1 Introduction

Technology is as old as mankind. Myriad small and large innovations have shaped the world, and are molding the future of civilization. The prevailing majority of these innovations have been developed haphazardly; their creators have not used any organized approach to finding new ideas. Despite the great past achievements of a random approach to innovation (the wheel, the automobile, the radio, the airplane, the computer, antibiotics, to name just a few), that approach has become increasingly inefficient in today's fiercely competitive marketplace. This chapter shows the principal shortcomings of *random innovation*, and the need to replace it with a method of *systematic innovation*.

1.1 Product development process

Every new product – whether the "product" is a technology, a device or a production process – originates from a new concept. To become a product, a concept must be generated, then evaluated and, finally, developed. This flow of activities constitutes the *product development process* (*PDP*) (Fig. 1.1).

The process begins with the recognition of a *need*. Then, the designer must transform this need into a *clearly defined problem*, or a set of problems. The output of this stage is a problem(s) statement accompanied by a list of various constraints (e.g., performance specifications, manufacturing limitations, economic conditions, statutory restrictions, etc.).

In the next phase, various *conceptual solutions* to the problem(s) are generated. Here, the most important *decisions* are made which bring together engineering, production, and commercial aspects of the problem.

In the following phase of the process, the generated *concepts* are evaluated against various criteria, and the most promising ones are selected for designing a *prototype*. The prototype is then built and *tested*. During this process, necessary corrections are usually made to the conceptual solution.

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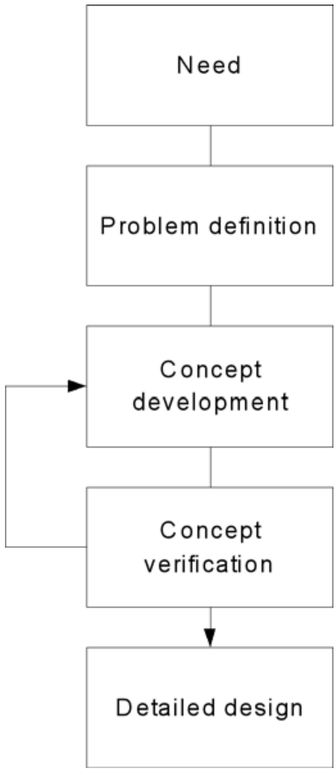

Fig. 1.1. Phases of a typical product development process.

Finally, in the *detail design phase*, the design is fully developed and the dimensions of all the components are determined, the materials specified, etc. Then, detailed drawings are produced.

Modern engineering sciences possess an extensive arsenal of powerful analytical methods and software tools for the efficient evaluation of new concepts, and the development of these concepts into successful processes or product lines. This arsenal has a centuries-long history of gradual evolution.

In the past, there was no other way to test an attractive idea, than to practically try it. Almost all basic chemical compounds have been obtained through a tremendous amount of blind testing by alchemists. Even Thomas Edison, while working on the design for the incandescent bulb, would perform over 6000 experiments with a vast variety of materials before settling on a satisfactory filament.

As science and technology continue to develop, the boundary between what is feasible and what is not becomes better understood. Many products, processes and their environments can, today, be reasonably well simulated. Nowadays, the chemical industry brings numerous new compounds to market every year. This could not be possible without well-developed theoretical methods for rational analysis and synthesis of proposed formulations. While working on a problem, an engineer can filter out weak concepts by using knowledge obtained from basic education, from his or her experiences and those of his or her predecessors, from information in patent and technical literature and, of course, by using computer-based systems such as computer-aided design (CAD), computer-aided manufacturing (CAM), finite element analysis (FEA), computational fluid dynamics (CFD) and others that substantially facilitate the product development process.

1.2 Stumbling blocks in PDP

The least understood and, therefore, often poorly managed first two phases of the product development process are *identification of a need* and *concept development*.

1.2.1 First stumbling block: technology strategy

The first phase – need identification – is, in addition to the market research, also the process of defining a technology strategy. The key question here is (or should be): "*What is the next winning technology to satisfy the potential or perceived market need?*" Answering this question requires a very good understanding of the trends of technology evolution.

In today's fiercely competitive market, manufacturing companies have to gamble their future on the market's next wide acceptance of a product or a technology innovation. They have to figure out what this "winning" innovation will be so as to better allocate adequate financial backing, manpower and other resources. Mistakes in making predictions result in yielding the advantage to competitors.

In 1990, U.S. Steel, then a leader in the American steel market, had a choice of investing in either the conventional hot-rolling technology or in a new compact strip production (CSP) technology. U.S. Steel decided to further improve the well-established, hot-rolling technology. Their competitor, Nucor Steel, funded the development of CSP. Today, Nucor is the leading US steel producer while its formerly formidable competitor is largely marginalized in the marketplace (Cusumano & Markides, 2001).

The two giants of film-based photographic equipment, Kodak and Polaroid, did not recognize the emergence of digital imaging technologies. They each received brutal blows from competitors that pioneered products employing those technologies (Leifer *et al.*, 2000).

Chester Carlson, the creator of xerography, offered his invention to dozens of companies. Each and every one of them turned him down, thus missing out on one of the most successful business opportunities of the twentieth century.

In 1992, start-up Palm, Inc. developed the prototype for its Palm Pilot. The gadget, however, did not excite venture capitalists in Silicon Valley. They saw it as just another personal digital assistant (similar to Hewlett-Packard's Psion, Apple's Newton, and

Windows CE PCs) and refused to fund bringing it to the market (Penzias, 1997). Unable to raise money on their own, Palm became a subsidiary of U.S. Robotics in 1995. Shortly thereafter, the Palm Pilot became hugely successful. Today Palm is again an independent and thriving company offering an impressive array of state-of-the-art handhelds and accessories.

The list of companies that lost their competitive position to more innovative rivals can be easily extended, but so can be the list of successful, "winning" products and technologies that did not have the initial support of management, or of the financial community.

Many business publications and consultants praise market research as the most reliable way to assess the market viability of emerging innovations. While various market research techniques often prove to be very useful for incremental improvements, they often mislead when used to appraise breakthrough innovations.

In the late 1960s, Corning became interested in a promising low-loss optical fiber technology. The company consulted with AT&T – an obvious potential customer – as to the prospects for this technology. AT&T guesstimated that a noticeable need for optical fibers would arise only in the first decade of the twenty-first century. Corning, however, was much more optimistic and set off on the development of this technology. The company had its major commercial success with MCI in the early 1980s (Lynn *et al.*, 1997).

The inability of even the best experts to predict the future of technology is illustrated by the following often-quoted phrases.

- "Heavier than air flying machines are impossible," Lord Kelvin, President of the Royal Society, 1885.
- "Everything that can be invented has been invented," Charles H. Duell, Director of the US Patent Office, 1899.
- "Who the hell wants to hear actors talk?" Harry Warner, Warner Brothers, 1927.
- "There is a world market for maybe five computers," Thomas Watson, Chairman of IBM, 1943.

A more recent example: Bill Gates could not foresee the rise of the Internet.

Hindsight is always 20/20, but how can we make sure that the products or technologies being pursued now are the ones that the market will need? How can we choose the best solutions? What are the criteria that will allow us to select the most promising concepts? Conventional approaches to the identification of next-generation winning products and technologies cannot provide reliable answers to these questions. The TRIZ perspective on these questions is addressed in Chapters 5 and 6.

1.2.2 Second stumbling block: concept development

Today, just as for many centuries, novel ideas in engineering (as well as in other areas of human activity) are mainly produced by the *trial-and-error* method. The essence of this method is a persistent generation of various ideas for solving a problem. There are

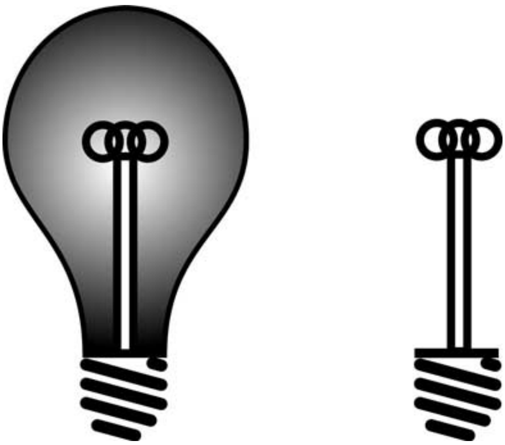

Fig. 1.2. Absent glass cannot break.

no rules for idea generation, and the process is often stochastic. If an idea is weak, it is discarded and a new idea is suggested. The flow of ideas is uncontrollable, and attempts (trials) are repeated as many times as is needed to find a solution.

Although seemingly random, most trials have a common attribute: they are more numerous along a so-called vector of *psychological inertia.* This inertia is determined by our cultural and educational backgrounds, previous experiences and "common sense." More often than not, psychological inertia is created by a deceptively innocuous question, *"How?"* (e.g., "how to fix this problem") that nudges the problem-solver toward traditional approaches, dims the imagination and is a key hurdle on the track to the best solution. In fact, the best solution often lies elsewhere, in territories that our common sense deems useless.

Example 1.1

A classic example relates to the psychological inertia of "rocket scientists," supposedly the most educated, sophisticated and innovative of all engineers. In the 1970s, the United States and the Soviet Union fiercely competed in the area of Moon exploration. Unable to afford the costs of an Apollo-like project for landing astronauts on the Moon, the Soviet Union decided to launch an unmanned lunar probe to deliver an autonomous vehicle to the back (dark) side of Moon's surface. The vehicle was to transmit TV pictures of that not-yet seen side to Earth. The incandescent light bulb was found to be the best light source, however existing light bulbs would not survive the impact of landing on the lunar surface. Even the most durable bulbs, those used in military tanks, cracked at the joint between the glass and the socket during tests.

A major effort was started to figure out *how* to strengthen the glass bulb. The situation was reported to the director of the whole Moon-landing project. His first question was: "*What* is the purpose of the bulb?" The answer was obvious – to seal a vacuum around the filament. However, there is an abundance of perfect vacuum on the Moon! This simple question solved the problem – no glass bulb was needed (Fig. 1.2).

Table 1.1. *Muffler alternatives*

Type of muffler	Cost ($)	Noise level (dB)	Back pressure (psi)
A	60	79	7.65
B	90	79	7.40
C	60	82	7.40
Targets	60	79	7.40

Example 1.2

A team of seasoned automobile designers was developing an exhaust system for a new truck. Specifications contained various performance and economic criteria, the most important ones being the noise level, back pressure (affecting the engine's efficiency) and cost. All of these attributes are largely influenced by the specific design of the muffler. There was no commercially available muffler that would meet all the target criteria, so for several months (!), the design team brainstormed the solution space, searching for an adequate muffler design.

Various solutions on *how* to improve the muffler designs were proposed, but none complied with the targets. Three alternative muffler designs A, B, and C that offered the parameters closest to the specifications were identified (Table 1.1). Only the very expensive muffler B had an acceptable technical performance, but its cost was excessive by a large margin. The new truck had to be launched, and budget-breaking muffler B was grudgingly approved.

Relief came unexpectedly from two young co-eds who, at the time, were taking the TRIZ class at Wayne State University. Analysis of the situation by TRIZ methods lead them to question *what* had to be achieved. The existing noise regulations address not the system components (muffler), but the noise exposure of a person on a sidewalk (Fig. 1.3a). Accordingly, the co-eds suggested adopting muffler C, but modifying another part of the exhaust system so as to meet the noise-level specifications. The solution was very simple and elegant.

While the original exhaust system was equipped with a straight tail pipe, essentially aiming towards the microphone, the co-eds bent the end of the pipe downward (Fig. 1.3b); now the sound, produced by the exhaust, does not affect the by-stander (and the measuring microphone), but is deflected to the ground.

Experiments showed that this solution met all the required criteria, and it was immediately implemented.

The fact that such simple solutions in both examples were missed, illustrates the obstructing power of psychological inertia.

The trial-and-error method results in valuable time being wasted when searching for solutions to difficult problems. Damages from the hit-and-miss approach are associated

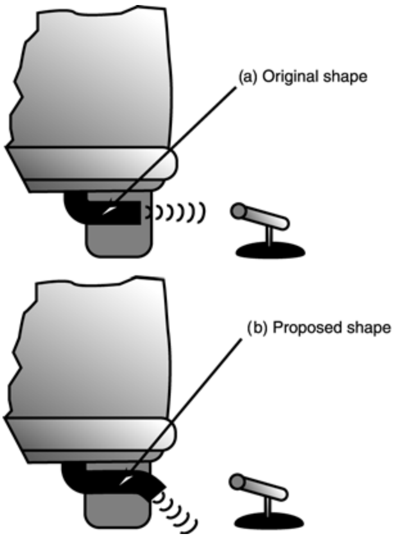

Fig. 1.3. Exhaust system modification.

with lost competitiveness and a waste of manpower and financial resources. Nor does it help that the random generation and selection of concepts fails to provide for the experience gained by solving one problem, and utilizing that experience to solve other problems.

Accordingly, the need for improving the concept generation process has long been necessary (some pre-TRIZ methods for creativity enhancement are described in Appendix 2).

1.3 TRIZ

The *Theory of Inventive Problem Solving* (*TRIZ*), developed by Genrikh Altshuller (Altshuller and Shapiro, 1956; Altshuller, 1994, 1999), states that while the evolution of technology is apparently composed of haphazard steps, in the long run it follows repeatable patterns. These patterns can be applied to the systematic development of technologies – both to solving product design and production problems and to the development of next-generation technologies and products.

TRIZ deals not with real mechanisms, machines and processes, but with their models. Its concepts and tools are not tied to specific objects and, therefore, can be applied to the analysis and synthesis of any technology regardless of its nature. TRIZ also treats all products, manufacturing processes and technologies as *technological systems* (more on that in Chapter 2).

The premise of TRIZ is that *the evolution of technological systems is not random, but is governed by certain laws.*

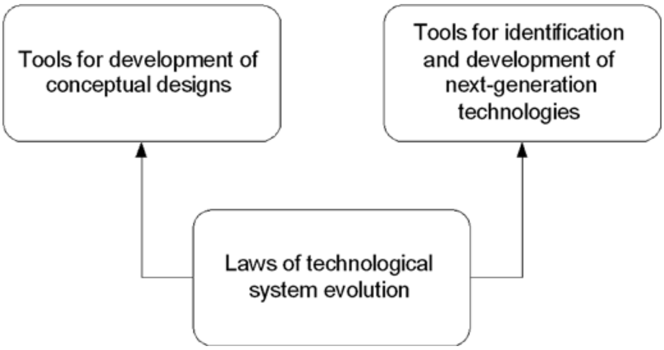

Fig. 1.4. Structure of TRIZ.

Knowledge of these laws allows the anticipation of the most likely next steps that the evolution of a technology will take. It also helps design better systems faster, without wasting time and resources on a random search for solutions.

One can draw an analogy between the use of the laws of technological system evolution (laws of evolution, for short) and the laws of mechanics. If the position of a moving object is known for a certain moment of time, its future position can be found by solving the corresponding equations of motion. The laws of evolution serve as "soft equations" describing the system's "life curve" in the evolution space. If the current system configuration is given, the future configurations can be reliably "calculated" (forecasted).

The name, *Theory of Inventive Problem Solving*, reflects Altshuller's initial intention when developing TRIZ. He wanted to replace the uncertainty of the trial and error process with a structured approach to resolving difficult engineering problems. However, the logic of research led him to develop a methodology that far exceeds the needs of immediate problem solving and allows for prediction of future challenges and, often, for their resolution.

Contemporary TRIZ is both a theory of technological evolution and a methodology for the effective development of new technological systems. It has two major subsystems based on the laws of technological system evolution: a set of methods for developing conceptual system designs, and a set of tools for the identification and development of next-generation technologies (Fig. 1.4).

Logically, the next chapter should describe the laws of evolution, since they constitute the foundation of TRIZ. From a pedagogic perspective, however, it is more beneficial to first introduce the concept development tools of TRIZ. To resolve this dilemma, the presentation of the laws of evolution is split into two parts. In this chapter, the laws are only briefly summarized, so that the reader may refer to them while learning the problem analysis and concept development tools (Chapters 2–4). A comprehensive discussion of the laws and their uses is given in Chapters 5 and 6.

1.3.1 Overview of the laws of evolution

The following laws of evolution have been formulated to date:

- law of increasing degree of ideality
- law of non-uniform evolution of subsystems
- law of transition to a higher-level system
- law of increasing dynamism (flexibility)
- law of transition to micro-level
- law of completeness
- law of shortening of energy flow path
- law of increasing substance–field interactions
- law of harmonization of rhythms.

The *law of increasing degree of ideality* states that *technological systems evolve toward an increasing degree of ideality*. The degree of ideality is essentially the benefit-to-cost ratio. The capabilities of various products (e.g., cell phones, computers, cars) are endlessly increasing, while their prices fall. Systems with a higher degree of ideality have much better chances to survive the long-run market selection process, i.e., to dominate the market.

The *law of non-uniform evolution of subsystems* states that *various parts of a system evolve at non-uniform rates*. This creates *system conflicts*, which offer opportunities for innovation. When improving a system by conventional means, one system's attribute is usually improved at the expense of deteriorating another attribute (e.g., the enhancement of dynamic characteristics of a car by equipping it with a more powerful engine at the expense of increased fuel consumption). Such a situation is called a *system conflict.* While conventional design philosophy urges the designer to seek the least expensive compromise, Altshuller found numerous methods for overcoming system conflicts, i.e., for satisfying both conflicting requirements.

Technological systems evolve in a direction from mono-systems to bi- or poly-systems (the *law of transition to higher-level systems*). Systems usually originate as mono-systems designed to perform a single function, and then gradually acquire capabilities to perform more, or more complex, functions. For example, a pencil (mono-system) → pencil with eraser (bi-system) → set of pencils of various hardness, various colors, etc. (poly-system). Eventually, the bi- and poly-systems may merge into a higher-level mono-system performing more complex functions.

According to the *law of increasing dynamism* (*flexibility*) rigid structures evolve into flexible and adaptive ones. A new system is usually created to operate in a specific environment. Such a system demonstrates the feasibility of the main design concept, but its applications and performance parameters are limited. In the course of evolution, the system becomes more adaptable to the changing environment.

The *law of transition from macro- to micro-level* states that *technological systems evolve toward an increasing fragmentation of their components*. In other words, shafts, wheels, bearings and other "macro" components are gradually replaced with molecules, ions, electrons, etc. that can be controlled by various energy fields. The evolution of cutting tools is an example of such a transition: from metallic cutters to electrochemical machining to lasers.

The *law of completeness* states that an autonomous technological system has four principal parts: working means, transmission, engine and control means. At early stages of the development of technological systems, people often perform the tasks of some of these principal parts. As the systems evolve, the "human components" are gradually eliminated. In a system "photographic camera", an object to control is the light, a working means is a set of lenses, and a focus-adjusting mechanism is a transmission. In manual cameras, the user's hand serves as both the engine and control means. Automatic cameras use an electric motor and a microprocessor to adjust the focus.

Technological systems evolve toward shortening the distance between the energy sources and working means (the *law of shortening of energy flow path*). This can be a reduction of energy transformation stages between different forms of energy (e.g., thermal to mechanical) or of energy parameters (e.g., mechanical reducers, electrical transformers). Transmission of information also follows this trend.

As its name suggests, the *law of increasing controllability* captures the evolution of controlled interactions among the systems' elements.

The *law of harmonization* states that *a necessary condition for the existence of an effective technological system is coordination of the periodicity of actions (or natural frequencies) of its parts.* The most viable systems are characterized by such a coordination of their principal parts when actions of these parts support each other and are synchronized with each other. This is very similar to production systems, in which "just-in-time" interactions between the principal parts of the manufacturing sequence result in the most effective operation. If the synchronization principle is violated, then the system's components would interfere with each other and its performance would suffer.

1.4 Summary

Today's market demands unique innovations that provide a conspicuous value to the customer. Companies must meet that challenge with fewer resources, at the lowest cost, with higher quality, and with shorter design cycle times. Conventional approaches to such unconventional demands simply will not get the job done. Systematic innovation in products and processes is an imperative for competitive leverage. Such innovation is possible only if the approach to its generation is equally unconventional. TRIZ is such an approach. It does not rely on psychological factors; it is based on the discovery of repeatable, and therefore predictable, patterns in the evolution of all technological systems (laws of technological system evolution). These patterns help engineers solve complex product design and production problems efficiently and economically.