# APPLICATION OF S-SHAPED CURVES

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## Abstract

This paper deals with the application of S-shaped curves in the contexts of inventive problem solving, innovation and technology forecasts. After explaining the origin of the logistic S-curve its application, as seen in publications from different domains, is reviewed. Despite much criticism and the failure to apply the logistic function for long-term forecasting, it continues to be a popular model for describing the evolution of systems (technological, economical, social and others) over time. This paper can help researchers and practitioners to understand the scope of application of S-shaped patterns, their limitations, and peculiarities.

## Keywords

Laws of Technical systems evolution, Resource limitations, Technology Future Analysis, S-shaped curve, S-curve.

## 1 INTRODUCTION

The regularity of systems' evolution as an initial slow change, followed by a rapid change and then ending in a slow change again are observed since statistical observation was established in the mid 18th century. Various scientists and researchers discovered, reinvented, and adapted the curves of nonlinear growth many times for different domains of knowledge. Therefore, S-shaped curves possess a lot of different names: Logistic curve, Verhulst-Pearl equation, Pearl curve, Richard's curve (Generalized Logistic), Growth curve, Gompertz curve, S-curve, S-shaped pattern, Saturation curve, Sigmoid(al) curve, Foster's curve, Bass model, and many others. Researches all around the world apply S-shaped curves for projecting the performance of technologies, to foresee population changes, for market penetration analyses, for micro- and macro-economic studies, for diffusion mechanisms of technological and social inventions, for ecological modelling, and for many other purposes.

What explains such a generic and universal application of logistic S-curves?

## 2 HISTORY OF THE S-SHAPED CURVE

### 2.1 Origin of the logistic curve and its basic concept

The logistic function as a model of population growth was first introduced by Belgian mathematician Pierre-Francois Verhulst (1804-1849) in 1838 [3]. Verhulst derived his logistic equation after he had read 'An essay on the Principle of Population' of English demographer and political economist Thomas Malthus (1766-1834). The logistic equation was introduced to describe the self-limiting growth of a population. This equation sometimes called the Verhulst-Pearl equation according to its rediscovery in 1920 by American zoologist and one of the founders of biometry Raymond Pearl (1879-1940).

Early in the 20th century, Alfred James Lotka from John Hopkins University, US and Vito Volterra from the University of Rome, Italy working independently but in parallel, generalized Verhulst's growth equation to model competition among different species. The Volterra-Lotka model, also known as the predator-prey equations, has opened the way to effectively managing competition in biology, ecology and technology domains. Today this model is frequently employed to describe the dynamics of systems [4].

Different types of competition can be distinguished [4, 5]:

- competition of one species for resources;
- two competitors: pure competition (loss-loss), predator-prey (win-loss), symbiosis (win-win), parasitic (win-impervious), symbiotic (loss-indifferent), and no competition;
- many competitors at the same time.

For example, a population of bacteria grows in a closed bowl of broth. The rate of chemicals in the broth to bacteria transformation is proportional to the number of bacteria present and the concentration of transformable chemicals. Thus, Verhulst's equation for this particular case can be written as:

$$\frac{dN}{dt} = aN\frac{(M-N)}{M} \qquad (1)$$

Where, N(t) – number of bacteria at time t; M – amount of transformable chemicals at t=0 (before growth starts); a - parameter that represents the interaction between the competitors.

Solution of equation (1) as a logistic function:

$$N(t) = \frac{M}{1 + e^{-(at+b)}} \qquad (2)$$

Where, b – is a constant, locating the process in time [5].

The law of natural growth over a period of time can be described through periods of birth, growth, maturity, decline and death for any system. This set of periods is often called the *life cycle* of system.

A bell-shaped curve is usually applied as a template to represent the rate of growth within a time span (see Figure 1). Whereas cumulative growth (cumulative number of "units" until any given points in time) follows an S-curve. Thus the S-curve became a visual symbol of cumulative growth. The simplest mathematical function that produces an S-curve is called a *logistic*.

The essential meaning of this function is 'the rate of growth is proportional to both the amount of growth already accomplished and the amount of growth remaining to be accomplished.' Understanding of that concept helps to catch part of the answer to the question: "Why does the S-curve approach possess forecasting powers?"

We believe the forecasting power of the S-curve is due to the basic concept of limiting resources that lies at the basis of any growth process. In diverse areas, limiting resources are named in different ways: scarcest resources (geochemistry), restricted resources (economy), limitation of resources (TRIZ[1]), resource constraint (theory of constraints) etc.
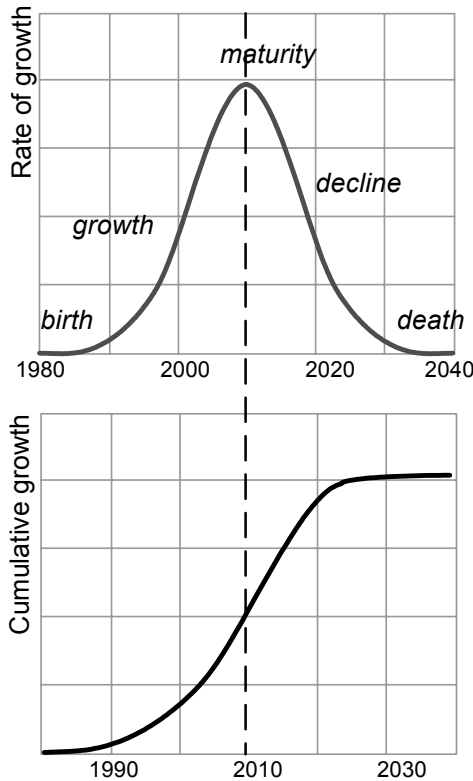


Figure 1. Life cycle bell-shaped curve and S-curve of cumulative growth.

In most cases, applying an S-curve for forecasting induces the correct measurement of the growth process that in turn can be applied to identify the law of natural growth quantitatively and to reveal the value of the ceiling (upper limits of growth) and steepness of the growth (slope of curve).

Obviously, the more precise the data and the bigger the section of the S-curve they cover leads to a lower level of uncertainties [6]. In other words, one can identify a more accurate ceiling and steepness with a larger data set. This effect causes some difficulties in applying an S-curve forecast for emerging technologies, which have not yet passed the "infant mortality" threshold (when the ratio of new to old technology has not reached 0.1).

## 2.2   Application of S-shaped curves

The law of natural growth was derived from research in Economics. The Malthusian growth model is the ancestor of the logistic function of Pierre Verhulst. Benjamin Gompertz in 1825 published work developing the Malthusian growth model further for demographic study (law of mortality). Since those times, S-shaped curves have been applied for studies in population dynamics and economic analyses.

In the early 1960s, S-shaped curves and envelop curves were regularly employed for technological forecasting [7]. The application of the logistic curve in combination with envelop curves for forecasting by extrapolation of trends issued many fascinating results for lightning systems,

particle accelerators, aircrafts, microelectronics, transportation systems, energy conversion technologies. For instance, the diffusion of innovation theory, formalized by Everett M. Rodgers [8] in 1962 postulated that innovations would spread in society in an S-curve.

The law of natural growth seems as simple as it is fundamental. Biologists have applied it to describe the growth of a species under competition. It has been used in medicine to describe the diffusion of epidemic diseases. Market studies of new products, usually based on the law of natural growth in a specific niche, use an S-curve analysis.

Fisher J.C. and Pry R.H. in 1971 [9] have shown that data describing the substitution of a new product or process for an old one can be fitted extremely well by a simple mathematical logistic function that produces an S-curve.

There are plenty examples of applying S-curves for studying the future of complex systems. It is simply not within the scope of this paper to count even the major ones.

For instance, at the International Institute for Applied Systems Analysis (IIASA[2], Laxenburg, Austria) logistic S-curves have been applied during the last 35 years for studies about

- the future  of primary energy sources and vectors,
- the evolution of agricultural technologies,
- the substitution of transportation systems,
- the development of discoveries,
- the elaboration of inventions and the diffusion of innovation,
- the transformation of the aircraft industry,
- macro- and micro- economic trends,
- the growth of crime and terrorism,
- environmental changes and problems,
- the evolution of telecommunication systems,
- and for many others.

The International Journal of Technological Forecasting and Social Change[3] published more than 320 articles from May 2002 to May 2007. About 14 articles considered in particular the application of the logistic S-curve of natural growth for forecasting purposes. More than 170 articles within this period mentioned S-curves on their pages.

In usual forecasting and strategic planning practice S-shaped curves enter as modular components in many methods and techniques. Table 1 summarizes the observed application of S-curves as a part of various forecasting methods.

A study of the application of S-curves, summarized in Table 1, shows that they are most often applied for analysing past data in order to disclose new trends and for proving known ones.

From a practical viewpoint, according to the results of various research, the processes of diffusion of novelties, substitution of systems, and competitive growth obey the same law of natural growth. Thanks to its fractal aspects

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[1] Theory of inventive problem solving

[2] IIASA is a nongovernmental, multidisciplinary, international research institution; it was founded in October 1972 by academies of science of 12 nations from East and West. The institute now has 18 National full Member Organizations [http://www.iiasa.ac.at/].

[3] ISSN: 0040-1625 "A major forum for those wishing to deal directly with the methodology and practice of technological forecasting and future studies as planning tools as they interrelate social, environmental and technological factors."

[10] the law of natural growth can be applied for almost any scale and complexity of systems from elementary particles up to the evolution of stars and knowledge acquisition.

| Method name: | Nature & Application: |
|---|---|
| Trend Impact Analysis [16] | Quantitative. For extrapolation of previously collected data |
| Curve fitting technique [16] | Qualitative and quantitative. For forecasting the critical variables within the State of the Future Index (SOFI) method |
| Decision Modelling based on Fisher and Pry model (1971) | Quantitative. For examining market, technological, social substitution dynamics |
| Statistical Modelling. Time-series analysis as a part of curve fitting [15, pp.577-595] | Qualitative and quantitative. For trend extrapolation. |
| Text Mining for Technology Forecast [17, pp.194-197] | Quantitative. For analysis of annual publications, to prove informative trends. |
| Life Cycle Analysis in the framework of strategic analysis | Qualitative. To identify the stage of a system's evolution. |
| Theory of Innovation Diffusion [8] | Qualitative and quantitative. For studying the technology adaptation dynamic. |
| Emerging issues analysis [18] | Quantitative. For identifying the issues before they reach the trend of problem phase for engineering and non-engineering fields. |

Table 1. Applications of S-shaped curves in the framework of other methods

## 3   S-CURVE IN THE FRAMEWORK OF TRIZ

In the scope of TRIZ research, in the mid 1970s it was proposed to employ the S-curve model for the *qualitative* study of technical systems evolution [1, 2]. In order to facilitate the positioning of the analysed system onto a logistic curve G.Altshuller proposed the application of three supplementary statistical curves: changes of number of inventions, changes of level of inventions, and changes of profitability during time. It was proposed also to apply a concept of three levels of resource limitations during the life cycle of technical systems (Figure 2):

- first level – limitation of working principle (limits of system's resources),
- second level – limitation of economic rationality (limits of available resources from the environment), and
- third level – physical limits of resources in super-system (e.g. limitations of fossil resources, limitations of available space, limitations of renewable resources – clean water).

In the scope of research into technological forecasting, we are looking for a method for the application of the concept of assessing multi-level resource limitations in order to improve the reliability of the forecast for emerging technologies that do not have enough history of their evolution (lack of data and knowledge).

It is necessary to notice that a similar concept of scarce resources was described as a Law of the Minimum by German geochemist Justus von Liebig (1803-1873) in 1840. The *Law of the Minimum* states 'that growth is controlled not by the total resources available, but by the scarcest resource'.

For chemistry, such a concept is known as the rate determining step, in management techniques as the critical path. Derivatives from the law of the minimum can be found in many areas of knowledge from economics, environmental, social and technological sciences.
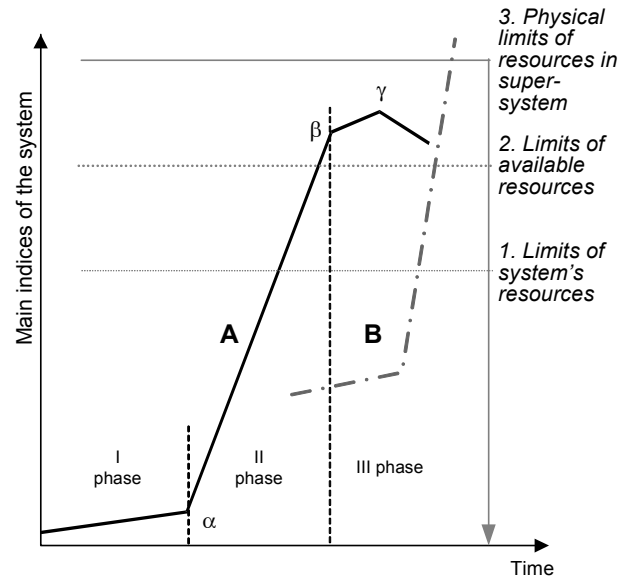


Figure 2. Styled S-curve of technical systems evolution and limits of resources

The law of natural growth and the S-curve play a key role in the set of height laws of technical systems evolution, postulated in TRIZ. The law of increasing Ideality of technical systems is in fact the derivation of the enveloped curve of successive substitutions of technical systems (see Figure 3).
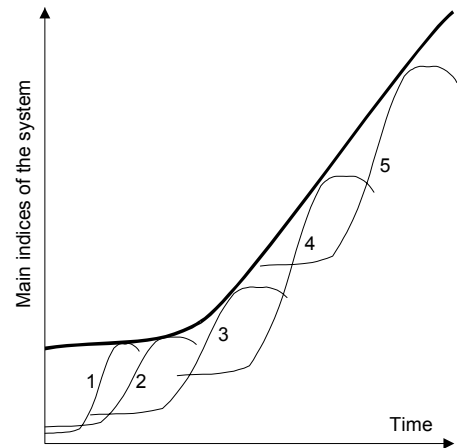


Figure 3. Successive substitutions of new systems for old ones following the law of Ideality growth.

Why does system 3 conquer system 2? In competition if system 3 shows a better ratio of Performance to Expense it has more chances to survive. Expense is our limiting resource. And this is exactly the meaning of the law of increasing Ideality: 'during their evolution the technical systems tend to improve the ratio between system performance and the expense required for this performance.'

The trickiest question is how to calculate Ideality in practice for particular systems [11]. After analysis of the available sources of knowledge, we did not find any

feasible ideas and procedures for computing Ideality (often called the 'Main index of the system'). It is not surprising that the founder of TRIZ first proposed to apply an S-curve analysis for qualitative analysis. Therefore, vertical scales in most TRIZ publications are purely qualitative or apply some arbitrary units.

Before presenting some data about TRIZ publications, it is necessary to clarify the different viewpoints on what is a 'forecast'.

If someone tells us, "it will rain". Will it be a forecast, a prediction or just a vision of the future? Usually we are interested to know when and where "it will rain." It is important to know how intensive it will be and how the temperature will change afterwards.

Frequently observed TRIZ-forecasts resemble "it will rain." For instance, the following assertion: motor vessels will be substituted by water-jet vessels. Yes, they will! However, it is interesting to know when?, were? and for which application?

In order to avoid misunderstandings, we would like to present our working definition of the term 'forecast'. We define a technology forecast in the framework of our research as "an explicit description of emergence, performance, features, and impacts of a technology in a particular place at a particular point of time in the future for a definite application." If some of the components of the above definition are omitted, such a description should be considered as a vision of the future rather than as a forecast. Visions of the future merit consideration and study, however, they have another area of application and should not be confused with forecasts.

In order to summarise the application of S-curves in the TRIZ community we made an express survey of publications at conferences within the time span 1999-2006 (ETRIA[4] TFC 2001-2006, and TRIZCON[5]) and publications on the website triz-journal.com 1997-2006[6]. The same articles from different sources where taken into account just once. Unfortunately, we had no opportunity to consider publications from MATRIZ conferences and many other publications in Russian, German, French, Spanish, Japanese, Korean, Chinese, Polish, Czech and others languages.

Excerpts from the results of our survey are presented in Tables 2 and 3.

In total, 137 papers mention S-curve applicability over the reviewed period. Most of them consider pure qualitative analysis of arbitrary parameters. Some of them do not consider any parameters on the vertical scale at all. The authors of only 14 papers during nine years tried to combine qualitative analysis with a quantitative one. Eight papers out of 14 are case studies, concerned with identifying a phase stage of the analysed system or evolutionary trends for a particular technology. The remaining five papers discuss the applicability of S-curve analysis using arbitrary units with some ideas about measurable parameters.

Different applications of the S-curve concept in TRIZ publications are presented below (Table 3, Figure 4). Dozens of various applications are grouped into five groups.

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[4] Annual TRIZ Future Conference of European TRIZ Association, Europe [http://www.etria.net ].
[5] Annual Altshuller Institute for TRIZ Studies International Conference, USA [ http://www.aitriz.org ].
[6] The TRIZ Journal Article Archive [ http://www.triz-journal.com ].

| Year | Source | S-curve is mentioned |
|------|--------|----------------------|
| 1997 | triz-journal | 13% |
| 1998 | triz-journal | 3% |
| | TRIZCON | 15% |
| | triz-journal | 13% |
| 1999 | | 14% |
| | TRIZCON | 16% |
| | triz-journal | 11% |
| 2000 | | 12% |
| | TRIZCON | 19% |
| | ETRIA TFC | 13% |
| | triz-journal | 5% |
| 2001 | | 11% |
| | TRIZCON | 15% |
| | ETRIA TFC | 12% |
| | triz-journal | 12% |
| 2002 | | 12% |
| | TRIZCON | 27% |
| | ETRIA TFC | 6% |
| | triz-journal | 7% |
| 2003 | | 10% |
| | TRIZCON | 11% |
| | ETRIA TFC | 14% |
| | triz-journal | 8% |
| 2004 | | 10% |
| | TRIZCON | 8% |
| | ETRIA TFC | 16% |
| | triz-journal | 7% |
| 2005 | | 10% |
| | TRIZCON | 12% |
| | ETRIA TFC | 7% |
| | triz-journal | 8% |
| 2006 | | 8% |

Table 2. Ratio of papers mentioning an S-curve in total publications.

| # | Application of S-curve | 11/1996 12/1999 | 01/2000 12/2002 | 01/2003 12/2006 |
|---|------------------------|-----------------|-----------------|-----------------|
| 1 | Just mentioned | 11 | 29 | 43 |
| 2 | Case studies using S-curve | 3 | 3 | 5 |
| 3 | Maturity of technology assessment in context of problem solving | 3 | 6 | 8 |
| 4 | Analysis of systems evolution in context of forecasting | 4 | 8 | 8 |
| 5 | Non-grouped hypothesis | 0 | 3 | 3 |

Table 3. Number of papers in TRIZ publications grouped according to application of S-curve concept.

In papers from the first group authors just refer to an S-curve and apply common knowledge (mostly taken from [1]) in order to illustrate proposed findings, speculations and particularities. The S-curve concept is applied mainly for educational purposes, in order to illustrate the stages of system evolution, for the illustration of laws of technical systems evolution, to provide information about natural growth. In other words, in order to master the future of technical and non-engineering (business, educational, environmental) systems.

The second group of papers include publications dedicated to the analysis of particular system evolution using an S-curve. They describe the practical experiment of employing quantitative data analysis in order to identify the evolutionary stage of certain technologies. Unfortunately, such papers are not so numerous even if they attract the attention of many readers. The level of "quantitativeness" in papers varies from data analysis using fitting techniques to quasi-quantitative studies.

Papers from the third group discuss how to define the direction of problem solving activities using an S-curve and systematic technology assessment. Some papers from this group present proposals about the integration of S-curve analysis in several toolboxes for designing new products.

Papers from the fourth group are focused on the forecasting and strategic planning contexts. They propose some rules and recommendations about analysis of systems evolution, history of the system and trend studies using S-curve analysis. The papers discuss the application of the S-curve for engineering and non-technical systems as well as short-term and long-term perspectives with cascading S-curves. Several papers from this group propose some recommendations for effective evaluation of patents.
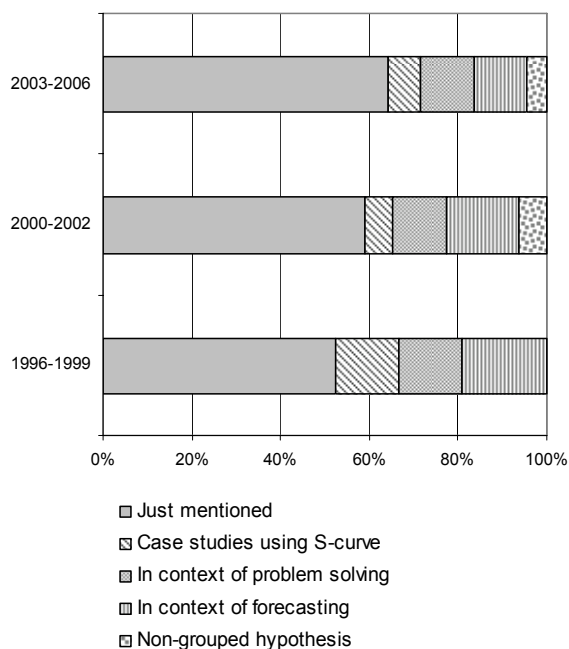


Figure 4. Application of S-curve in TRIZ publications (based on data from Table 3).

In the fifth group, several papers that do not fit any group are collected. They represent some authors' speculations, early-ripe hypotheses, and ideas about combining the S-curve concept with other theories and approaches for uncommon needs.

## 4   ENVELOPE CURVE EXTRAPOLATION

There is an easy concept behind extrapolation techniques: let past experience be a guide for future expectations. One can distinguish several ways to apply the envelope curve extrapolation in combination with the logistic S-curve of natural growth.

One of the better known methods can be named "*shift to the super-systems*". The main idea is to plot several growth curves for alternative technologies using the same key parameter and to fit the envelop curve for the constructed curves (e.g. see Figure 4.2).

The application of envelope curves for long-term technological forecasting started to be popular at the end of the 1950s. This technique is still in use to develop long-term visions. However, today for strategic planning it is more important to foresee technology substitution time and conditions. That is why envelop curve technique results can be found in books, but not in articles and conference papers.

There are many pitfalls and particularities of the process for designing the envelop curve extrapolation of this first type. It is commonplace to discuss whether the trend will not continue as before or if it will continue. In fact, this question can be dealt with by means of system dynamic [19].

In order to emphasise another pitfall and repeat once again the importance of careful selection the parameters for the vertical scale, Figures 4.1 and 4.2 present two diagrams. These two graphs are taken from the book [7] to which G.Altshuller referred [2] when discussing the applicability of S-curve analysis for inventive problem solving and qualitative technology forecasting.

The same parameter was plotted in both graphs. The one in Fig 4.1 is misleading. because an inappropriate scale is used. Speed of matter, according to the laws of physics cannot exceed 299 792 458 metres per second.

The analysis of such examples leads to multiple questions. For instance, how can we be sure about the appropriateness of the chosen scale beforehand? What is a relevant parameter to elaborate an enveloped S-curve for long-term forecasting? For example, should it be the speed of the transportation system or should it be a time to move the load or person from one location to another one? It should be noted, today in Europe high speed trains rise in popularity, because they connect city-centres and the final trip takes less time.

Another way to apply the enveloped curve extrapolation can be named "shift to the sub-systems." Several interesting illustrations were presented in paper [10] of T.Modis in 1994. By applying qualitative and quantitative analyses of the computer market the author put forward a fractal aspect of natural growth depicted by an S-curve. One of the conclusions that were proved later suggests that "any growth process can be analysed in terms of natural growth sub-processes."

It is noticeable how one picture can replace a lot of text explanations. For instance, the link between the slope of the envelop curve and the rhythm of technology substitutions (depicted by sub-S-curves) can be learned from Figure 5 distinctly. Another interesting derivative result from Figure 5 is the hint about shortening life-cycles of technologies (sub-S-curves) when the envelop curve flattens (in the beginning and at the end of natural growth).

Due to the limitations of a conference paper, it is impossible to present here all the richness of the application of envelop curves. Here only two of many ways are presented.
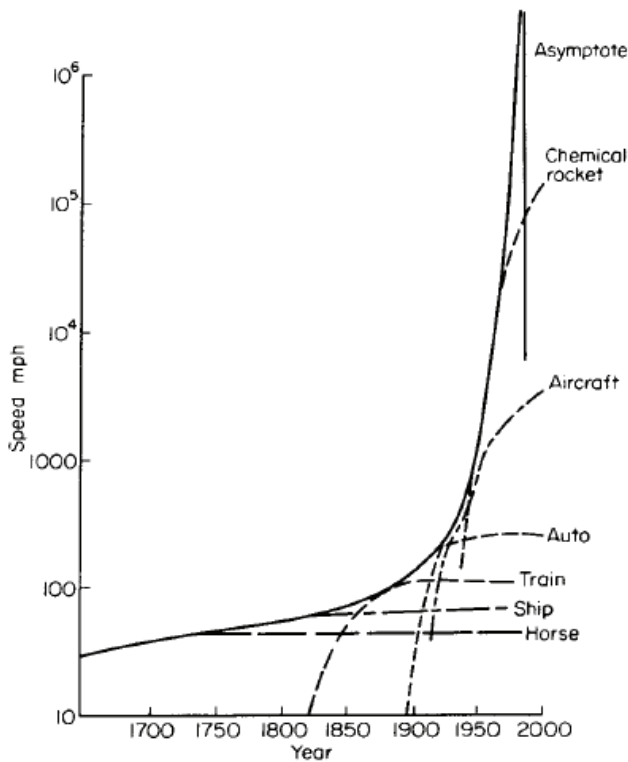
Figure 4.1. Speed trend curve plotted in 1961.  Source [7].
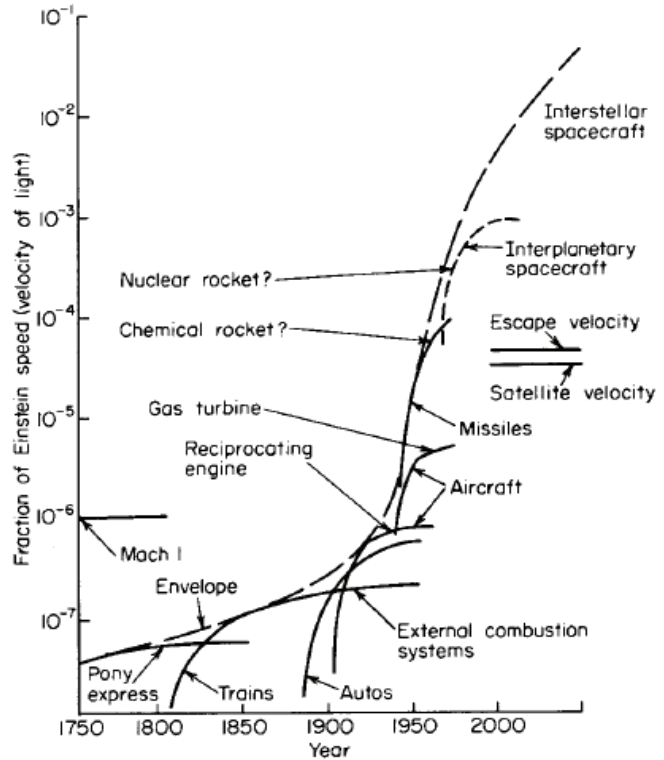


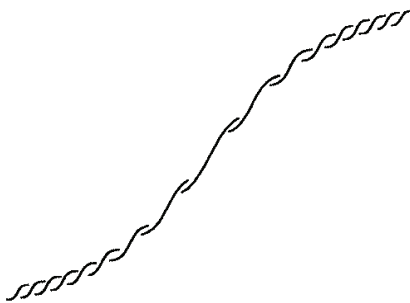Figure 4.2. Speed trend. Source [7].



Figure 5. Styled Envelop curve. An envelop logistic pattern is decomposed into constituent logistics. The horizontal axis represents time (Source [10]).

## 5   SOME FEEDBACK FROM PRACTICE

The target of our research is to improve the process of forecasting for emerging technologies and the quality of the forecasts produced. We next apply the following basic assumptions:

- limitations of resources drive evolution of any technology;

- thus, the technology's future can be mapped using knowledge about scarce resources;

- application of the law of natural growth with a logistic S-curve, performed in a computable way, can contribute essentially to the accuracy of the long-term forecast.

In order to check the above assumptions and hypotheses about reliable forecasting using OTSM-TRIZ[7] knowledge

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[7] At the end of the 1970s the founder of TRIZ G.Altshuller anticipated the further evolution of TRIZ towards a General Theory of Powerful Thinking, which will be useful

two forecasting projects were performed during September 2003 – December 2006 in collaboration with the European Institute for Energy Research (EIFER), Karlsruhe, Germany. Some theoretical and practical results of these projects are described in reports and conference papers [21, 22, 23].

In the framework of this paper, we would like only to emphasise the question of measurable parameters for the vertical scale of the S-curve of system evolution. This question is a corner stone of the application of logistic S-curves for medium- and long-term forecasts as we perceive from theoretical and practical studies.

According to the law of Ideality increase [1], Ideality is defined as a ratio between the system Performances and the Expenses required for these performances.

$$I = \frac{\sum P}{\sum E} \tag{3}$$

Where, P – is system performance including all positive results within the life-cycle of the system; E – is the needed expenses of resources including all harmful and undesirable effects within the life-cycle of the system.

The practical application of the Ideality concept [12] shows us the necessity of taking into account not only the technical aspects of Ideality ($P_t$, $E_t$) for analysed systems (see Equation 3), but also Economic, Social and

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for dealing with non-engineering problems and complex cross disciplinary problems as well. At the beginning of the 1980s G.Altshuller initiated research to develop this theory. OTSM is the Russian acronym usually applied to indicate the General Theory of Powerful Thinking. For details see paper of N.Khomenko et al. [20].

Environmental factors. Hence, in order to calculate Ideality in practice it is necessary to measure somehow Economic performance and expenses (Pe, Ee), Social performance and expenses (Ps, Es), and Environmental parameters (Pen, Een). Therefore, an instant Ideality can be described as:

$$I = f(It, Ie, Is, Ien) \tag{4}$$

Where, It (technical Ideality) equals the ratio of $\Sigma Pt/\Sigma Et$; Ie – is economic Ideality ($\Sigma Pe/\Sigma Ee$); Is – is social Ideality ($\Sigma Ps/\Sigma Es$); Ien – is environmental Ideality ($\Sigma Pen/\Sigma Een$).

For the purpose of system evolution forecasting it is necessary to consider changes of Ideality over time (within the forecasted timeframe at least). Consequently, changes of Ideality over a time can be described as:

$$\frac{dI}{dt} = f(\frac{dIt}{dt}, \frac{dIe}{dt}, \frac{dIs}{dt}, \frac{dIen}{dt}) \tag{5}$$

Currently, we are working on a practical way to solve this equation or bypass it.

There are some practical approaches for measuring the instant technological Ideality. However, it is an open question: "How to quantify Idealities from other contexts using compatible units?"

Analysis of technology forecasting practice gives the evidence that it is only the technological context which is not sufficient for reliable forecasting of system evolution. The future state of certain technologies depends on the nearest super-systems (contexts) transformations and intrinsic interactions between super-systems, systems and sub-systems. This processes demands more knowledge which we can get from data about the technical feasibility of emerging technologies and from known technology barriers.

In order to handle situations with economic, social and environmental issues a 'proverbial wisdom' is to perform a series of interviews with experts (e.g. kind of Delphi surveys). As we can sum up after the literature reviews, such practice produces qualitative results with many hidden biases [13, 14, 15].

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In the practice of forecasting emerging technologies, there is an inevitable question to be answered: How to forecast the future of emerging technologies using an S-curve and the law of natural growth before systems pass the 'infant mortality' threshold (Figure 2, α point)?

The working hypothesis we are testing actually proposes to measure the process of natural growth of knowledge to predict the future of emerging technologies.

Before overcoming the 'infant mortality' threshold and arriving at the exploitation phase of the life-cycle, a new technology passes through exploration and experimentation stages. Each phase has its learning curve of knowledge growth (see Figure 6). Learning curves represent knowledge acquisition in a percentage of solved problems. Problems can be mapped [22] for emerging technologies using techniques and methods from OTSM-TRIZ [20].

There are still several questions to be answered and tested through the practice of forecasting. An important one, among others, is How to measure knowledge, obtained within exploration and experimentation phases? How can one calculate the time necessary for decisions about the transition to the next phase (e.g. experimentation)?

# 6   SUMMARY

The application of the law of natural growth has imperishable value for the understanding of the transformations of complex systems. Evolution of any kind of system can be represented as successive S-curves of technologies.
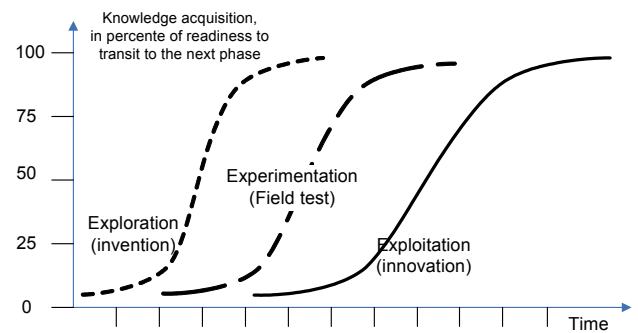


Figure 6. Knowledge acquisition for emerging technology.

One can find logistic curves inside S-curves due to the fact that the logistic curves represent fractal aspects. One can also find chaos by getting the logistic equation discrete, especially within technology substitution phases. The logistic S-curve of natural growth is a basic model of the Volterra-Lotka equations, which are reliable for describing and forecasting different forms of competition and technology substitutions. Applied in a discrete form with careful definition of competing 'species', logistic equations would give a picture, where growth in competition, self-organization, complex adaptive behaviour, interactions in fractals can be shown.

One of the strongest points of S-curve application is that it is based on nature. It represents a natural law of growth by using simple logistic equations. Thus, quantitative analysis of system transformation contributes essentially to the reliability of forecasting.

The weak point of S-curve application is linked to the necessity of applying data about the past of system transformations in order to fill the logistic equation with meaning. The results of studies [5] showed that "the more precise the data and the bigger the section of the S-curve they cover, the more accurately the parameters can be recovered." In other words, when a system is closer to the end of its evolution, it lessens the level of uncertainties and increases the accuracy of the forecast with the S-curve.

There is a question: 'When can we use an S-curve?' In other words, 'When should we address cumulative growth?' S-curves and logistic equations depict natural growth in competition. When the analysed process can not be measured as growth (or decline) in competition a simple qualitative application of an S-curve usually produces some misleading results and conclusions. According to our experience and as reported in the results of various literature, it is not trivial to identify appropriate measurement parameters for the vertical scale of the S-curve for medium- and long-term forecasting. Nevertheless, it is unavoidable for getting a forecast, and not only a vague moot vision. The obtained forecast can be dramatically different, depending on the selected parameter for measuring the evolution of the system.

*"The ultimate test of the forecaster is an accurate and reliable forecast not the elegant or easily applied method."*

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