first and foremost they will be critical and question the actual sustainability of a new product. They will carefully consider the pros and cons of the product. Companies that do quality control can also be part of this group.

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2.8 Innovation Journey: Navigating Unknown Waters

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2.8.1 Introduction

Product design and creation can been regarded as comprising an "innovation journey," biased by unforeseen setbacks along the road. In fact, real and sustainable innovation success should rather be viewed as "by-products along the journey" than as end result. If one takes a closer look to the contingencies during such a journey, the retrospective attributions of success to certain approaches or persons will prove to be misleading; such rash "attributions reinforced top managers' belief that managing innovation is fundamentally a control problem when it should be viewed as one of orchestrating a highly complex, uncertain and probabilistic process" (Van de Ven *et al.*, 1999, p. 59).

An innovation journey should be imagined as a journey into unknown waters or an uncharted river (Van de Ven *et al.*, 1999, p, 212). This metaphor helps "to develop an empirically grounded model of the innovation journey that captures the messy and complex progressions" while travelling (pp. 212–213). Consequently, according to van de Ven and colleagues, "innovation managers are to go with the flow – although we can learn to maneuver the innovation journey, we cannot control it" (p. 213).

2.8.2 Method

Still, while conceiving innovation processes as uncertain open ended processes of more or less organized social action, one can identify certain patterns and a number of typical key components characterizing the journey and helping the actors to navigate along uncharted rivers. Van de Ven *et al.* (1999, pp. 23–25) suggest the following components (see Figure 2.8.1): During an initiation period, (1) an innovation project is (often quite slowly) put in motion, sometimes (2) triggered by a "shock," and (3) project plans are developed, less as a journey map but rather to legitimate the project *vis-à-vis* corporate management. In the developmental period (4) the initial innovation idea proliferates into numerous variations, but soon (5) setbacks and mistakes are encountered "because plans go awry or unanticipated environmental events significantly alter the ground assumptions of the innovation." Projects often end in vicious cycles, or (6) actors decide, often after power struggles, to change the criteria of success and failure. (7) Various innovation personnel join the project and leave it, experiencing euphoria and frustration, while (8) investors and top management accompany the process, serving as checks and balances on one another. (9) Interaction with other organizations can have a supportive or negative impact on the innovation project, while (10) wider sectorial infrastructures are being developed with competitors, government agencies, and others. During the implementation or termination period (11), innovation adoption occurs "by linking and integrating the 'new' with the 'old' or by reinventing the innovation to fit the local situation." After implementation (12), investors and top management "make

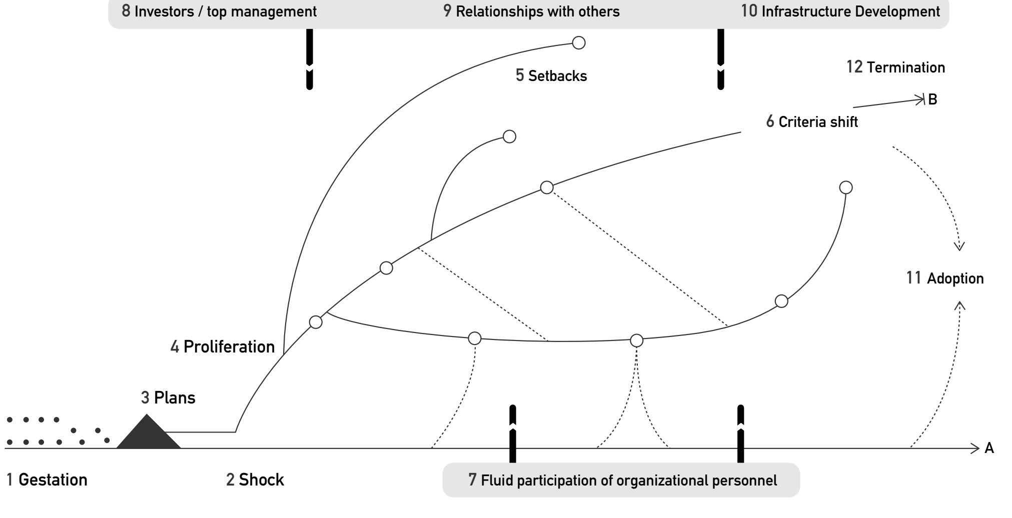

Figure 2.8.1 Key components of the innovation journey (Van de Ven *et al.*, 1999, p. 25)

attributions about innovation success or failure. These attributions are often misdirected but significantly influence the fate of innovations" (Van de Ven *et al.*, 1999, p. 24).

Regarding navigating innovation journeys by learning "to go with the flow," this advice sounds somewhat humble and unambitious. Do innovation actors (managers, users, and policy makers) really have no serious chance to guide innovation projects toward desired targets? Rip (2010) suggests that actors interested in strategic interventions will be more successful if they understand the co-evolutionary nature of the overall process and its institutional environment: "At least, they can avoid being [un]productive, as would happen when using a command-and-control approach while technological innovations are following their own dynamics."

2.8.3 Discussion about Innovation Journeys

In order to better understand the options and limitations for interventions in an innovation journey, it is useful to apply a heuristic offered by the school of evolutionary-economic analyses of technology dynamics.[5] This was discussed in Section 2.7.4 but is worth repeating here. This heuristic is built on the findings of "innovation studies," in particular on the seminal work of Nelson and Winter (1977, 1982), who observed different technological "regimes" characterized by longstanding specific "search strategies" of engineers, determining to some extent the development trajectory of a given regime. Rip and Kemp (1998) added to this the public and private strategies and policies of relevant actors: Technological innovation is socially constructed, including the governance of a regime.

As discussed in Section 2.7.4, scholars combined these conceptual elements into the heuristic of a "multilevel perspective" on sociotechnical transitions (e.g., Geels and Schot, 2007), characterized by niche innovations on a micro level, sociotechnical regimes on the meso level, and wider sociotechnical landscapes on the macro level. Studied with the help of this heuristic, one can see regime transitions (see Figure 2.8.1) that are spurred by promises and expectations about technological options and innovation (Van Lente, 1993). Actors anticipate and assess their options *vis-à-vis* changing regimes and create de facto new patterns governance triggering "irreversibilities" (Callon, 1991). In short, sociotechnical regimes are determining the leeway of actors to steer innovation processes, in other words the "governance" (e.g., Benz, 2007; Kuhlmann, 2001). In a stylized description of the innovation journey (see Figure 2.8.3), three types or clusters of governance activities can be distinguished where the innovation journey enters into a new phase because a trajectory with its own dynamics is started up: the build-up of a protected space, stepping out into the wider world, and sector-level changes (vertical dimension in Figure 2.8.3), each cutting across activities in scientific research, technological development and markets, regulation, and societal context (see the horizontal dimension in Figure 2.8.3). "Each phase has its own dynamics and the trajectory is not easy to modify. But just before 'gelling,' it is still possible to exert influence, while there is some assurance that a real difference will result because the intended shift becomes part of the trajectory" (Rip, 2010).

[5] See, for a more detailed discussion, Section 2.7, "Constructive Technology Assessment."

Figure 2.8.2 Xsens' MVN Biotech motion measurement system (left) and MTx motion tracker (right) (See Plate 16 for the colour figure)

2.8.4 Example from Practice

An example of a successful innovation journey (actually several journeys) is provided by Xsens.[6] Today Xsens is a leading developer and global supplier of 3D motion-tracking products based upon miniature inertial sensor technology. The company was founded in 2000 by two graduates of the University of Twente, the Netherlands. Inspired by the possibilities of tiny motion sensors for measurement of the performance of athletes, they specialized in sensor technologies and sensor fusion algorithms. In 2000 Xsens launched its first measurement unit, which was used for human motion measurement and industrial applications.

After more than 10 years of experience and several trips and setbacks along "uncharted rivers," Xsens today is recognized for its motion-tracking and motion capture products with best-in-class performance, outstanding quality, and high ease of use. Clients of Xsens include Electronic Arts, NBC Universal, INAIL Prosthesis Center, Daimler, Saab, Kongsberg Defence Systems, and many other companies and institutes throughout the world. Xsens is working with many industry partners, including Autodesk, Sagem, and Siemens.

As an innovation actor, Xsens navigated through all three stylized phases of a journey: building up a protected space, stepping out into the wider world, and deling with sector-level changes:

1. The company started with a promising technological option (inertial tracking) with a potential to be developed in numerous directions. In 2000 the founders depended on other partners and explored various market niches – in this case, there was almost no "protected space," facilitated by a parent organization, for example a large company, or by public innovation policy (in other cases, say the windmill energy technology in Denmark and Germany, facilitated by electricity feed-in law; see Hendry and Harborne, 2011). But

[6] The text of this paragraph draws on http://www.xsens.com/ and http://en.wikipedia.org/wiki/Xsens (accessed January 9, 2012).

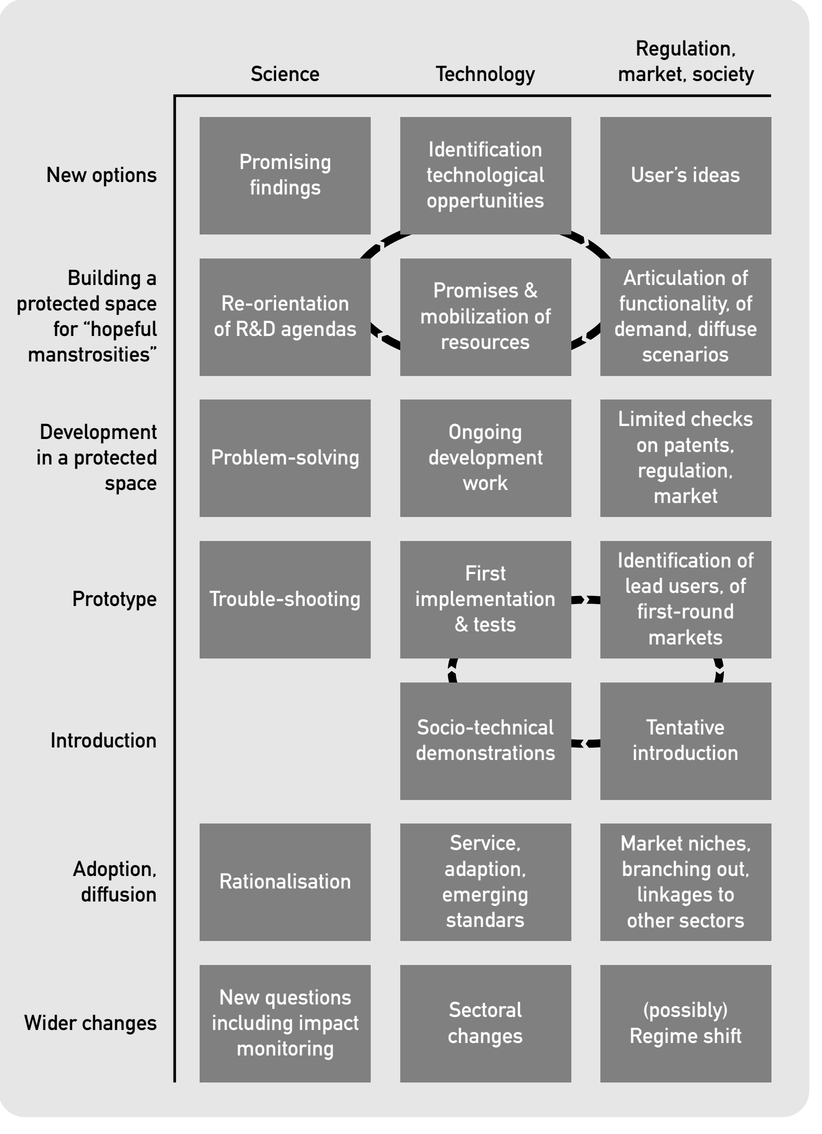

Figure 2.8.3 Mapping the innovation journey in context (Rip and Schot, 2002)

through exploration and learning, Xsens experienced quite a lot of cumulative development. Initially the company tried to launch the human motion measurement devices as speedometer for joggers, assuming that joggers are always ready to spend money for trendy gadgets; this failed. Shortly afterward, the innovators explored the application of the tracking sensors with disabled people.

2. This helped to make steps toward the integration of several "motion trackers," which facilitated applications with ergonomic research in industry, creating again new

application potential – the scope of achieved and accepted innovations made it possible "to step out into the wider world."

3. One of the most successful products – developed after several setbacks and learning loops – was the MVN Inertial Motion Capture suit,[7] a cost-efficient system for full-body human motion capture (see Figure 2.8.2). The MVN is based on unique, state-of-the-art miniature inertial sensors, biomechanical models, and sensor fusion algorithms. Meanwhile it has found applications in film and commercials, game development, training and simulation, live entertainment, biomechanics research, sports science, rehabilitation, and ergonomics – and some of the applications even helped to induce sector-level changes.

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2.9 Risk-Diagnosing Methodology

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2.9.1 Introduction

This chapter introduces risk-diagnosing methodology (RDM), which aims to identify and evaluate technological, organizational, and business risks in new product development.

[7] See http://www.xsens.com/en/general/mvn (accessed January 9, 2012).

RDM was initiated, developed, and tested within a division of Philips Electronics, a multinational company in the audio, video, and lighting industry. Also Unilever, one of the world's leading companies in fast-moving consumer goods, decided to adopt and implement RDM on a worldwide basis. Since its initiation, RDM has been applied to new product development projects in areas as diverse as the development of automobile tires, ship propellers, printing equipment, landing gear systems, lighting and electronic systems, and fast-moving consumer goods in various industries in Germany, Italy, Belgium, the Netherlands, Brazil, China, and the United States. RDM proved very useful in diagnosing project risks, promoting creative solutions for diagnosed risks, and strengthening team ownership of the project as a whole (Halman and Keizer, 1994; Keizer, Halman, and Song, 2002).

2.9.2 Requirements for an Effective Risk Assessment

The true nature of project risk is determined not only by its likelihood and its effects, but also by a project team's ability to influence the risk factors (see e.g., Keil *et al.*, 1998; Sitkin and Pablo, 1992; Smith, 1999). Thus a project activity should be labeled "risky" if the following criteria apply:

- The likelihood of a bad result is great.
- The ability to influence it within the time and resource limits of the project is small.
- Its potential consequences are severe.

To be effective, a risk assessment needs to help identify potential risks in the following domains:

- *Technology:* Product design and platform development, manufacturing technology, and intellectual property.
- *Market:* Consumer and trade acceptance, public acceptance, and the potential actions of competitors.
- *Finance:* Commercial viability.
- *Operations:* Internal organization, project team, co-development with external parties, and supply and distribution.

The most powerful contribution of risk assessment comes at the end of the feasibility phase of the innovation process, at the contract gate (see also Figure 2.9.1). At this stage, the transition to the actual product development and engineering of a particular product or product range takes place; uncertainty has to be managed, taking into account the potential risks relating to all the aspects of manufacturability, marketability, finance, human resources, and so on. In this phase of the project, management still has the ability to substantially influence the course of events and make a considerable impact on the eventual outcome (Cooper, 1993; Wheelwright and Clark, 1992). However, a periodical reassessment of potential risks in subsequent phases is still required.

In sum, it would appear that a comprehensive risk assessment approach would do the following:

- Evaluate each potential risk on its likelihood, its controllability, and its relative importance to project performance.

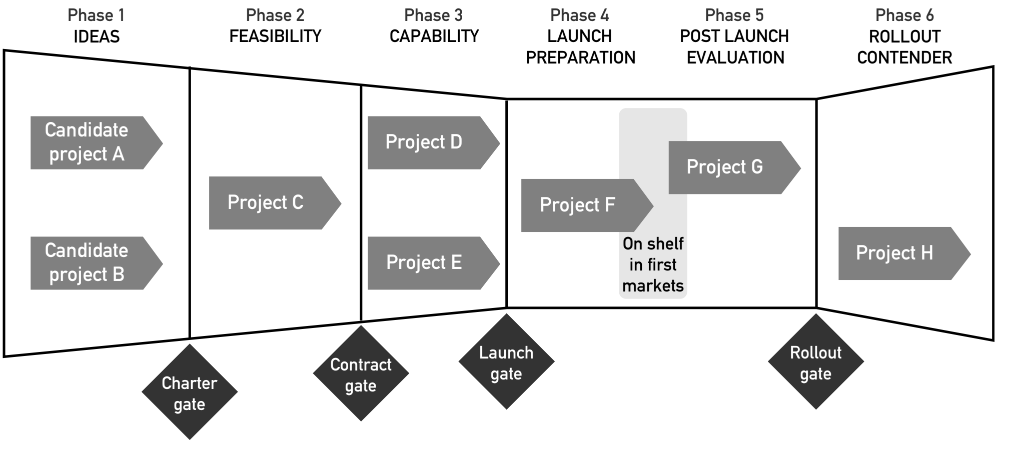

Figure 2.9.1 A typical innovation funnel

- Take a cross-functional perspective by identifying and evaluating technological, market, and financial as well as operational risks.
- Conduct the risk assessment at the end of the feasibility phase, and periodically reassess the project for unforeseen risks and deviations from the risk management plan.
- Identify and evaluate the product innovation risks individually, and generate, evaluate, and select alternative solutions in subgroups and plenary sessions.

2.9.3 The Risk-Diagnosing Methodology (RDM)

The purpose of RDM is to provide strategies that will improve the chance of a project's success by identifying and managing its potential risks. RDM is designed to be applied at the end of the feasibility phase, and should thus address such issues as consumer and trade acceptance, commercial viability, competitive reactions, external influential responses, human resource implications, and manufacturability. In this subsection, we will describe the successive steps (see also Figure 2.9.2) of RDM.

Initial Briefing

The first step of RDM is meant to build a full understanding of the conditions to be met at the start of the RDM process and to make the necessary appointments. The initial briefing takes place between the risk facilitator and project manager. This initial briefing should cover both general and project-specific topics. Project-specific topics include its objectives and unique characteristics, its stakeholders, the nature of its current phase, and the commitments required from its participants. More general topics include how information about the project will be made available to the risk facilitator, how this information will be kept confidential, who will participate in the RDM process (e.g., stakeholder, a project manager, a project team, and experts), how participants will be informed of their involvement, when and where the RDM process will take place, and what may be expected from it. Special care must be taken to include in the team technological, business, and marketing expertise. The output of this initial

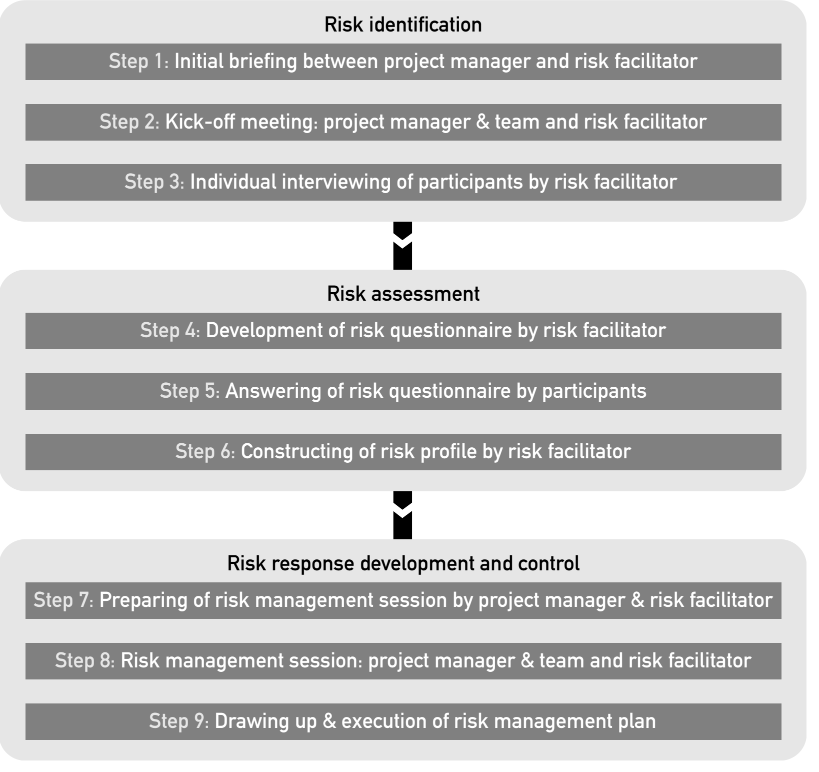

Figure 2.9.2 Outline of risk-diagnosing methodology (RDM)

briefing is twofold: agreements between the project manager and risk facilitator on actions to be taken, and invitations to a "kick-off" meeting for participants in the RDM process.

Kick-off Meeting

The objective of this meeting is to make sure that all participants know what to expect during the RDM process and are willing to cooperate. During the kick-off meeting, the following topics are addressed: objectives of and steps in the RDM process; the expected input, level of involvement, and amount of time from participants; the confidentiality of the interviews and other information provided by participants; and the expected output of the RDM process. After the kick-off meeting, agreements are made on the date, time, and location of the interviews and on the date, time, and location of a plenary risk management session.

Individual Interviewing of Participants

The objective of this step is to develop a comprehensive overview of all critical aspects in the innovation project. To enable participants to describe freely what they see as the riskiest aspects of the project, the risk facilitator interviews all participants individually. Each interview takes about 1.5 hours, during which the participant is led to think carefully on the project and its risks, and on his or her contribution specifically. Every participant is asked to study the project plan and the reference list of potential risk issues (see Appendix 2.9.A). In every new interview, the preceding interviews are taken into account (without mentioning the respondent's name) to test the completeness and correctness of the already gathered data. The protocol for the interviews is as follows:

- A short introduction of both participant and risk facilitator, and explanation by the risk facilitator of the objective of the interview.
- "Gaps" in the project: "What do you see as gaps in knowledge, skills, and experience for this project?" and "Can these gaps be bridged within the time and resource constraints of the project?"
- The reference list with potential risks: "What other gaps might be difficult to bridge?"
- Closing the interview: "Did we forget something?"
- Next steps: The risk facilitator briefly explains again what the interviewee can expect next, especially the risk questionnaire and the risk management session.

Processing the Interviews: Design of a Risk Questionnaire

After having interviewed all the participants, the risk facilitator analyzes the interview notes and clusters the critical issues according to the risk categories distinguished in Appendix 2.9.A (e.g., product technology risk, manufacturing technology risk, and project team risk). Then the risk facilitator designs a risk questionnaire, in which the critical issues from the interviews are translated into positive statements of "objectives to be realized" (see Figure 2.9.3). For example, if in one of the interviews a risk team member says, "We will be using a new ingredient in our product solution, and I have read in a

Risk Statements:	What is the *level of certainty* that the statement will be true? Very Very Low High					*Ability of team to influence* course of actions within time & resource limits Very Very Low High					*Relative importance* of statement for obtaining project success Very Very High Low				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1. The new product will be safe to use for people with a sensitive skin.	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2. With the trade customer clear after sales arrangements have been agreed.	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
3. For localized dye damage we have an appropriate solution.	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Figure 2.9.3 Example of a risk questionnaire

journal that this material sometimes causes skin irritations," the statement would be formulated thus: "The new product formulation will be safe to use also for people with sensitive skin."

Answering the Risk Questionnaire

Respondents are asked individually to score the risk statements that they have developed on three five-point scales (see Figure 2.9.3):

- The level of certainty that the objective formulated in the risk statement will be realized.
- The ability of the team to reach an appropriate solution using the project's allotted time and resources.
- The relative importance of the objective to project performance.

Respondents are asked to answer the questionnaire as completely as possible, but not to respond to those issues about which they have no idea or opinion. The typical number of risk statements in these questionnaires is 50–60, and it takes 45–60 minutes to complete.

Constructing the Risk Profile

After the respondents have completed the risk questionnaire, the risk facilitator constructs a risk profile from their scores. Every risk statement is reported with its scoring for the three evaluation parameters (see Figure 2.9.4 for an example).

The risk profile presents both the degrees of risk perceived by the majority of the respondents and the distribution of their perceptions. Although the criterion can be chosen differently, we have chosen to mark with a dot the column in which a support of a minimum of 50% (the average of the scores) is reached. This will give an initial view of the thinking of the majority of the respondents. Next, the risk facilitator classifies the risk statements in two ways. First, every risk statement is classified along the three parameters into four groups by the following decision rules:

- ("∗"): At least 50% of the scores are 1 or 2 on the 5-point scale (1 being *very risky*), and there are no scores of 5 on the 5-point scale.
- ("0"): At least 50% of the scores are 4 or 5 on the 5-point scale, and there are no scores of 1 on the 5-point scale.
- ("m"): At least 50% of the scores are 3 on the 5-point scale, and there are no scores of 1 or 5 on the 5-point scale.
- ("?"): For all remaining cases. There exists a lack of consensus, visible in a wide distribution of opinions. After discussion with the interviewees, the "?" scores may be changed to one of the other three.

Next, the risk facilitator classifies each risk statement into a "risk class" by examining the questionnaire responses. RDM uses five risk classes: S = safe; L = low; M = medium; H = high; and F = fatal. For example, a combination of scores "∗,∗,∗" on a given risk statement would result in its classification as so risky that not lessening this risk would be fatal for the project (which would then be assigned a risk class of F), while the combination "0,0,0" would result in a classification as safe (risk class S). The total number of possible

Risk Statements:		What is the *level of certainty* that the statement will be true? ‘C’ Very Very Low High					*Ability ofteam to influence* course of actions within time & resource limits ‘A’ Very Very Low High					*Relative importance* of statement for obtaining project success ‘I’ Very Very High Low					Score for each dimen-sion of risk			**Risk Class**
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	*C*	*A*	*I*	
1. The new product will be safe to use for people with a sensitive skin.	N resp.	0	0	1	3	5	0	0	1	3	5	0	2	5	2	0	0	0	m	**L**
	≥ 50%				●						●			●						
2. With the trade customer clear after sales arrangements have been agreed.	N resp.	3	2	4	0	0	0	2	5	2	0	3	5	1	0	0	*	m	*	**H**
	≥ 50%		●						●				●							
3. For localized dye damage we have an appropriate solution.	N resp.	1	3	2	0	2	2	2	0	4	0	4	0	1	1	2	?	*	?	**L-F**
	≥ 50%		●					●				●								

N resp: Number of team members who scored in certain column	
≥ 50%: Column in which at least 50% of team response is first met	
‘*’:	At least 50% of the scores are 1 or 2 on the five point scales and there are no scores of 5
‘0’:	At least 50% of the scores are 4 or 5 on the five point scales and there are no scores of 1
‘m’:	At least 50% of the scores are 3 on the five point scales and there are no scores of 1 or 5
‘?’:	Lack of consensus: There is a wide distribution of opinions.
Risk Classes used: **S** = Safe; **L** = Low Risk; **M** = Medium Risk; **H** = High Risk and **F** = Fatal risk.	

Figure 2.9.4 Example of a project risk profile

combinations of risk scores is 64 (see Keizer, Halman, and Song, 2002). If there is a distribution of opinions, the risk score can be represented by a range between the lowest and highest risk classes that can be reached if the respondents achieve consensus (e.g., L-M or H-F). For example, in Figure 2.9.4, the scores indicate a lack of consensus within the team for risk statement number 3. If, after discussion and clarification, the team as a whole is convinced that the statement “finding an appropriate solution for localized dye damage” is very uncertain and very important to project success, the risk range will change from “L-F” to “F.” It should be stressed that this lack of consensus in the risk profile is very valuable information and should not be “swept under the carpet.” It has happened more than once that a member of a team had a clearly divergent opinion that appeared, after discussion and clarification, to be right!

Preparing a Risk Management Session

In this RDM step, the project manager reaches agreement with the risk facilitator on the agenda for the risk management session. Certain risks will be better tackled in a plenary session, and others in subgroups. The choice will depend on the number and difficulty of

- Every one's viewpoint is valid!
- No holding back – Say what's worrying you!
- No management hierarchy
- The things we don't want to hear are probably the key issues
- Explain from your area of expertise

Figure 2.9.5 Rules of engagement for a risk management session

risks requiring a solution. Experience suggests that a risk management session will require a one-day meeting where the team can work in plenary as well as syndicate (subgroup) meetings.

Risk Management Session

The objective of the risk management session is to achieve consensus on action plans for dealing with the high risks and on procedures for dealing with the medium and lower risks. In addition to the project manager and the risk facilitator, all persons who participated in the RDM process are invited to this session, which the project manager usually leads. A typical session includes an introduction to the objectives of the meeting, the program, and some "rules of conduct."

Our experience has shown that observing these rules of conduct (see Figure 2.9.5) helps participants to increase the effectiveness of the process and foster breakthroughs in problem solving. Not only do these rules enforce the requirements generally agreed on for brainstorming (Ivancevich and Matteson, 1996) but also they limit as far as possible the potential negative effects of group dynamics discussed in this section. After the introduction and an agreement to follow the rules of conduct, the risk facilitator presents the risk profile: What are the high risks everyone agrees on? What are the risks about which opinions differ but that could potentially turn out to be high? The risk facilitator also shows how certain issues are related to each other.

The first part of the risk management session is designed to create a common understanding of the risks and to generate ideas for managing them. In the second part of the risk management session, the group is split up into subgroups, which are asked to work further on the suggested ideas and to formulate action plans specifying what needs to be done, by whom, and when. Appendix C presents some trigger questions that might help the subgroups design these plans. In the third part of the session, the subgroups present the outcomes of their respective discussions. After further clarification and discussion, the project team decides on which follow-up actions should be taken to manage the diagnosed risks, and on how to present the results to senior management.

Drawing Up and Executing a Risk Management Plan

The risks and corresponding action plans are brought together in a risk management plan. In addition to documenting the risk assessment results and the outcome of the risk management session, the risk management plan states who is responsible for each of the diagnosed risks,

Project: Golden Eagle **Project number**: 01A2552	**Risk issue #**: T07 **Project Leader**: Tom Jefferson
Risk Issue: Deformation of the product due to overexposure	
Date of assessment: 13 June 2001 **Risk Type**: Manufacturing Technology **Risk Class**: F **H** M L S	**Action Responsible**: Marc Erlich **Start Date**: 18 June 2001 **Due Date**: 3 Sept 2001
Clarification of risk issue: During production an uneven cooling down of the product surface causes instability in product surface structure	
Actions Agreed on: 1. Investigate alternative mould options 2. Investigate how GE has solved this problem	
Follow-Up agreements: 1. Report results and present proposal in project review session of 14 September 2001 2. In case of satisfying new mould option make supplementary work package proposal 3. In case GE-solution is applicable and alternative mould options don't work out, develop cross-over proposal to negotiate with GE	
Mitigation plan status: PT-meeting 6/25: Drafts for mould options a/b/c/d are ready PT meeting 7/23: Prototypes for mould options a/b/c/d casted PT meeting 8/7: Prototypes a/b/c/d tested, prototype c seems satisfactory PT meeting 8/21: PT meeting 9/3:	

Figure 2.9.6 Example of a risk-tracking form

how much time and resources are needed to deal with these risks, and how progress will be monitored and reported. This plan enables management to decide upon the feasibility of the project and make a "go" or "no go" decision. The action plans drawn up by the subgroups are documented in risk-tracking forms (see Figure 2.9.6). These provide a framework for recording information about the status and progress of each diagnosed risk. To guarantee follow-up, besides regular monitoring and control of the project risks in project team meetings, senior management should also require formal approval of the risk management plan and verify the progress of the risk actions plans in all subsequent gate reviews.

It may be necessary to repeat the RDM for some product innovation projects. In particular, in cases where the project newness and complexity are great, modifications and unforeseen issues are almost certain to arise; this might demand reassessment of the overall risks at later stages of the project. Senior management in consultation with the project team therefore should reconsider at each stage whether to repeat the RDM process or simply to have the project team update the existing risk management plan.

2.9.4 Added Value of RDM

Evaluation studies show that professionals in the field of new product development are very satisfied with the way RDM allows them to identify, confront, and manage risks in their projects (Vuuren, 2001). Factors causing this satisfaction are, for example, that RDM helps to pull out the key risk issues and actions and to clear misunderstandings and varying interpretations about the existing project risks. Similarly the limited time that is needed to conduct the whole process, the application of the rules of engagement, and the appeal to think crossfunctionally contribute a lot to this satisfaction. Also the use of the risk reference list is evaluated positively: It stimulates the team to think more in detail about the project and to identify risks the team hadn't thought of before. RDM provides the project team with the following:

- A list of classified risks identified while there is still time.
- A risk evaluation on scenarios that can be followed.
- A plan on how the major risks will be tackled.
- A solid basis for communicating the risks, project planning, and required resources with senior management and other stakeholders.

Appendix 2.9: Reference List with Potential Risk Issues in the Innovation Process

I.	**Product family and brand-positioning risks**
1.	New product helps to achieve business strategy,
2.	Project is important for project portfolio,
3.	New product contributes to brand name position,
4.	Project includes global rollout potential and schedule,
5.	New product fits within existing brand.
6.	New product fits with brand image.
7.	New product enhances the potential of product family development.
8.	New product provides opportunities for platform deployment.
9.	New product supports company reputation.
10.	New product has brand recovery potential.
11.	New product has brand development potential.
12.	New product's platform will be accepted by consumers.
II.	**Product technology risks**
1.	New product's intended functions are known and specified.
2.	New product fulfills intended functions.
3.	In-use conditions are known and specified.
4.	Interactions of product in use with sustaining materials, tools, and so on are understood.
5.	Components' properties, function, and behavior are known.
6.	Correct balance between product components is established.
7.	Assembled product meets safety and technical requirements.
8.	Alternatives to realize intended product functions are available.
9.	New product shows parity in performance compared to other products.
10.	New product shows stability while in storage (in factory, shop or warehouse, and transportation, and at home).
11.	New product format meets functional requirements.
III.	**Manufacturing technology risks**
1.	Raw materials are available that meet technical requirements.
2.	Process steps to realize the new product are known and specified.
3.	Conditions (temperature, energy, safety, etc.) to guarantee processing of good product quality are known and specified.
4.	Production means (equipment and tools) necessary to guarantee good product quality are available.

5. Scale = up potential is possible according to production yield standards.
6. Production system requirements (quality and safety standards, training of human resources, facilities, etc.) will be met.
7. Product-packaging implications are known and specified.
8. Manufacturing efficiency standards will be met.
9. Alternative approaches to process the intended product will be available.
10. Adequate production capacity is available.
11. Adequate production start-up is assured.
12. The reusability of rejects in production is foreseen.

IV. Intellectual property risks

1. Original know-how will be protected.
2. Required external licenses or know-how is known and available.
3. Relation to legal and patent rights of competitors is known and arranged.
4. Relevant patent issues are understood.
5. Patent-crossing potential is known and arranged.
6. Trademark registration potential is known and arranged.

V. Competitor risks

1. Product will provide clear competitive advantages.
2. Introduction of new product will change existing market share positions.
3. Introduction of the new product will have an impact on market prices.
4. New product will be launched before competitors launch a comparable product.
5. Response actions toward public and media expected from competitors will be anticipated.
6. New product enables the creation of potential barriers for competitors.
7. Implications of being technology leader or follower for this project have been identified.
8. Competitor's actions will be monitored and followed with adequate response.
9. Competitor's challenges will be monitored adequately.

VI. Supply chain and sourcing risks

1. Suppliers will meet required quality.
2. Capacity available to meet peak demands.
3. Appropriate after-sales services are available.
4. Contingency options are available for each of the selected suppliers.
5. Financial position of each supplier is sound.
6. Past experiences with each of the suppliers are positive.
7. Suppliers are ready to accept modifications if required.
8. Supply contracts can be canceled.
9. Each supplier will be reliable in delivering according to requirements.
10. Required quantities will be produced for acceptable prices.
11. Appropriate contract arrangements with suppliers will be settled.

VII. Consumer acceptance risks

1. Product specifications meet consumer standards and demands.
2. New product fits consumer habits and/or user conditions.
3. New product offers unique features or attributes to the consumer.
4. Consumers will be convinced that they get value for money, compared to competitive products.
5. New product appeals to generally accepted values (e.g., health, safety, nature, and environment).
6. New product offers additional enjoyment, compared to competitive products.
7. New product will reduce consumer costs, compared to competitive products.
8. Non-intended product use by consumers is adequately anticipated.
9. Target consumers' attitudes will remain stable during the development period.
10. New product will be communicated successfully with target consumers.
11. New product will provide easy-in-use advantages, compared to competitive products.

12. Primary consumer requirements are known.
13. Target consumers will accept the new product’s key product ingredients.
14. Niche marketing capabilities are available if required.
15. Communication about new product is based on realistic product claim.
16. Advertising will be effective.
17. Product claims will stimulate target consumers to buy.
18. New product has repeat sales potential.

VIII. Trade customer risks

1. Product specifications will meet trade customer standards and demands.
2. Trade customers will welcome the new product from the perspective of potential sales.
3. Trade customers will welcome the new product from the perspective of profit margin.
4. Trade customers will welcome the new product given required surface and volume on shelf and storage facilities.
5. Trade customers’ attitudes will remain stable during the development period.
6. New product will be communicated successfully to trade customers.
7. Right distribution channels will be used.
8. Trade will give new product proper care.
9. Trade-supporting persons will endorse the new product.

IX. Commercial viability risks

1. The market target is clearly defined and agreed.
2. Market targets are selected based on convincing research data.
3. Capital cost projection for new product is feasible.
4. Delays in product launch will leave the commercial viability of the new product untouched.
5. Sales projections for new product are realistic.
6. Estimated profit margins are based on convincing research data.
7. Profit margin will meet the company’s standards.
8. The estimated return on investment will meet the company’s standards.
9. Volume estimates are based on clear and reliable estimates.
10. Product viability will be supported by repeat sales.
11. Suppliers will get attractive purchasing agreements.
12. Knowledge of pricing sensitivity is available.
13. Adequate investments to secure safety in production will be made.
14. Long-term market potential is to be expected.
15. Financing of capital investment is secured.
16. Fallback to prior product concept is feasible.

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2. Market targets are selected based on convincing research data.
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10. Product viability will be supported by repeat sales.
11. Suppliesr will get attractive purchasing agreements.
12. Knowledge of pricing sensitivity is available.
13. Adequate investments to secure safety in production will be made.
14. Long-term market potential is to be expected.

15. Financing of capital investment is secured.
16. Fallback to prior product concept is feasible.
17. New product is commercially viable in case of market restrictions.

X. Organizational and project management risks

1. Internal political climate is in favor of this project.
2. Top management actively supports the project.
3. Project goals and objectives are feasible.
4. Project team is sufficiently authorized and qualified for the project.
5. Project team will effectively utilize the knowledge and experience of (internal) experts.
6. Roles, tasks, and responsibilities of all team members are defined and appropriate.
7. Decision-making process in the project is effective.
8. Communication between members in the project team is effective.
9. Required money, time, and (human) resources estimations are reliable and feasible.
10. Required money, time, and (human) resources will be available when required.
11. External development partners will deliver in time, and conform to budget and technical specifications.
12. Sound alternatives are available to external development partners.
13. Collaboration within the project team is effective.
14. Project will effectively be organized and managed.
15. Collaboration with external parties is effective.
16. Collaboration between project team and the parent organization is effective.
17. Project team is highly motivated and committed.
18. Project team is paying attention to the right issues.
19. Project has effective planning and contingency planning.
20. Project team is learning from past experiences.

XI. Public acceptance risks

1. It is clearly understood who is responsible for the public relations of the project.
2. The key opinion formers for the new product are known.
3. Support of key opinion formers will be assured.
4. Legal and political restrictions will be adequately anticipated.
5. Environmental issues will be adequately anticipated.
6. Safety issues will be adequately anticipated.
7. Possible negative external reactions will be effectively anticipated.
8. In case of new technology, prior (external) experience will be consulted.

XII. Screening and appraisal

1. New product performance targets will be tested and measured adequately.
2. Trade customer appreciation will be tested and measured adequately.
3. Consumer appreciation will be tested and measured adequately.
4. Adverse properties as a consequence of the technological change will be tested and measured adequately.
5. Credibility of the (internal) measures to external agencies is warranted.
6. Tests will provide reliable evidence.

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2.10 A Multilevel Design Model Clarifying the Mutual Relationship between New Products and Societal Change Processes

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2.10.1 Introduction

Designers working on the development of sustainable and energy-efficient products inevitably run into issues such as user acceptance, infrastructural integration, or governmental regulations. Although such topics may not be part of their specific expertise, these issues cannot be ignored during the design process. First, this is because societal issues largely determine the development of many energy-efficient products, for instance through public awareness regarding the depleting resources of fossil fuels and the availability of sustainable energy technologies. Secondly, these issues cannot be neglected because the successful implementation of many energy-efficient products is largely determined by existing frameworks such as infrastructures and legal regulations, as well as other aspects that cannot be directly influenced by an individual designer. This means that the broader context in which new products will be functioning has to be considered during the design process (Joore, 2008, 2010). To support designers and to demarcate their efforts, it is necessary to structure the design process and the role of designers in such a way that the mutual relationship between new products and the sociotechnical or societal context in which these products function is taken into account in a systematic manner.

2.10.2 A Multilevel Design Model

In 2010 a new multilevel design model (MDM) was published (Joore, 2010) that may help to clarify this relationship between physical artifacts, on the one hand, and more intangible societal topics, on the other. The MDM combines two types of models that will be described in this section. The first group of models originates from the field of industrial design engineering and systems engineering, for instance the V-Model that is often used during the development of complex technological and software systems (KBST, 2004). Although these models may offer sufficient insight into the technological aspects of a design process, they are often formulated around the development of one single product or system, such that the broader sociotechnical and societal aspects are not sufficiently addressed.

The second group of models originates from the area of sustainable systems innovations and transition management. Here we refer to a dynamic multilevel model developed by Geels (2005) and methods like constructive technology assessment (CTA) and the innovation journey, which are described in detail in elsewhere in this section. These models offer a detailed insight into the interrelationships between innovations and their sociotechnical and societal contexts, However, these models often are based on qualitative and descriptive research and a high abstraction level, whereas the embedding of the model's outcomes toward the practice of industrial product development has not yet been formalized by a standardized design method.

Combining both groups of models leads to the MDM, which can be considered a descriptive multilevel systemic approach combined with a prescriptive design process. The design process consists of four phases: (1) experience, (2) reflection, (3) analysis, and (4) synthesis. This process is applied to four aggregation or system levels, being described as the (1) product–technology system (indexed by *P*), (2) the product–service system (indexed by *Q*), (3) the sociotechnical system (indexed by *R*), and (4) the societal system (indexed by *S*). Figure 2.10.1 shows a scheme with these four design steps in relation to the system levels and the multilevel design model. This figure also shows for each system level the envisioned transformation processes (T_S, T_R, T_Q, and T_P) between objectives at each system level (S2′, R2′, Q2′, and P2′) toward new situations, systems,

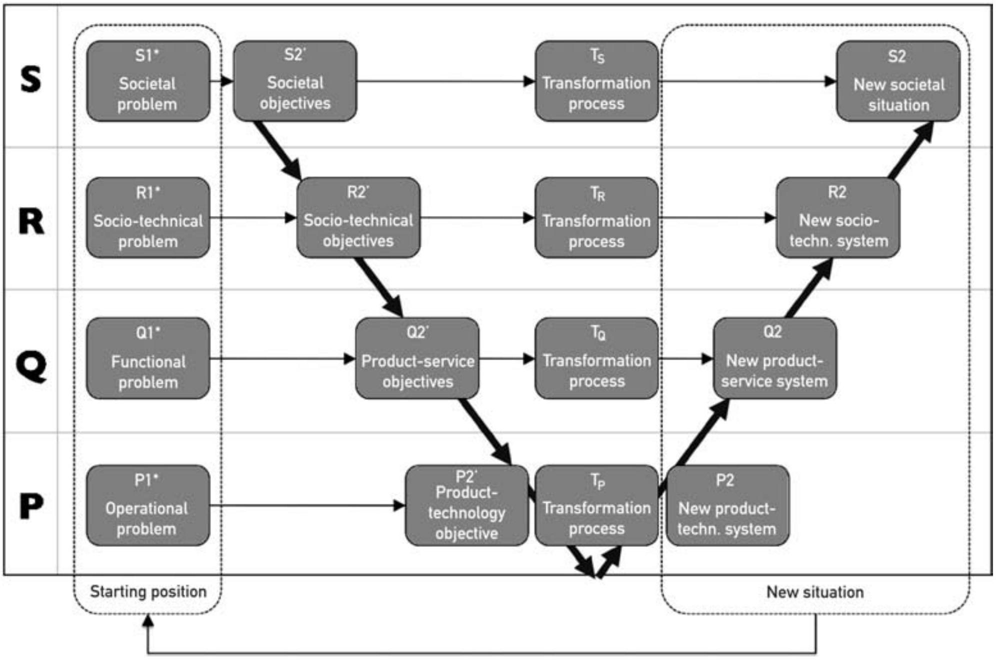

Figure 2.10.1 Multilevel design model (Joore, 2010, 88)

Table 2.10.1 Explanation of the multilevel design model

Design phase System level	Experience Starting position, characteristics of current system (not represented in Figure 2.0.1)	Reflection Value judgment regarding starting position, problem definition	Analysis Objectives and criteria for new (sub)system	Synthesis Design, creation of new (sub)system	Experience Characteristics of new (sub)system
Societal system (S)	S1: properties of society, measured with Environmental Sustainability Index or Quality of Life Index	$S1^*$: value judgment regarding societal situation, definition of societal problem	$S2'$: preferences regarding social order, based on worldview and values, resulting in objectives for ideal new societal situation	Ts: vision development process, resulting in future vision for new societal situation	S2: living in society, executing societal experiment
Sociotechnical system (R)	R1: properties of current sociotechnical system	$R1^*$: value judgment regarding sociotechnical situation and system deficiency	$R2'$: dominant interpretative framework, leading to objectives for new sociotechnical system	Tr: system design process, leading to proposal for new sociotechnical system	R2: experiencing new sociotechnical system, for example by means of niche experiment
Product–service system (Q)	Q1: properties of current product–service system	$Q1^*$: value judgment regarding functioning of product–service system, resulting in functional problem	$Q2'$: determining functional demands and requirements to be met	Tq: design of a new product–service system	Q2: using and experiencing new product–service system
Product–technology System (P)	P1: properties of current product–technology system	$P1^*$: value judgment regarding functioning of product–technology system, definition of operational problem	P2: target definition regarding new product and technology, leading to program of demands	Tp: product design process, leading to (prototype of) new product–technology system	P2: simulation, testing, using and experiencing new product

and products and services (S2, R2, Q2, and P2). The objectives are based on the experience of and reflection on existing problems at each level ($S1^*$, $R1^*$, $Q1^*$, and $P1^*$). The meaning of the symbols used in the MDM is further explained in Table 2.10.1.

To emphasize the difference in size or dimension of the system at the various levels, the model resembles a V-shape. Arrows in this V-shape indicate the relations that occur at and between various levels. At each level an identical process is presented. Only the width of the various layers differs, creating the characteristic V-shape. The main difference compared to the V-model used in systems engineering is the fact that sociotechnical and societal issues are explicitly part of the MDM.

2.10.3 Example Based on the Development of an Electrical Transport System

The MDM can be clarified by comparing the design of an electric transport vehicle, a transport service, and a regional transport system. The choice to use examples from this domain is made because the field of transport is complex enough to visualize the various aspects of the MDM, while the area of transportation also covers many energy issues. The example is visually represented in Figure 2.10.2.

Level P: The Product–Technology System

Products form the basic level of the MDM. These can be defined as “physical objects that originate from a human action or a machine process.” As these objects are made up of technical components, the term *product–technology system* is being used. However, to improve readability we will generally refer to these as *products*. Products refer to tangible, inextricably linked technical systems, physically present in place and time. With most of these artifacts, you could “drop them on your toes.” Product–technology systems generally fulfill one clearly distinguishable function. A system dysfunction occurs as soon as one or more technical components are missing.

An electric vehicle or a battery-charging station is an example of a product–technology system. The vehicle is discernible in place and time and fulfills a clearly defined primary function aimed at transporting people or things. As soon as certain technical components are missing, the product ceases to function as such, for example with a flat tire or an engine that is out of order. The direct relationship with the vehicle as a product–technology system is limited to individual persons, such as the driver, passengers, and maintenance mechanic.

Level Q: The Product–Service System

The second level of the MDM is formed by product–service systems. These can be defined as “a mix of tangible products and intangible service designed and combined so that they jointly are capable of fulfilling final customer needs” (Tukker and Tischner, 2006, p. 24). A product–service system is built up of physical as well as organizational components, which form a united and cohesive whole that together fulfills a specific function, usually definable in time and place. The system fulfills one or more clearly defined functions that can no longer be performed if one of the technical or organizational components is missing. The product–service system can indeed be compatible with certain policy, legal, social,

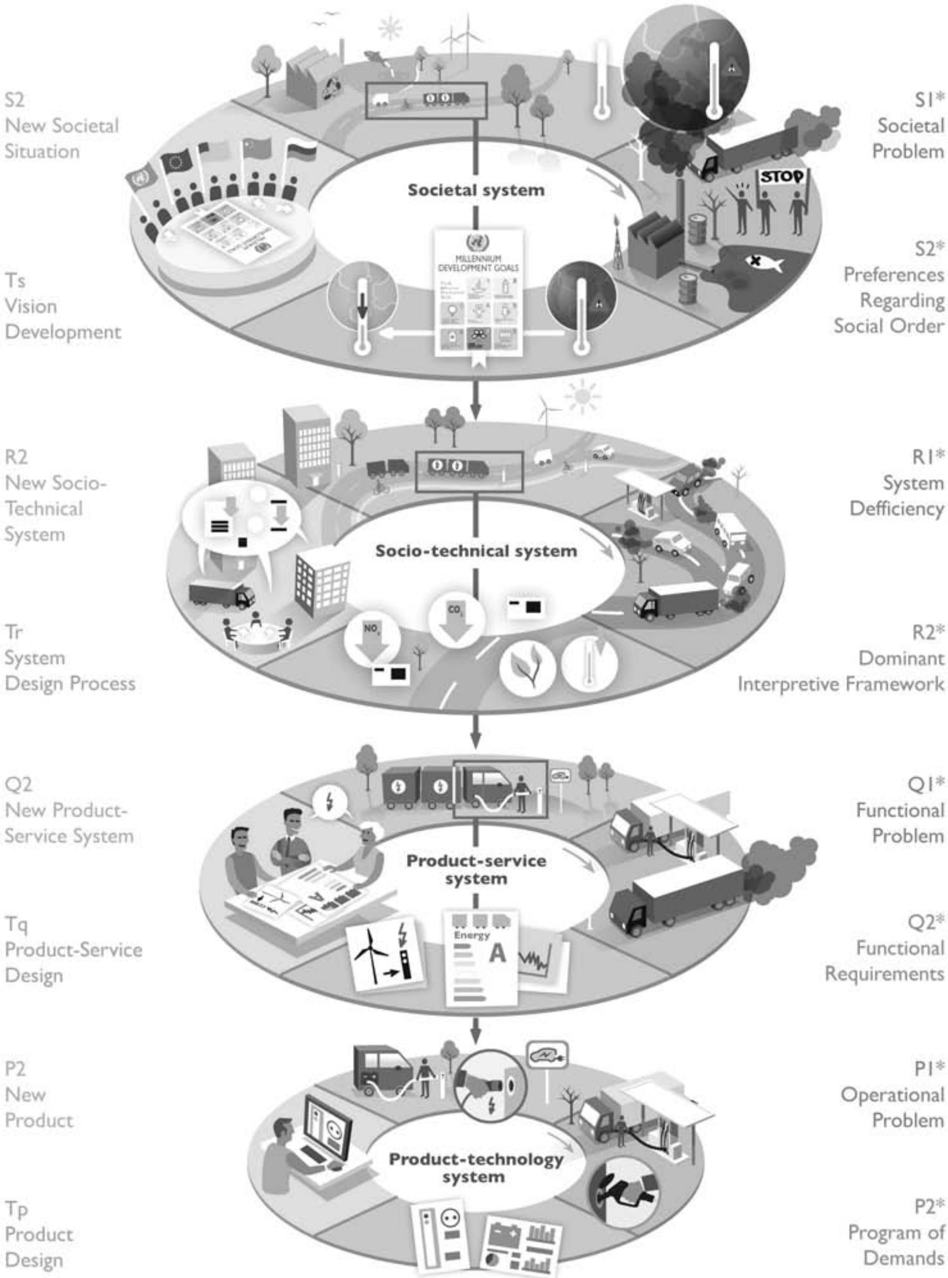

Figure 2.10.2 Multilevel representation of the electric transport case (See Plate 19 for the colour figure)

cultural, or infrastructural elements, but these do not form an inextricable part of the product–service system.

An example of a product–service system is an electric transport service, which is made up of technical as well as organizational components. If, for example, the truck driver is missing or business problems occur, the transport service may no longer work. The product–technology system "electric vehicle" may still be able to function perfectly well, but the product–service system "transport service" no longer works. To function properly, good roads and corresponding traffic regulations are necessary. When using electric vehicles, battery-charging units may be essential. However, these do not form an inseparable component of the product or the service itself, but they are part of the even larger "sociotechnical system."

Level R: The Sociotechnical System

The third level of the multilevel design model is the sociotechnical system. This can be defined as "a cluster of aligned elements, including artifacts, technology, knowledge, user practices and markets, regulation, cultural meaning, infrastructure, maintenance networks and supply networks, that together fulfill a specific societal function" (Geels, 2005). Changes that take place at this level are often referred to as a *system innovation*, which can be defined as "a large scale transformation in the way societal functions are fulfilled. A change from one socio-technical system to another" (Elzen, Geels, and Green, 2004, p. 19). At this level a large number of components are combined that are not necessarily formally related to each other. Several elements together form a joint system that fulfills a combination of functions that have a narrow, joint relationship with each other. Product–service systems, accompanying infrastructure, government legislation, and cultural as well as social aspects may form a mutually interdependent whole. In contrast to the first two levels, the sociotechnical system continues to function if one or more elements are missing, and elements may even assume each other's function.

In this way, road transport can be considered a sociotechnical system, where transport vehicles, rental trucks, freight trains, and other means of transport meet each other on public roads. They are joined there by buses, pedestrians, and cyclists. Other elements that are part of this system are the traffic rules, the insurance and licenses that a company must have, the fuel stations, the price that is paid for that fuel, the availability of parking places, and the attitude of citizens toward the various forms of transportation. In case of the introduction of electric transport, electric battery-charging points may need to be introduced as new parts of the sociotechnical system.

In case one of these subsystems fails, its function can be taken over by another subsystem. If the buses stop running, people will take the bicycle. If diesel becomes too expensive, people will buy a car that runs on gasoline. However, switching to electric transport may not be so easy, as battery-charging points are currently hardly available. Even so, the current position of fuel stations is not suitable to place these battery-charging points, as they are often located in rather remote areas. While this is no problem when filling up a tank of gasoline in a few minutes, these remote areas are not very attractive when waiting several hours for a battery to be charged. Here, government may play an intermediary role, for instance when deciding to support the placement of battery-charging points in inner-city areas. However, even when supported by policy regulations it will still take a substantial amount of time until these battery-charging stations are as readily available as regular fuel stations. This example shows that changes at the sociotechnical level often take more time and have a greater societal impact than changes at the level of individual product–service systems.

Level S: The Societal System

The highest level of the MDM is being defined as the *societal system*, being "the community of people living in a particular country or region and having shared customs, laws, and organizations" (*Oxford Dictionary*). This is, just like the previous level, built up from a combination of material, organizational, policy, legal, social, cultural, or infrastructural elements. Changes that take place at this level are often referred to as a *transition*, which can be considered "a gradual, continuous process of societal change, where the character of society (or of one of its complex subsystems) undergoes structural change" (Rotmans *et al.*, 2000, p. 11).

Whereas the sociotechnical system can more or less be defined and demarcated, at the societal system level a complete summary can no longer be made of which elements do or do not make up the components of the system. It extends over several influence spheres and domains, and the boundary between these areas cannot easily be determined. Also the societal system does not fulfill one distinct function, but is made up of functions that are not necessarily related.

An example of development on the society level is the influence of the sociotechnical system "road transport" on other sectors. Noise pollution and toxic emissions as a consequence of road transport affect the health of people, including when these people are not part of the transport system. The transport system can function perfectly even when everybody who lives along highways becomes ill. This indicates that this problem is apparently located at the societal system level and can no longer be resolved within the boundaries of one delimited sociotechnical system.

2.10.4 Benefits for the Design Process

The examples given in this section show that the development of new energy-efficient products, for example a new electric transport vehicle, is very much interwoven with development in the broader system context in which the new product will be functioning. If no battery-charging points are available, the acceptance of electric vehicles will be hindered. At the same time, companies will invest in the development and placement of battery-charging points only when a substantial amount of electric vehicle owners are willing to pay for their use. In other words, especially at the higher system levels there may often arise a "chicken–egg" situation that may hinder the introduction of new sustainable and energy-efficient products.

The use of the MDM may not solve these chicken–egg dilemmas. However, they may help the designer to demarcate the scope of a specific design process in which he or she is involved. Consciously distinguishing between the various system levels may help designers to determine what projects may suit their specific expertise. For instance, the designer of a new electric vehicle must know everything about engineering, materials, production processes, draft angles, and other technological details. The designer of a transport service doesn't necessarily need to bother about the design of the physical artifact. Here it is more about business model generation and developing innovations in which the vehicle has become part of a broad “transport solution.” At a still higher level it can then be about the development of a future vision of the way mobility will develop in a wider sense during the next 10 years, and the way that policy measures may influence this development. It seems obvious that the designer who is skilled in designing the technical details of a new vehicle does not necessarily require the same qualities as the designer who is skilled in the development of a “transport solution” or a future vision aimed at what mobility will look like in the year 2020.

Secondly, distinguishing between the various system levels may help designers to determine the design methods that are most suitable for a specific project. The manner in which the design process progresses at the level of the product–technology system appears to be mostly in keeping with the various models in the areas of industrial design engineering and system engineering. At the product–service level, the way in which the design process progresses appears to be mostly in keeping with the various models in the areas of sustainable product development, as these models have a rather strong focus on the organizational aspect. Change processes that take place on the sociotechnical level appear to be mostly in keeping with the various models in the field of sustainable system innovations and transitions. Here it is usually a matter of slowly progressing, difficult-to-direct developments. At the societal level, it is also usually a matter of progressing, difficult-to-direct developments, so the question is of course if it is at all possible to speak about a “design process” at all.

Thirdly, distinguishing between the various system levels may help designers to determine the way that a certain design should be tested. Testing a new technological product can often be done in a laboratory setting, with users commenting on the design in a protected environment. Trying a new transport service probably needs a broader setting, perhaps introducing the service for several weeks or months in a small-scale experiment in a dedicated environment. Finding out the effect of certain sociotechnical or societal system changes would need even more time, so that the impact of specific interventions (like the introduction of a certain policy regulation) can be measured over a longer period of time. Here the concept of a strategic niche experiment of bounded sociotechnical experiment (Brown *et al.*, 2003) may be useful.

Fourthly, distinguishing between the various system levels may help to determine which actors to involve during the design process. As for the involvement of actors and designer, at the product–technology level it is generally a matter of a limited group of actors who are in direct contact with the product. In most cases, one organization can be identified that delivers the product. At the product–service level, the relationship with actors is mostly restricted to a limited number of parties that are usually in a formal or legal relationship, for example as consumer-suppliers or as formally cooperating partners. At the sociotechnical level, agreements between actors are less tightly defined, although they can be formalized collectively, for example in the form of legislation, regulation, or collective standardization. At the societal level, the influence of the system extends to all sorts of parties that do not maintain any deliberate relationship with each other, but become implicitly related as developments touch several sectors of society.

2.10.5 Conclusions

In this section the MDM has been described, and I have clarified the design specified process by distinguishing four separate system or aggregation levels. Distinguishing between these levels may help designers of sustainable and energy-efficient products to execute the design process more effectively. Firstly, it may help them to determine the specific skills that may be required for a certain design project, asking themselves if a certain project indeed matches their specific expertise. Secondly, it may help them to determine the design methods that are most suitable for a specific project. Thirdly, it may help them to determine the way that a new design should be tested, choosing for instance between short-term in-house laboratory experiments or long-term sociotechnical experiments. Fourthly, it may help them to determine which actors to involve during the design process.

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