# An Application of Directed Evolution™

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## Abstract

Technological Forecasting reports the probabilities of certain design parameters falling within particular confidence intervals at some future time. TRIZ Forecasting, based on classical TRIZ, is a proactive approach to forecasting developed during the 1970s. Using the Patterns of Evolution of Technological Systems, TRIZ Forecasting identified critical design advances for future products and processes in order to narrow the field of parameters and define a tighter range for confidence levels. Over the last two decades the Kishinev TRIZ School continued the overall advancement of TRIZ as well as TRIZ Forecasting. By 1995, TRIZ Forecasting had developed into **Directed Evolution™** -- an application of the Ideation/TRIZ Methodology (I-TRIZ). This improvement, which incorporated several hundred Lines of Evolution, constitutes a process for identifying comprehensive sets of potential evolutionary scenarios. Now, tomorrow's best designs can be created today.

A case study uses the TRIZ Forecasting application to improve an endoscopic surgical instrument for a major medical device manufacturer, then shows how Directed Evolution™ creates a design for the future. A four-stage Directed Evolution process is presented.

**Key Words:** Directed Evolution, Endoscopic, Evolution, Future Designs, Patents, Patent Fences, Patterns of Evolution, Ideality, Ideation International Inc., Innovation, Lines of Evolution, Product Evolution, S-Curve, Solution Concepts, Surgery, Sutures, Systems Life Cycle, Technological Forecasting, TRIZ (Theory of Innovative Problem Solving).

## Introduction – Technological Forecasting, TRIZ Forecasting, and Directed Evolution™

It is self-evident that technology is a major governing force in economic activity. Advanced recognition of feasible technological developments and emerging innovations that will shape the future are extremely import to industrial, financial and social enterprises. Since the mid-1950s, Technological Forecasting has been used to anticipate future development patterns. It has since evolved to include trend exploration, morphological modeling, the Delphi process, and several probabilistic modeling systems.

Another forecasting method – TRIZ Forecasting – was a natural outgrowth of the TRIZ research in the Patterns of Evolution of Technological Systems. (These patterns were discovered as the result of a rigorous analysis of hundreds of thousands of innovative design applications in different areas of technology.) The creative ideas necessary for developing a next-generation product or process can be systematically generated by using these patterns. Thus, contrary to traditional Technological Forecasting, TRIZ Forecasting "forces" the system to its most probable future development by inventing it before it would occur naturally. There are eight Patterns of Evolution:

1. Stages of Evolution
2. Evolution Toward Increased Ideality
3. Non-Uniform Development of System Elements
4. Evolution Toward Increased Dynamism and Controllability
5. Evolution Toward Increased Complexity and then Simplification
6. Evolution with Matching and Mismatching Elements
7. Evolution Toward the Micro-Level and Increased Use of Fields
8. Evolution Toward Decreased Human Involvement

Lines of Evolution provide detailed descriptions of how a system evolves – and therefore provide even greater predicting power. For example, the pattern entitled "Evolution Toward Increased Complexity and then Simplification" contains the following Lines:

1. Mono- to Homogeneous Bisystem
2. Mono- to Heterogeneous Bisystem
3. Mono- to Homogeneous Polysystem
4. Mono- to Heterogeneous Polysystem

By the mid-1990s, TRIZ Forecasting had grown to become Directed Evolution™ – a process which offers a systematic way of identifying comprehensive sets of potential scenarios of evolution for:

- products/services/processes
- technologies
- organizations
- industries
- markets

Directed Evolution is based on an extended set of Patterns/Lines of Evolution, as well as other tools developed within the Ideation/TRIZ Methodology (also known as I-TRIZ). Over 350 Lines of Evolution had been identified to date.

While sharing a similar general goal, the three approaches – traditional Technological Forecasting, TRIZ Forecasting and Directed Evolution – yield different results in predicting the optimum direction to follow in system design, and each employs unique tools to achieve its objectives. These differences are directly related to the primary question answered by each approach:

| Approach | Main question |
|---|---|
| Traditional Technological Forecasting | "What is going to happen with my product or process parameters?" |
| TRIZ Forecasting | "What change(s) should be made to move my product or process to the next position on a specific pre-determined Line of Evolution?" |
| Directed Evolution | "Which evolutionary scenario should be selected from an identified comprehensive set of scenarios to make it a winner?" |

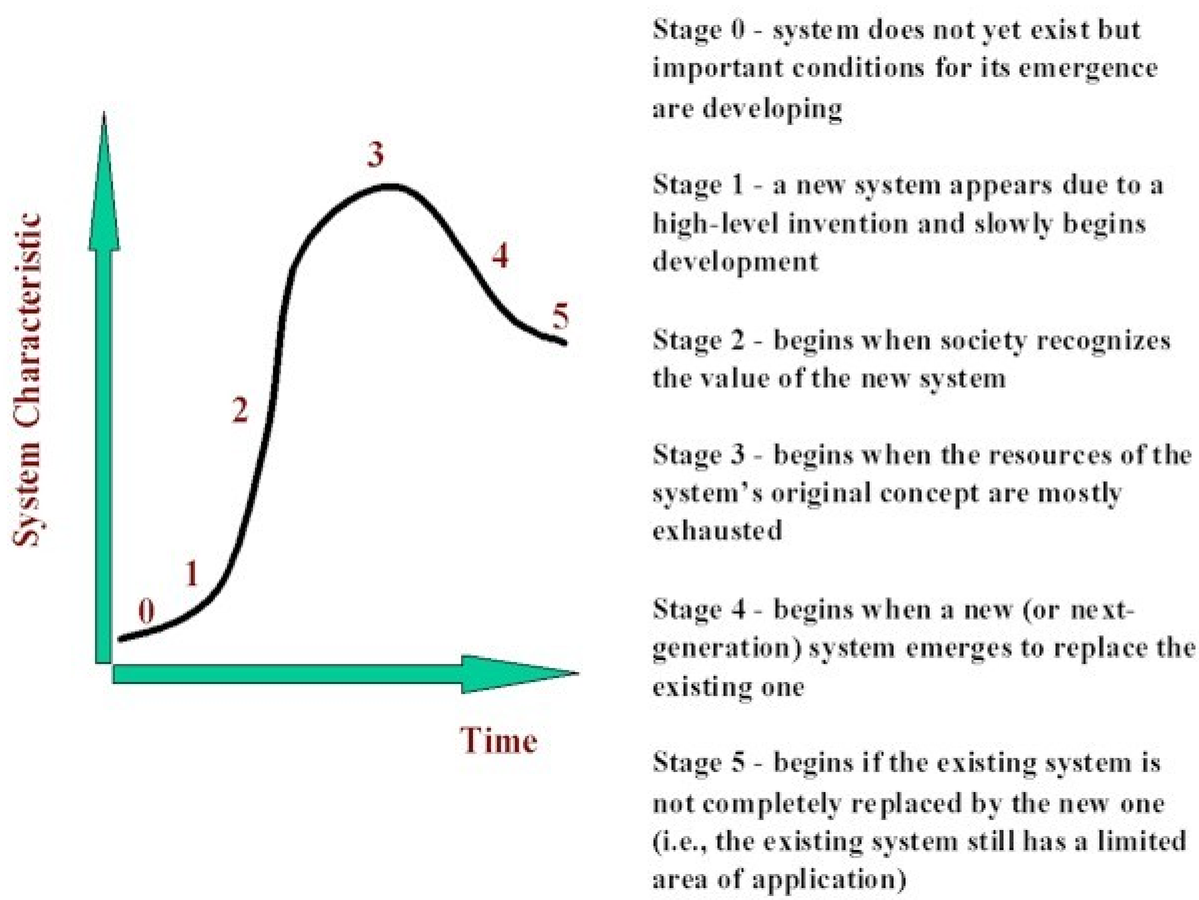
## Directed Evolution Postulates

The theoretical foundation of Directed Evolution includes the following, postulates based on the history of technological evolution and other areas of human activity.

**Postulate 1. Patterns of Evolution**
As they evolve, most man-made systems follow predetermined patterns rather than representing a collection of random events. A study of the history of various systems reveals these patterns and allows for the pro-active design of tomorrow's systems today. A strategy that utilizes the various steps along a given Line of Evolution can maximize profit and maintain market leadership.

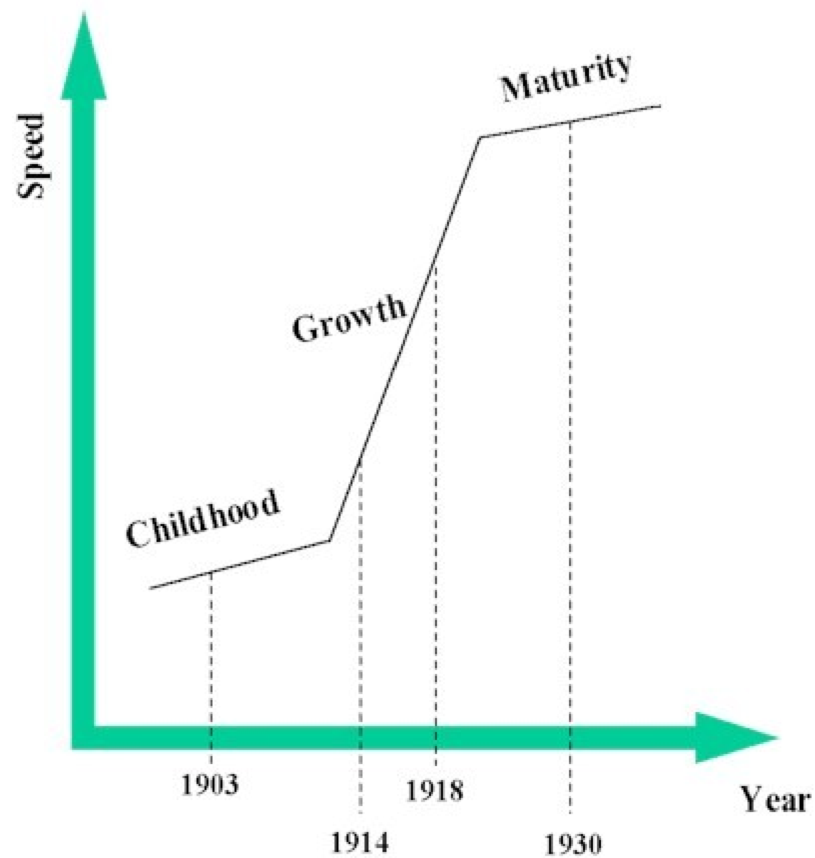
The first of the eight Patterns of Evolution (listed earlier), entitled "Stages of Evolution," can be represented by the classic s-curve (Figure 1), which illustrates the life cycle stages of infancy, growth, maturity and decline.

Figure 1 - System Evolution ("S-Curve")



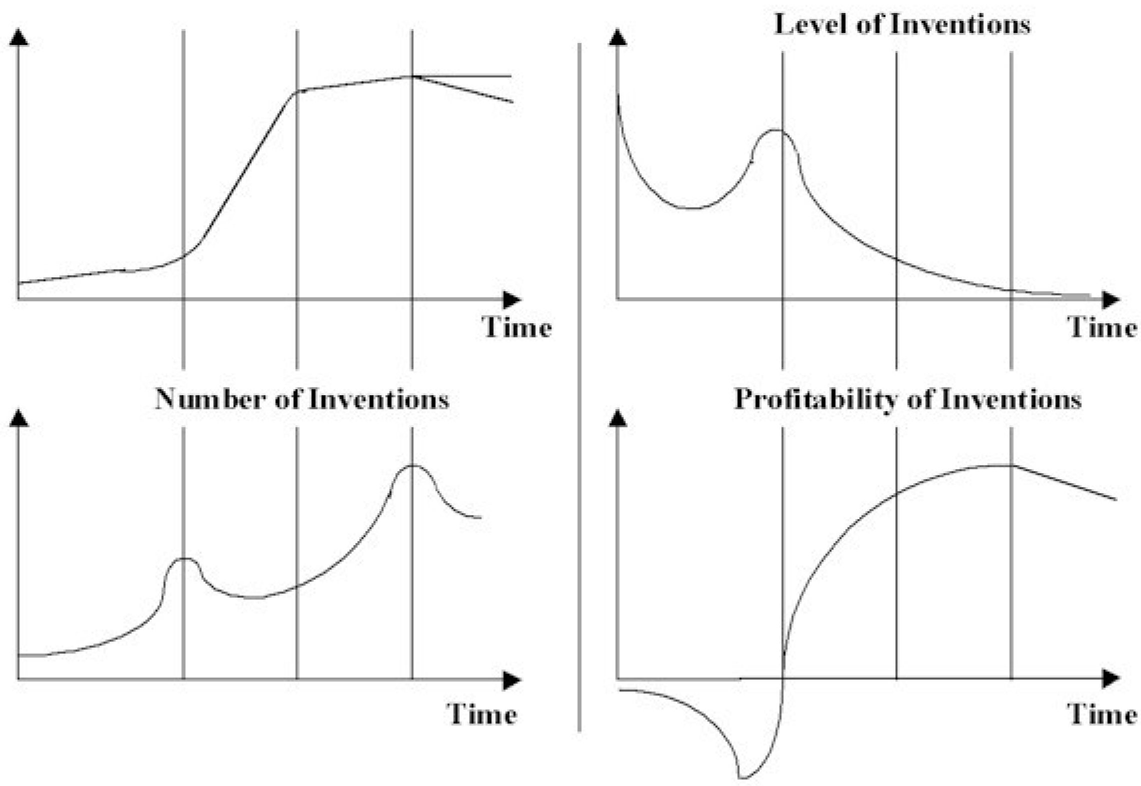

To illustrate how the s-curve can be used, consider the characteristic of airplane speed with respect to the development of the airplane. According to the s-curve, a new concept should have been introduced before 1930 (Figure 2). Looking at several related curves on a single graph allows us to plot the position of a current design in order to predict development before it takes place. Understanding the pattern entitled "Non-Uniform Development of System Elements" explains why aircraft industry designers were short-sighted in continuing to develop the engine while ignoring the airframe.

Figure 2 - Airplane Evolution




The total life cycle of a system is composed of several s-curves. Continued success of a product or process is sustained when new systems are incorporated during the growth of the existing system (Figure 3).

## Figure 3. S-Curve Analysis




**Postulate 2. Market-driven Evolution**
Most existing man-made systems evolve to satisfy customer needs. The customer wants a design with more functionality and quality but with a reduced price and fewer harmful effects. This means that the natural evolution of a system is one toward increasing *ideality* (as stated in the second Pattern of Evolution). Ideality is defined as

$$I = \frac{U}{H}$$

where:
I = Degree of Ideality
U = Sum of useful functions
H = Sum of all harmful effects, including cost/pollution

System evolution is a function of society's judgment of what is useful and what is harmful, and the perception of what is useful and what is harmful can change as place, time and circumstances change.

**Postulate 3. Evolution at Expense of Resources**
A system's evolution consumes resources existing in the system itself, its neighboring systems, and/or the system environment. Each evolutionary step requires new resources that may in turn be used for further development.

The initial stages of evolution use simple, obvious and easily-accessible resources. Complex, derivative and hidden resources are incorporated later.

New generations of products or processes usually appear when new types of resources are discovered (frequently, resources of material structure).

**Postulate 4. Overall System's Priority for Long-term Forecasting**
A system's short-term evolution (or improvement) usually depends on the system's inherent resources. A forecast based on the given system's trends and expert opinions is adequate for most decisions. Long-term development, including emerging new generations, breakthrough, etc., depends on the evolution of the overall technology and/or market rather than on the given system's features and resources.

The general Patterns/Lines of Evolution are used to structure and organize all of humankind's accumulated knowledge.

**Postulate 5. Alternatives in Evolution**
The current system has more than one (but not many) fairly equal ways to evolve to the next step, based upon different resources. The most competitive system is usually the first one introduced, thus attracting the majority of financial and human resources. If a solution has never been found for a specific problem, that does not mean a solution will be found using the Ideation TRIZ methodology. Nor does the development of at least one solution to a given problem preclude the likelihood that TRIZ methodology will help identify others that should be analyzed so that the best solution will selected.

It should be noted here that any single patented solution can be circumvented. However, it is possible to collect an exhaustive set of solution concepts by involving various resources existing in the given system and/or its environment so that a strong patent fence can be created around a specific area of technology.

## The Directed Evolution Process

The Directed Evolution process can be summarized by the steps shown below. The process utilizes multiple Lines of Evolution for technology, marketing, organizations (enterprises), etc. for the purpose of determining multiple scenarios/directions of system evolution. These scenarios are then analyzed from various points of view, and the most promising ones are then selected. The remainder can be considered for future use or disregarded as nonviable. Future directions for development may be patented, thus becoming part of a patent fence. Once the best direction is identified, financial and staffing decisions can be made. The chosen direction may take lead for an extended time period until the technical concept's resources are exhausted. Meanwhile, it is necessary that the next generation of the system is developed in order to sustain increased performance.

**1. Analysis**

- Based on patents and other available information, study the history of a given system to understand how it has evolved. Identify the system's current position on all known and applicable Lines of Evolution.
- Develop specialized Lines of Evolution for the given system based on 1) All applicable known universal and general Lines, and 2) Applicable specialized lines known for similar systems.

**2. Identify Technological Capabilities for Evolution**

- Identify missing and possible future steps in the Line of Evolution.
- Identify what innovations are necessary for development of the technological capabilities needed for these future steps by the formulating problems that must be solved.

**3. Identify Market Input**

- Identify potential customers and their expectations.
- Screen potential directions for the technology.
- Select the directions that meet market exceptions.

**4. Plan and Implement**

Develop a schedule for research, marketing, development and implementation of selected ideas including:

- **Marketing and advertisement** - Apply I-TRIZ analytical and knowledge-based tools for the purpose of developing solutions to identified problems
- **Anticipatory Failure Determination** - Applied to identify and avoid potential dangers associated with a selected reaction, as well as problem formulation and solution development.

Directed Evolution is an ongoing process. The evolution of a system should be monitored in order to incorporate emerging technologies and materials that offer improvements. Directed Evolution is a way to control the destiny of a product, technology, process or organization.

# CASE STUDY – Endoscopic Surgical Instrument

Ideation International scientists conducted a preliminary Directed Evolution (DE) of the endoscopic surgical instrument (linear cutter family). During the process, numerous valuable Solution Concepts were discovered, some of which will directly impact how surgery will be performed in the future. These concepts have been documented in laboratory books and are under legal protection. A summary of the DE process follows:

## Wound Closure – An Historical Perspective

The following is a brief history of sutures and mechanical devices used in would closure. The development of two methods of wound closure, coupled with endoscopy, have resulted in two separate billion dollar plus worldwide markets.

### Needles, Sutures, and Sterilization

Ever since man has stood upright, the need to close wounds has existed. In the beginning, bone needles and animal sinew were used. With the discovery of copper, bronze and iron came the invention of eye needle used with various fibers found in nature such as stalk fibers, flax, linen, silk and cotton. In the late 1800s, with the help of men like Joseph Lister, we began learning about sterilization and disinfectants (the first of which was carbolic acid). Later, sutures were placed in small glass bottles and dry heat was applied to kill the bacteria. In the 1920s and 1930s, steam and chemical sterilization methods were developed. In the 1960s, gamma radiation sterilization became a standard process.

Needle and suture materials continued to evolve in parallel with sterilization. Fine steel needles were used, which were curved and sized according to the suturing procedure, then chemically polished. The string of suture material was attached by flattening the non-pointed needle end, wrapping the flat metal around the suture, then crimping it in place in a process called "swedging." In later methods of wound closure, a hole was punched in the end of a needle and the suture strand was inserted and glued in place. Today, a laser is used to drill the hole.

Over the 20th century, suture materials changed from silk and cotton to polymers, both absorbable and non-absorbable, which were braided or extruded as monofilament. Nowadays there is a suture material to fit every procedure. Also important is suture packaging, which serves as a sterile barrier and whose physical configuration also affects suture performance.

A broad-based inventory of sutures is a mainstay for any modern operating suite, and is expected by today’s surgeon.

### Mechanical Devices

The modern internal stapling device was invented around 1905 by a Hungarian surgeon and his brother. Their goal was to prevent the leaking of bowel contents (which were believed to be very infectious) during surgical resection. The device consisted of fine silver staples that were forced through the tissue and formed into a suture. The staples were left in the body after surgery with no ill effects.

In the early 1930s, the Hungarian surgeon Von Petz invented the staple delivery device that carries his name. Until the 1950s, this was the only internal stapling device available to surgeons.

In the early 1950s, Stalin commissioned an institute in Moscow to continue the development of surgical staples. This institute developed reusable skin staplers, internal staplers of various sizes, linear cutters that lay down four rows of staples while cutting between them, and circular staplers for reattaching bowel sections. Produced by hand in small quantities, the patented staplers were available only to a few surgeons.

In 1958, an American surgeon brought a stapler back from Russia and showed it to the founders of U.S. Surgical (which incorporated in 1964). U.S. Surgical built a business around their reusable surgical stapler. Then, in 1978, Ethicon marketed its first disposable stapler – and the race was on. During the next 15 years, a billion dollar mechanical and endoscopic market developed.

## Applying the Patterns of Evolution (Example)

### Apparent Directions for Cutter Evolution

The evolution of linear cutters indicated that the predominant method for increasing the system's ideality has been to increase each tool's level of specialization. Based on patent research, almost all developers are following this approach, and for that reason, this part of the project will not be shared.

### Non-Apparent Directions of Evolution for Sutures

Another way to increase a system's ideality is *universalization*. According to the I-TRIZ Patterns of Evolution, systems become more universal through an increase in dynamism and a transition to the micro-level for realization of the system's functions. This suggests that tissue interaction would be affected by a formless medium (liquid or jelly) that could take any shape, rather than by pre-shaped objects such as staples or sutures.

### Sewing vs. Stapling

The right side of Figure 4 shows the two threads of a sewing machine prior to the formation of a stitch. A sewing machine creates nearly continuous pressure on the two sides of the material. A staple provides a discontinuous pressure because there is space between the staples if they are in a simple row.

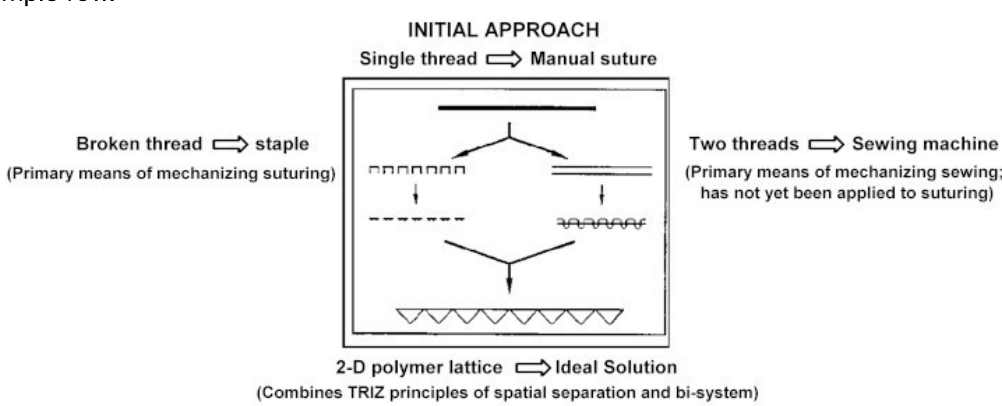



**FIGURE 4**

### Using Adhesive

In TRIZ terms, the process of using adhesive to close wounds can be characterized as follows:

USEFUL EFFECT: Attaches tissue

HARMFUL EFFECT: Contact with adhesive damages surface layers of tissue

CONTRADICTION: Adhesive should be present between the two layers of tissue to attach them. There should be no adhesive present between the tissue layers so as not to damage them.

## One Possible Solution Concept

To demonstrate the utilization of the Patterns of Evolution, one of many possible conceptual designs for a future surgical instrument is described below. This concept is the result of joining the benefits of sewing and stapling with the pattern "Evolution Toward the Micro-Level." With the development of this conceptual design, it is possible to create the next generation of instruments, along with an associated and highly effective patent fence.

**Description**

The components of the instrument include a housing, closing anvil, and cartridge in the shape of a reservoir containing a liquid polymer. The reservoir has a nozzle and is connected to a pressure source. Under very high pressure, the polymer is extruded through the nozzle in a narrow knifelike stream, pierces the tissue, and comes in contact with the anvil. Upon contact with the tissue, the polymer solidifies (polymerizes). Angular application in two directions forms a **V** on the underside. This continuous system of triangles holding the tissue together is seen at the bottom of Figure 5.

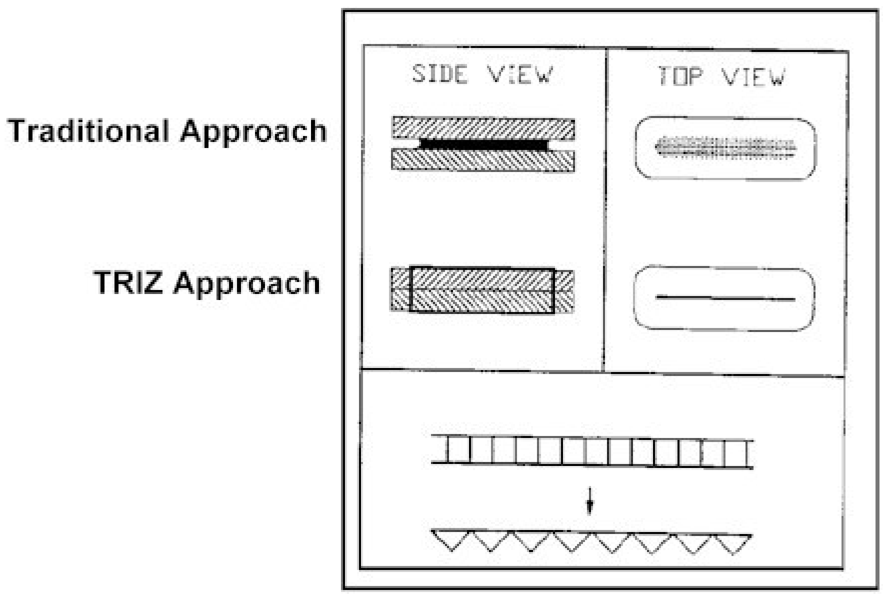



**FIGURE 5**

For this device, polymers that have already been approved for medical applications can be used. The polymer may contain additives that make the material stronger or more conductive. Magnetic or chemically reactive additives, for example, could enhance interaction with the tissue.

**Implementation**

Polymer solidification may be based upon:

| | |
|---|---|
| Temperature | Polyethylene-type polymer is extruded in a molten state |
| Chemical | Cyanoacrylate-based polymers for polymerization on contact with water in tissue |
| Chemical | Polymerization due to changes of the environment pH, for polymers |

| | |
|---|---|
| | which are liquid in acid or alkali environment and polymerize in the neutral environment of the organism |
| Radiation | Polymerization due to ultraviolet light, X-rays, etc |
| Action | Polymerization caused by electric or magnetic fields, etc. |

Different polymerization techniques can be combined with different homeostasis techniques (temperature, chemical or radiation protein denaturation in the seam's proximity).

Sewing may be combined with cutting, either by a mechanical blade or by a pressurized liquid (possibly using the same polymer extruded in the form of a continuous wall, thereby creating a layer of separation between the tissue).

**Current Approach**

- Staples of different sizes are needed for different tissues/procedures.
- All staples in cartridge are of the same size.
- Limited number of staples in cartridge.
- Disruptive replacement of cartridge is necessary in the case of a long seam.

**Directed Evolution Approach**

- One universal, adjustable seam-making cutter
- Seam can have variable attachment pitch
- Seam can be of unlimited, uninterrupted length
- Straight and curved seams are possible

**The Complete Process**

The complete process would include several Lines of Evolution, including the ones identified as being used by the competition. Depending upon the resources of an organization, patent fences can be built to render the competition's current Line of Evolution a "dead end."

By looking at several Lines of Evolution, an organization can protect the important end points, as well as the path along the way. A good strategy would be to introduce a new model that is competitively better but not as far along the Line of Evolution as is possible. Because the organization already knows the next three or four model changes, resources can be shifted to other areas of development.

## The Importance of Directed Evolution

All we know for certain about the future is that it will be different from the present. Products, organizations, skills and attitudes that serve a business well today may have little relevance under the conditions of tomorrow. If a business is to survive, it must change. This change must be timely and appropriate to meet the needs of the future.

Forecasts related to Directed Evolution provide important input to the process of strategic planning. These predictions have been used to gain a better understanding of the threats and opportunities likely to be faced by established products and markets. Consequently, the nature and magnitude of necessary changes can also be assessed. Reliable forecasting enables a business to pro-actively plan for the future as opposed to merely reactively responding to critical events. During recent years, numerous techniques for technological forecasting have been developed in order to obtain the maximum use from the information available. Because technology is responsible for many of the most important changes in our society, forecasting future advances in technology and the associated impacts can be as vital for top management in their formation of corporate strategy as it is for the technologist reviewing his research and development program. Technological change may result in bottlenecks or the redefinition of an industry or market. Drawn from the Ideation/TRIZ Methodology, Directed Evolution helps management obtain a more accurate picture of the future and, consequently, improve decision making. Thus the effort this process requires is justified.

This could be the only real justification for Directed Evolution. Decisions are only definitive for the present. The question that faces the long-range planner is not, "What should we do tomorrow?," but, "What do we have to do today to be ready for an uncertain tomorrow?" The question is not, "What will happen in the future?," it is instead, "What future events do we have to factor into our present thinking and action?," What time spans do we have to consider?," and, "How do we make decisions about the future as we simultaneously make decisions in the present?" The planning horizons for most companies are relatively short: on the order of 5 to 10 years. It is just as important to apply Direct Evolution to short-term and long-term decisions, since many significant changes can occur in a decade.

The time period for which Directed Evolution is necessary should match the planning horizon of the company. This is a function of the rate at which company activities can respond to change rather than the rate at which the environment itself is changing.

## Summary

Directed Evolution assists business decisions in the following ways:

1. Offers wide-range surveillance of the total environment in order to identify developments (within and without the business' normal sphere of activity) that could influence the industry's future and, particularly, the company's own products and markets.

2. Estimates the time frame for important events in relation to the company's decision-making and planning horizons. This gives an indication of the urgency for action.

3. Provides more refined information following a detailed forecast where the initial analysis found possible but insufficient evidence of a major threat or opportunity in the near future. Continues monitoring trends that, while not expected to require immediate action, are nevertheless likely to become important at some point in the future and must therefore be kept under review.

4. Suggests major reorientation of company policy to avoid situations that pose a threat or to seek new opportunities by:
– Redefinition of the industry or the company's business objectives in light of new technological competition.
– Modification of the corporate strategy.
– Modification of the research and development strategy.

5. Improves operational decision-making, particularly in relation to:
– Research and development portfolios
– Research and development project selection
– Resource allocation between technologies
– Investment in plant and equipment, including laboratory equipment
– Recruitment policy

## Level of Investment

When attention is focused on need rather than ability to pay, the importance of Directed Evolution is obviously a significant business consideration, particularly for smaller businesses. The large firm in a mature industry is unlikely to be overwhelmed by a sudden technological development, though its effects may be catastrophic. For such a company, Directed Evolution could be confined to monitoring the business and technological environment for early warning of the occasional advance. Only when monitoring alerts the company of some new development will more defined forecasts be needed. But, a company adopting an offensive strategy should devote correspondingly more resources to Directed Evolution.

1. All companies should undertake some form of Directed Evolution
2. The amount of effort devoted to Directed Evolution should take into account:
    - The rate of change in that technological environment
    - The planning horizons determined by the technological and marketing lead time needed for new products or processes
    - The complexity of the underlying problems
    - The research and development strategy
    - The size of the company, but only as this limits the availability of resources for Directed Evolution

## Conclusion

As the pace of technological progress continues to increase, so will the need for Directed Evolution. Any growth is likely to be hindered by exaggerated claims of achievement. Since the benefits from research and development decisions are gained in the future, it is incumbent upon the research and development manager to be satisfied that the results of the investment are relevant to the market needs and the competitive technologies at the time they will reach fruition.

All research and development decision makers must take a conscientious view of the future. Directed Evolution cannot enable decision-makers to predict the future with certainty, but it can assist them in defining their choices.