APPLICATION OF S-SHAPED CURVES (edited transcript)

Presented at ETRIA TRIZ Future Conference 2007, Frankfurt

by Dmitry KUCHARAVY and Roland DE GUIO, 7th November 2007.

...A law that becomes violated is not much of a law[1]...

The famous book about the innovator's dilemma [1] Cristinsen starts with insights from the hard disk industry. It is interesting to notice, that those insights are based on the rigorous data analysis and fitting logistic S-shaped curves to data. Some results of the analysis were published 1992 in the article about limits of the technology S-curves [2].

Application of S-shaped curves is interesting but a narrow topic among many in our research about Technological forecasting. The certain area of application for the extrapolation methods by logistic S-curves for technological forecasting can be clarified using publications of Ayres, Martino, Makridakis, Armstrong, Porter, Glen and others [3, 4, 5].

The aim of presented results is to convince readers that it is dangerous practice to plot S-curves as free-hand drawing. Unfortunately, it is usual practice, especially in TRIZ society. Every second presentation within ETRIA TRIZ Future Conference 2007, Frankfurt mentions S-curve, but all of them are done arbitrary by hand. Why is it destructive? Despite such a practice provides quick and visionary results, free-hand made curves mislead researches and hide the real trends.

We are going to provide our arguments, observed peculiarities, and conclusions through six Questions about simple logistic curves:

Q1: What does S-curve mean?
Q2: Why does it work?
Q3: Where is it applied and why?
Q4: Qualitative or quantitative?
Q5: So what?
Q6: What would we do with it?

Q1: What does S-curve mean?

S-shaped curves are numerous and different not only by essence, but mostly by names. They possessed many names[2] through the history since at 1833 Belgian mathematician Pierre-Francois Verhulst proposed logistic equation as model of population growth. Basically all S-shaped curves can be subdivided by symmetrical and non-symmetrical.

In presented topic we are going to apply most generic name which reflects the very essence: logistic curve of natural growth. Model of *natural growth* of autonomous systems *in competition* might be described by logistic equation and symmetric (simple) logistic S-curve where 'natural growth' is the tendency of parameters to increase its value during time (i.e. evolution). While something growth, something is going to

[1] From article of T.Modis

[2] 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 other names can be found.

decline in accordance with First law of thermodynamics[3]. Therefore, any growing process is tightly linked with competition for resources. Many different types of competitions are recognized [6, 7]; but this question is out of our scope.

In the scope of logistic equation the 'natural growth' is defined as the ability of a *'species'* to multiply inside finite *'niche capacity'* through a given time period. In other words, for technological systems, 'species' are growing variable (variable the value of which grows during time). For instance, efficiency of engine, population, size, weight, number of words, … i.e. value we are interested about. In engineering practice, a function of system and critical-to-quality features and their values are identified explicitly. 'Niche capacity' for engineering systems can be interpreted as available resources of space, time, substances, consumers and other material and non-material (e.g. knowledge, cultural needs) elements required for operation.

Internal mechanism of natural growth under competition for resources can be presented various ways. For instance in system dynamic one of the patterns of system's behavior (system archetype) called 'limits to growth' is described with help of causal loop diagram the next way:

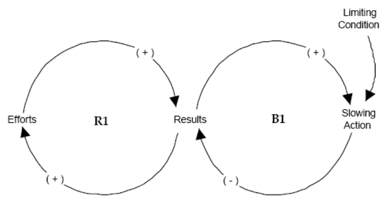

Figure 1. Causal loop diagram for limits of growth[4]

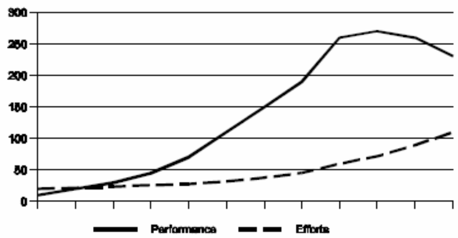

Figure 2. Arbitrary diagram for limits of growth4

For socio-technical systems the three-parameter S-shaped logistic growth model is applied for describing a continuous "trajectories" of system's growth or decline through time.

$$N(t) = \frac{\kappa}{1 + e^{-\alpha t - \beta}} \quad (1)$$

Where, *N(t)* – number of 'species' or growing variable to study; *e* - the base of the natural system of logarithms, having a numerical value of approximately 2.71828..

The three parameters that specify the curve, are κ, α, and β:

[3] *Thermodynamics*: the first law of thermodynamics is a statement of the conservation of energy for thermodynamic systems, and is the more encompassing version of the conservation of energy. The conservation of energy states that the total amount of energy in any closed system remains constant but can't be recreated, although it may change forms, e.g. friction turns kinetic energy into thermal energy. (Wikipedia, Nov. 2007)

[4] Source: Braun, W. *The System Archetypes*. The Systems Modeling Workbook. 2002.

κ – is the asymptotic limit of growth[5] (it might depend on available space, market niche, or carrying capacity); for case N(t) << κ, logistic model closely resembles exponential growth;

α – growth rate parameter specifies "width" or "steepness" of S-curve;
it is frequently replaced with a variable that qualifies time required for "trajectory" to grow from 10% to 90% of limit κ (carrying capacity), a period named *characteristic duration, or Δt*;

β – parameter specifies the time (t_m) when the curve reaches 0.5κ or the midpoint of the growth trajectory $N(t_m)= \kappa/2$; point of inflection t_m implies symmetry of simple logistic function;

Usually the parameters α and β are calculated by fitting the data.

Equation (1) is a solution of differential equation (2) applied as model for exponential growth with limiting feedback:

$$\frac{dN(t)}{dt} = \alpha N(t)\left[1 - \frac{N(t)}{\kappa}\right] \qquad (2)$$

Where limiting term $\left[1 - \frac{N(t)}{\kappa}\right]$ is close to 1 if N(t) << κ and approach 0 as N(t) → κ.

In order to present each parameter explicitly, we apply fit to data for annual TRIZ-publications in English from 1996 to 2006. Data collected on the basis of publications at conferences within the time span 1999-2006 (ETRIA[6] TFC 2001-2006, and TRIZCON[7]) and publications on the website triz-journal.com 1997-2006[8]. The same articles from different sources where taken into account just once. Prepared data to fit logistic curve are presented in Table 1.

Table 1. Cumulative number of TRIZ publications in English (1996-2006)

Year	TRIZ Journal	TRIZCON	ETRIA TFC	total, year	**cumulative**
1996	5			5	*5*
1997	32			32	*37*
1998	70			70	*107*
1999	68	26		94	*201*
2000	65	32		97	*298*
2001	75	36	30	141	*439*
2002	86	41	51	178	*617*
2003	99	26	31	156	*773*
2004	87	27	49	163	*936*
2005	90	37	58	185	*1121*
2006	103	34	58	195	*1316*

Logistic curve is fitted to data using Loglet Lab version 1.1.4 software[9].

[5] Another name is 'perceived potential'.
[6] Annual TRIZ Future Conference of European TRIZ Association, Europe [http://www.etria.net].
[7] Annual Altshuller Institute for TRIZ Studies International Conference, USA [http://www.aitriz.org].
[8] The TRIZ Journal Article Archive [http://www.triz-journal.com].
[9] http://phe.rockefeller.edu/LogletLab/

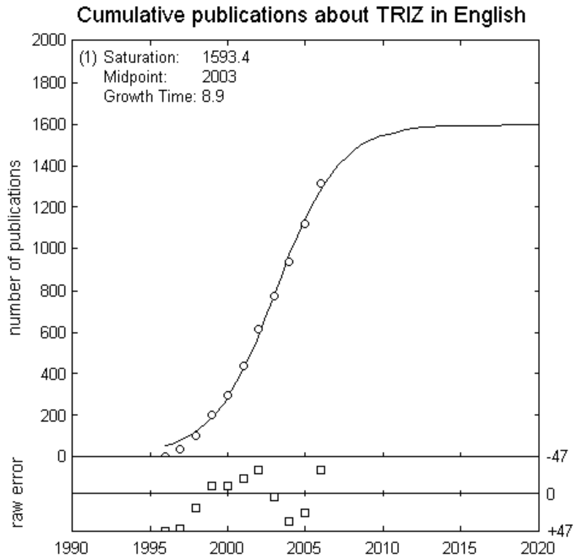

Figure 3. TRIZ publications in English

How this fit is useful to forecast evolution of TRIZ publications can be checked next years. The past data gives us opportunity to recognise a trend and to extrapolate it to the future. We are going to apply this example to illustrate the three parameters of simple logistic curve only.

In the bottom of Figure 3 the raw residuals are presented. Residuals show how accurately the curve fits the data. Residual presents the difference between an observed value and the fitted value for the same value of time. A correct fit has residuals randomly above and below the x-axis. A cluster of consecutive points locating all above or all below the x-axis may indicate an inaccurate fit.

Logistic S-curve represents cumulative growth of variable to study, when bell-shaped curve is a symbol of growth rate. If we count number of TRIZ publications year after year, the data will be close to the bell-shape distribution (so-called 'normal distribution'[10]). Data will represent a rate of growth. If the data will be represented as cumulative number of TRIZ publications, the data can be approximated using simple logistic S-curve. While the rate of grows follows a bell-shaped curve, the cumulative growth traces out an S-curve. If we have bell-shaped curve, the S-curve can be derived and vice versa (see Figure 4.)

[10] Known as Gaussian distribution. Johann Carl Friedrich Gauss became associated with these distributions after he analyzed astronomical data using them.

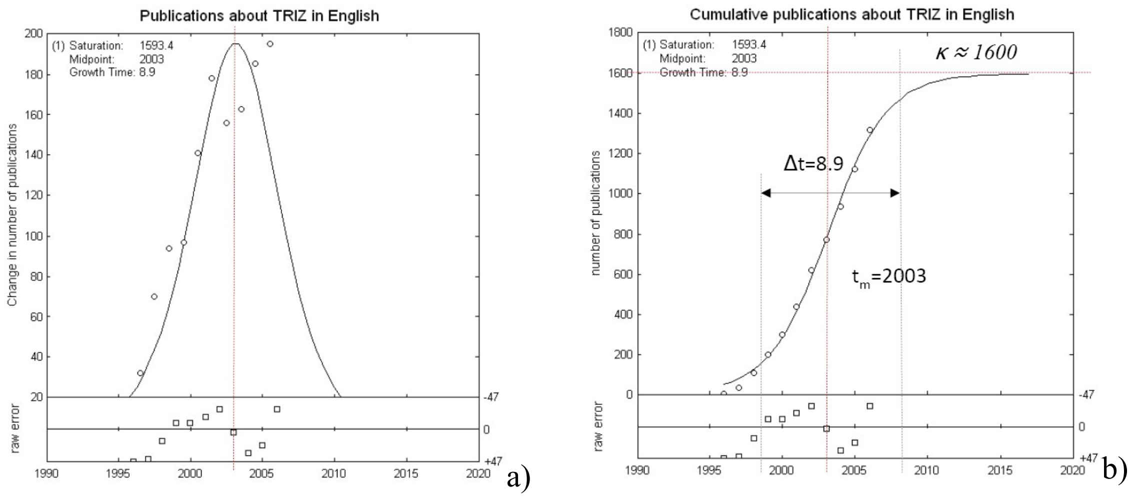

Figure 4. Rate of growth and cumulative number of TRIZ publications

Different publications [8, 9, 10, 11] report higher performance of practical forecasting with simple symmetrical S-curves. Thus, we focus our research efforts on application of this type of curves, despite of existence of others [12]. The simple logistic is useful in part because of its small number of parameters, the clear interpretation of obtained results, it is easy-to-apply, and it is possible to apply for the description of more than one logistic pulse (bi-logistic, and multiple logistics).

What are the meanings of each of *three parameters for simple logistic curve*? First parameter is the ceiling of growth is represented by κ in equation 1. Proposed fit to data results the expected value of κ (number of publications) within confidence intervals ($1430 < \kappa < 1750$; Figure 7). Second parameter represents growth period. In TRIZ dictionary it correspond to the time period between points α and β. This growth period closely resemble to linear growth. Third parameter of simple logistic specifies time (t_m), when curve reach midpoint of the growth trajectory. This is point of symmetry of simple S-curve. The t_m corresponds to the vertex of bell-shaped curve.

It is necessary to notice, that fitting technique using past data gives opportunity to obtain two parameters out of three as result of fitting curve to data. However, the point of biases is the assumptions about upper limits of growth.

The results of study based on forty thousand fits [13] showed that the more precise the data and the bigger the section of the S-curve they cover, the more accurately parameters can be recovered. The reliability of forecasting about ceiling is higher when available data cover more than half of S-curve. What can be done when there is lack of data?

In scope of TRIZ, the *causal method* is applied to compensate the lack of data. Frequently as causal variables are applied number of inventions, level of inventions and profitability values [15]. Nevertheless, in his famous Creativity as an Exact Science [15], G. Altshuller discusses about three levels of limiting resources a system faces within its evolution along S-curve: limits of system resources, limits of available resources and physical limits of resources in super-system.

To improve reliability of medium and long-term technological forecasting it is proposed to apply the knowledge about limiting resources (causes), in order to forecast limits of growth for particular system when lack of data for emerging technologies does not allow applying the naïve method.

Naïve and Causal methods

Naïve methods: $Y_{t-d}, \ldots, Y_{t-2}, Y_{t-1}, Y_t \rightarrow Y_{t+h}$

Causal methods: $X_{t-d}, \ldots, X_{t-2}, X_{t-1}, X_t \rightarrow X_{t+h}$

$$\begin{array}{ccc} X_{t-d}, \ldots, X_{t-2}, X_{t-1}, X_t & \rightarrow & X_{t+h} \\ \downarrow b & & \downarrow b_h \\ Y_{t-d}, \ldots, Y_{t-2}, Y_{t-1}, Y_t & & Y_{t+h} \end{array}$$

Figure 5. Naïve and Causal methods. Adapted from [14]

Where, Y – the variable to be forecasted; X – causal variables; d – periods of historical data; h – periods in the forecast horizon; t – time period (e.g. year); b – the causal relationships in the historical data; b_h – the causal relationships in the forecast horizon.

Naive model: a model that assumes things will behave as they have in the past. In time series, the naive model extends the latest observation. For instance, Random walk model (sub-set of naïve models): it assumes that, from one period to the next, the original time series merely takes a random "step" away from its last recorded position. Causal model: a model that goes beyond of variable of interests by asking "why"?
Naïve methods apply past data about the variable to be forecast (Y) in order to identify the trends and extrapolated them into the future. Causal methods apply causal variables (X) to foresee future changes of target variable (Y). A causal variable (X) is one that is necessary or sufficient for the occurrence of an event (Y). It is assumed also that X precedes Y in time. Past data about causal variable (X) are used in order to identify trends and apply this knowledge to foresee future values of target variable (Y).

Natural law of logistic growth under competition can be described by various ways. It entirely depends on aims of analysis and selected values on the axes. For instance, the logistic growth curve can be linearized with Fisher-Pry transform [16, 13, 9].

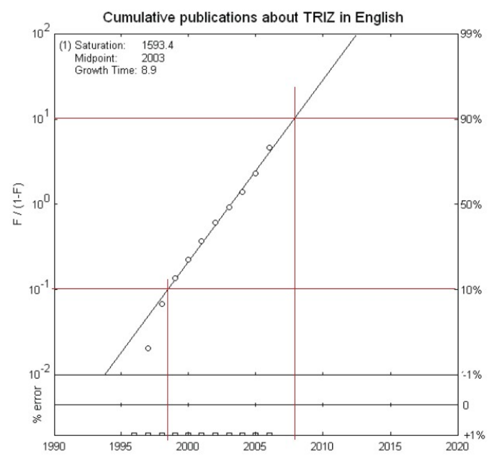

Figure 6. Fisher-Pry transform

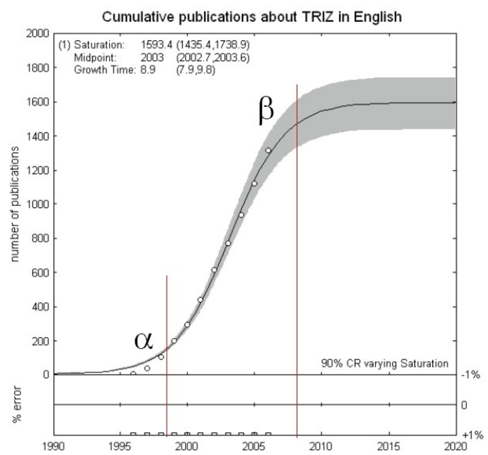

Figure 7. S-curve with confidence intervals

The plot on the Figure 6 presents the same data and trend as S-curve on the Figure 4. Fisher-Pry transform facilitates comparison to other logistic growth processes, as soon all the curves are normalized to limit of growth κ (see equation 3), more than one logistic can be plotted on the same chart. Therefore, competition of multiple systems over time can be simulated, presented and analyzed.

$$FP(t) = \left(\frac{F(t)}{1 - F(t)}\right), \text{ where } F(t) = \frac{N(t)}{\kappa} \qquad (3)$$

When FP(t) is drawn on a semi-logarithmic scale, the S-curve becomes linear. The merit of presentation using Fisher-Pry transform is ability to put on the same diagram competitive systems with various performance and different working principles. The "infant mortality" threshold[11] corresponds to 10^{-1} (or 10%) on Figure 6. The "saturation" threshold[12] corresponds to 10^{1} (or 90%) on Figure 6.

The diagram on the Figure 7 shows the results of fit to data with confidence intervals. In accordance with applied algorithm to consider data accuracy and residual, the cumulative number of articles (ceiling) lies in between 1435 and 1738 articles, when midpoint of growing process is located between July 2002 and June 2003. Characteristic duration of growth estimated in between 7.9 and 9.8 years.

In order to forecast technological systems evolution using natural law of growth and logistic curves it is applied four assumptions:

1. How big will be value of limit of growth ("ceiling")? It is necessary to find a law of nature (repeatable regularity) which will give proof of ceiling.
   In order to improve accuracy of forecasting, it is proposed to analyze the dynamic change of limiting resources for driving contradiction of system evolution.

2. Logistic growth (S-shaped curve) can facilitate an accurate forecast. It is proposed to apply the logistic model which is symmetric around the midpoint. This assumption is based on hundreds of reported successful forecasts using S-shaped curves and several reviews.

3. Characteristic duration (Δt) and time to reach midpoint of curve (tm) can be defined using past data. In order to reinforce and recheck two out of three parameters of S-curve it is proposed to apply knowledge about cycles of socio-technical systems evolution.
   [Kondratieff cycles, Schumpeter business cycles, Tchijevsky cycles, Mensch, Marchetti, Modis, etc.]

4. Technological evolution for certain function(s) is continuous process (e.g. transportation systems). If the evolution from one technology to another one took place in past, it will happen in future as well.

In order to improve reliability of forecast using logistic growth curves, it is necessary to support each assumption by practical and theoretical results.

[11] In TRIZ-literature it is named α-point.

[12] In TRIZ-literature it is named β-point.

Q2: Why does it work?

…Everything can be fitted with enough parameters1…

Logistic curve describes evolution of system under limitation of resources through time. In the other words, it represents changes of system parameters under competition. This is the essential meaning of S-curve. What are the strong points and what are the weak points of such representation?

Strength:

- Properly established logistic growth reflects the action of a natural law. It works everywhere, independently from scale. E.g. for nano-level (molecule clustering), micro-level (yeast growth), macro-level (economy of country), and mega-levels (stars and galactic growth).
- Relatively easy to apply. Clear concept and working mechanism. It is clear what is behind of plotted curve, those we trust to S-curve description.
- Can be applied for systems where the growth mechanisms are understood and where the mechanisms are hidden. For instance it is difficult to explain, why number of articles for English TRIZ publication will not grow the same way as during last five years. Presented results were unexpected before fitting logistic curve to data.

…and Weakness:

- What is growing variable (species) and what is the underlying competing mechanism in particular case? It is not evident what can be selected to measure growth of system evolution. Most of the presentations within the ETRIA TRIZ Future conference have nothing on vertical axis. It is a challenging problem to define growing parameter and to measure it. Lack of formal procedure to define growing variable is not particular problem of TRIZ society. In border of our research we tried to find the answer in different domains by asking practitioners and reviewing literature. A formal procedure to identify growing variable with confidence is 'on demand' till now.
- Biases towards low or high ceiling: 'no two people, working independently, will ever get EXACTLY the same answer for an S-curve fit'.
- Should we fit S-curve to the raw data or to cumulative number? This question is not easy to answer especially at the beginning of forecasting. Which sort of data is wholesome to disclose trends of particular system evolution? The answer depends on essential mechanism of system growing under competition and how do we perceive this mechanism.
  Fitting technique errors and uncertainties mostly depends on applied data and algorithm which have certain accuracy and precision.

Analysis of strengths and weaknesses of logistic S-curves application in context of technological forecasting can be found at publications of Modis [11, 13], Ayers [10], Christensen [2], Martino [4] and many others.

Q3: Where is it applied and why?

Before analyzing publications about logistic S-curve in English speaking TRIZ society, it is interesting to see how many papers were published in one of the leading international journal "Technological Forecasting and Social Change[13]". Data about publications at other journals: Future, International Journal of Forecasting, Journal of Future Studies, Journal of Product Innovation Management, the Futurist, Ecological Modelling and many others were not taken into account.

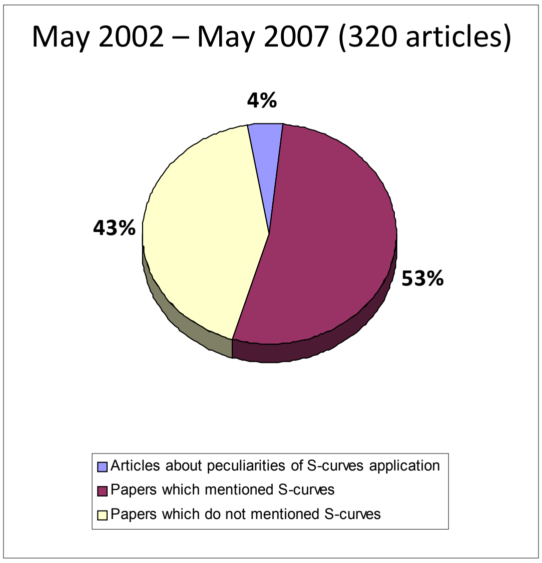

Figure 8. Publications at the International Journal of Technological Forecasting and Social Change (2002-2007).

The International Journal of Technological Forecasting and Social Change 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.

Various books and publications report application of S-curves as a part of several forecasting methods: Trend Impact Analysis, Curve fitting technique, Decision and Statistical Modelling, Text and Data Mining, Life Cycle Analysis, Theory of Innovation Diffusion, Emerging issues analysis and others [17, 18, 19, 20, 21, 22].

In order to predict technological futures for better decision making, studies about technology maturity at the industry level are regularly performed. Our review of literature showed, that most of them apply the logistic curves analysis as an important part.

In his famous book 'Stalemate in Technology' [23], German scientist Gerhard Mensch applied logistic curves to disclose regularities of basic innovation development for long run of industrial revolutions. Logistic curves and Fisher-Pry transform give opportunity to foresee technology substitution.

At the International Institute for Applied Systems Analysis (IIASA , Laxenburg, Austria http://www.iiasa.ac.at/) logistic S-curves have been applied by Marchetti, Nakicenovic, Grübler and other researchers during the last 35 years for studies about

- the future of primary energy sources and vectors and energy dynamics,
- 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,

[13] http://www.elsevier.com/wps/find/journaldescription.cws_home/505740/description#description

- macro- and micro- economic trends,
- the growth of crime and terrorism,
- environmental changes and problems,
- the evolution of telecommunication systems...

Detailed studies about technology maturity and substitution for different industries were done by Constant (1980) for aircraft engines; Roussel (1984) for foam rubber; Grübler (1987) for steel and coal industries; Modis and Debecker (1988) for computer industry; Van Wyk, Haour, and Japp (1991) for permanent magnets; Christensen (1992) for disk drive industry; Ausubel and Marchetti (2001) for transport systems; Modis (2005) for Internet growth; Foster (1986) for many examples from a range of industries. It is impossible to take into account whole set of studies done with use of logistic curve as soon it is a common practice during last decades.

The main question for such studies is about technological substitution: When and How one technology will substitute another one? For instance, within period from 1980 to 1990 more than 50 research reports in English were issued, dozen published books present hundreds diagrams with logistic S-curves. In his article about strengths and weaknesses of S-curves [11] Theodor Modis write: “For the last 22 years I have been fitting logistic S-curves to data points of historical time series at an average rate of about 2–3 per day. This amounts to something between 15,000 and 20,000 fits.”

It is difficult to find some area of systems evolution were S-curves analysis has not been applied yet. Hundreds of biographies of creative persons like Mozart, Bach, van Gogh were presented through logistic curves. In order to understand some mechanisms of scientific discoveries the process of discovery the stable chemical elements was analysed as sequence of successive S-curves (Figure 9).

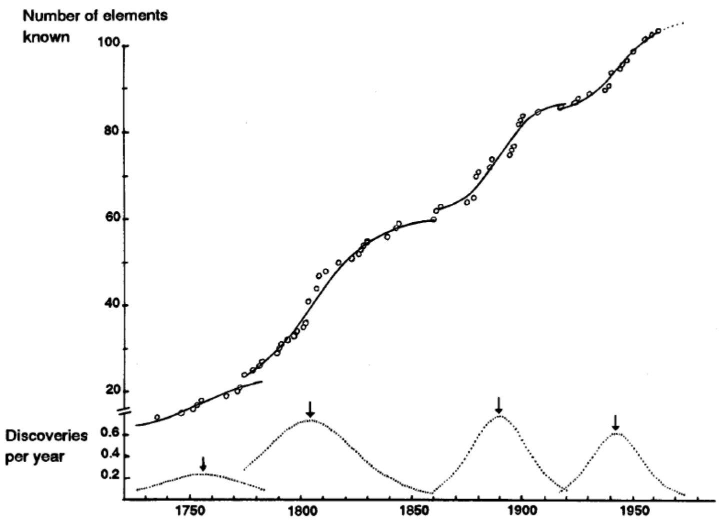

Figure 9. Clusters of discovery chemical elements. *Source: [13]*

Study using logistic curves about virus propagation and competition among death diseases leaded to unexpected conclusion that "…disease starts to phasing out well before effective medication becomes perfected and widespread…" [13].

Computer technologies dynamics and transfer of market value from platform IBM+DEC to the platform Microsoft+Intel follows logistic curve as well (Figure 10). The midpoint of two S-curves, when two platforms shared marked equally correspond to 1993.

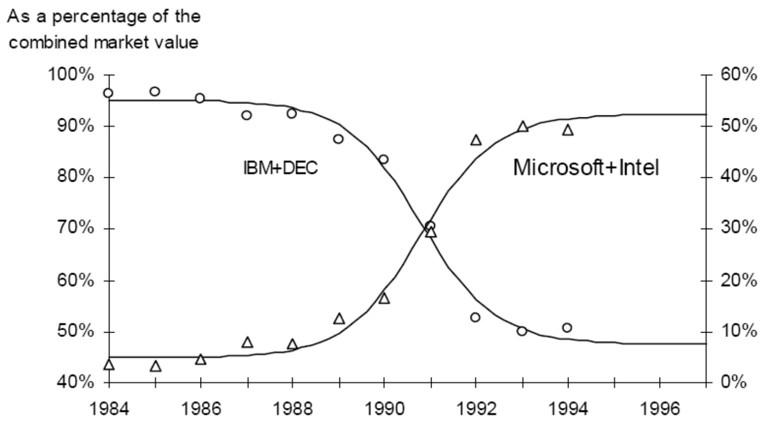

Figure 10. Transfer of market value. Source: [13]

Competition between two technologies can be presented in linear vertical scale. However, for competition between several technologies it is much more practical to use the logarithmic scale (e.g. see Figure 6).

International Institute for Applied Systems Analysis is a nongovernmental, multidisciplinary, international research institution. It was founded in October 1972 by academies of science of 12 nations from East and West. Now, the institute has 18 National full Member Organizations (http://www.iiasa.ac.at/). This unique institution, established in time of Cold War with participation of United State, former Soviet Union, Germany, Japan and other countries. What is the link between this multidisciplinary research institution and logistic curve of growth? During more than 35 years, researches of this institute apply the law of logistic growth for their research. Incomplete list of projects covers next areas and technologies:

- 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…

Interim reports and many publications about are available through the Internet (e.g. http://www.iiasa.ac.at/Admin/PUB/ , http://www.cesaremarchetti.org/publist.php) today.

For instance, how does a long term study about primary energy sources look like?

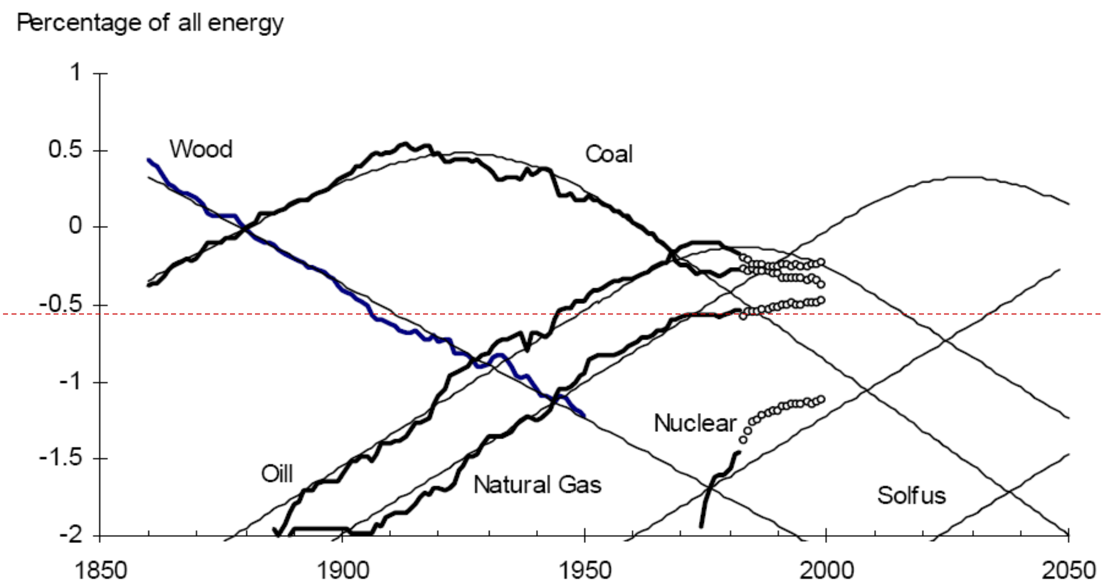

Figure 11. Competition between primary energy sources.
Source: Adapted by Modis T. [13] from a graph at [24][14].

Dots on the Figure 11 present data when lines are the fitting results. We can estimate how good lines correlate with the data. In order to understand mismatching of data and curves it is necessary to notice, that vertical scale is logarithmic.

What is fascinating at Figure 11? It is unknown what it will be[15], however it is projected when and where the 'unknown' primary energy source will start to grow and what will be the speed of growth.

On the Figure 11, at each moment there is 100% of energy represented through different primary energy sources. For instance, the substitution process shows that the major energy source between 1880 and 1950 was coal, when oil became the dominant source from 1940.

Q4: Qualitative or quantitative?

The intriguing question is: should we perform qualitative study in favor of quantitative one? Regarding to TRIZ traditions the qualitative analysis using S-curve of system life cycle is preferable for inventive problem solving practice [26]. Outside of TRIZ researches society there are proposals for applying S-curves qualitatively as well. For instance it is suggested by Molitor to develop "patterns of change" based on qualitative application of S-curves [22]. It was reported about 100 pattern of change which can be applied in border of forecasting models.

However, there are much more case examples of quantitative application of logistic curves of growth application. More than 150 articles of Marchetti, dozens articles and 4 books from Modis, dozens articles and software from research team of Ausubel are just a part of the long list for quantitative application of logistic S-curves for study about artificial and natural systems.

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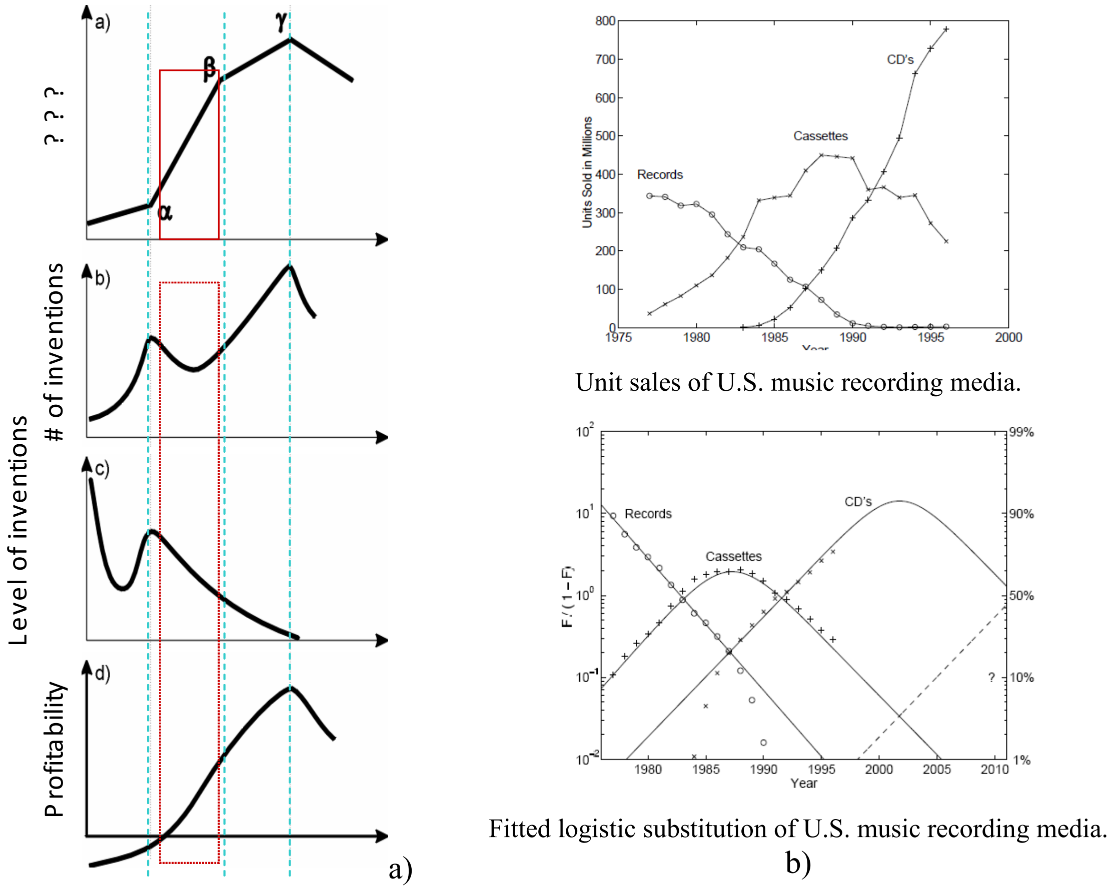
[14] "Data, fits, and projections for the shares of different primary energy sources consumed worldwide. For nuclear, the dotted straight line is not a fit but a trajectory suggested by analogy…The small circles show how things evolved since 1982 when this graph was first put together" [13, p.161]

[15] "… The futuristic source labelled "Solfus" may involve solar energy and thermonuclear fusion…" [13, p.162]

Using analysis, proposed by Altshuller [15] it is possible to identify a position of analyzed system on the S-curve. Even the questions regarding to vertical axis of diagram and exact plot of S-curve itself stay unclear. This approach was adapted and tested in different countries for different technologies [27, 28, 29, 30, 31, 32]. Presented studies show the potential and limitations of analyzed technologies qualitatively using quantitative analysis of inventions dynamic, level of inventions and profitability. Nevertheless, such analysis has not been applied for study about competition of several technologies. In fact, it does not present the answer for questions When and Where the technology "B" will substitute the technology "A"?



Unit sales of U.S. music recording media.

Fitted logistic substitution of U.S. music recording media.

a) b)

Figure 12. a) quantitative TRIZ application of S-curve; b)qualitative analysis: US music recording media (1997). Source: Adapted from [25]

On the Figure 12 b an analysis of US music recording media using the quantitative logistic substitution model is presented [25]. In a time, when forecast about U.S. recording media was done, it was unknown, what will be the technology to conquer CD disks. Authors supposed it would be DVD. However, despite mistaken view about technology, quantitative forecast using logistic substitution model predicted pretty well the time and the speed of a new technology (MP3) growth.

The answer for question about "qualitative or quantitative" is not so easy. Now we can not answer for the question directly. Both approaches have strong and weak points. Before reformulating the question it is necessary to look to the nearest super-system (where forecast suppose to be applied): What is more useful for decision making[16] and decision taking? Results of performed research about the last question can be expressed in a shape of the following contradiction:

[16] Decision making refers more to development decision and prepare all necessary components for, whereas decision taking is the act of deciding. Decision taking results responsibility.

> If method to assess technology barriers apply qualitative analysis, then it can be applied for long term forecast due to conformity with law (of dialectic) of transformation quantity to quality; however, it is difficult to achieve repeatable results from experts, it costs a lot, it takes a lot of time (low frequency to update results), the results contains a lot of biases.
>
> If method to assess technology barriers apply quantitative analysis, then the results can be obtained a repeatable way, the process is cost effective, it is possible to update result frequently, the results consist less biases; however, it is not compatible with law of transformation 'quantity to quality', consequently it is mostly applied for short-term forecast.

It is required to forecast the sequence of transformations quantity to quality and to be able to measure new (unknown at present time) quality in order to apply quantitative models for continuing the chain of technology transformations.

---

law of transformation quantity to quality

"For our purpose, we could express this by saying that in nature, in a manner exactly fixed for each individual case, qualitative changes can only occur by the quantitative addition or subtraction of matter or motion (so-called energy)."
[Engels' Dialectic of Nature. II. Dialectics. 1883]

In other words, for long term forecast, it is necessary to answer: How can we satisfy the law (dialectic) of transformation quantity to quality in a long run?

In fact, the analysis should be qualitative *and* quantitative. The desired result about the method to study the future can be formulated the following way: it provides repeatable results, using cost effective process, results can be updated frequently, results do not consist biases of experts, it represent transformation of quantity to quality, it describes future qualities a measurable way.

In order to summarize Pro and Con of qualitative and quantitative application of S-curves the table on Figure 13 is proposed. This figure presents results of a brief comparison analysis of application the logistic S-curves in three contexts: inventive problems solving, management of innovations and technological forecast.

For instance, in border of inventive problem solving context, one of the critical question for quantitative application of S-curve analysis is: How to measure a new quality? Pioneering inventions (Altshuller, 1979) or Basic innovations (Mensch, 1979) produce new qualities. Measurement of anything implies comparison with known things. Cognition question arises in such a situation. Probably due to this issue, the basic innovations take so long time to be adapted. For instance, according to Mensch's study, it took 111 years for photography, 20 years for vulcanized rubber, 26 years for gasoline motor, 79 years for incandescent light bulb, 29 years for high voltage generator.

Context	Qualitative	Quantitative
Inventive problem solving	Pro: Quick and easy to perform. No necessity to collect and refine data. Con: Ambiguity of definition (e.g. large, small). Partial & biased.	Pro: Clear definition of features and values to improve. Con: How to measure a new quality?
Management of innovation	Pro: Low resistance for implementation. Con: How to position the innovations in time, in space, and in competitive environment?	Pro: Plausibility for decision making and strategic planning. Higher-impartial. Con: It takes a lot of efforts for data gathering and refining.
Technological forecasting	Pro: Compatible with long-term forecast. Con: Inaccuracy of forecasting in time (when?) and in space (where?). Higher-biased. How to deal with competitive technologies?	Pro: Results are measurable and precise. Repeatable, adaptable, and cost effective. Con: Based on past data and trends. Indirect biases through computation models, assumptions and data.

Figure 13. Qualitative or Quantitative application of S-curve study.

Other examples are from technological forecasting context. First, How to take into account by qualitative S-curve analysis the competitive technologies? It is generally known, that any system evolves in the competitive environment. How to consider this fact in border of qualitative analysis of S-curves?

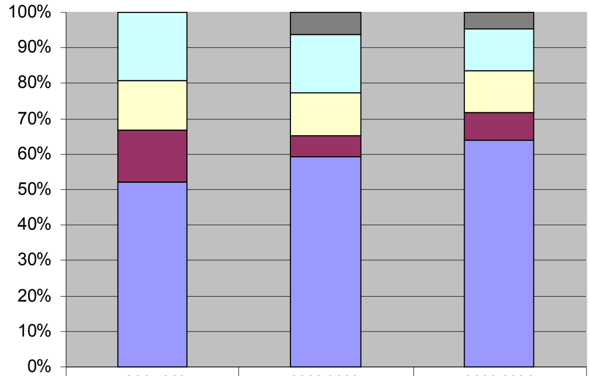
Second, quantitative analysis using logistic S-curves can hide biases and assumptions in the applied computational models. That is why the simple (symmetric) logistic S-curves are so popular for forecasting. Thanks to its simplicity, it does not give a place for hiding biases and preconceptions. For complex mathematical models it is difficult to differentiate biases and model peculiarities.

Third, based on the past data, quantitative logistic curves reveal the trends from past. This is a reason they have a limited foresight. New trends appear as synergy of competition and cooperation between technologies permanently. How to incorporate them in the forecast models?

In TRIZ society, the dominant S-curve analysis is *qualitative* one. From 1996 to 2006 it was published more than 1300 articles in English language. In order to summarize 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[17] TFC 2001-2006, and TRIZCON[18]) and publications on the website TRIZ Journal[19] (1997-2006). 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.

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

Out of 1300 publications only 11 papers present the case studies with trials to apply S-curves quantitatively. Total number of papers which mention S-curve of technical system evolution is about 137 (see Figure 14). The diagram on the Figure 14 shows the dynamic of interests in application of S-curve in different contexts in three periods: before 2000, from 2000 to 2002, and from 2003 to 2006. In context of forecasting there were published about 20 papers about S-curve usability. In context of problems solving, the growing interest to S-curve outputs 17 papers. Case studies with quantitative analysis about patents, profit and level of inventions result 11 publications. Most of the articles just mention S-curve as useful analytical tool without details – 83 papers.



	1996-1999	2000-2002	2003-2006
Non-grouped hypothesis	0	3	3
In context of forecasting	4	8	8
In context of problem solving	3	6	8
Case studies using S-curve	3	3	5
Just mentioned	11	29	43

Figure 14. TRIZ-publications about S-curve in English.

Q5: So what?

It is necessary to notice that:

- Extrapolation of trends using logistic S-curves model is essentially quantitative forecasting methods with qualitative interpretation of results.
- When the analyzed process cannot be measured a qualitative application of S-curves can produce misleading results and conclusions.
- The forecast can be dramatically different, depending on the selected parameters and the way to scale it using simple logistic curves.

Why is it dangerous to plot S-curve by hand without clear parameters on the vertical axis? It is misleading to plot S-curve without measurable parameters as soon we put our unverified assumptions and hypothesis, but present them as the results of data observation. Non-existing, imaginable trends are presented as result of practical verification with data. In fact, such "trends" are not the trends, but only ideas how trends can be. Instead of observation of facts and tendencies based on past data, there are hypothetical trends based on particular experience, private opinions and speculation. Such a practice reinforces biases and complicate situation in scope of long-term forecasting when many competitive technologies and several contexts should be taken into account. Such a practice leads to time and other resources consumption for going wrong directions.

Self-complication and self-confusion take place as result of drawing S-curves by hand, without measured data behind. Obtained "trends", based on the particular hypothesis can not be validated, as soon there is no data to be checked and no algorithms to construct curves behind of them.

In forecasting practice it is not enough to arrange measurable growing variable. It is important to scale growing variable properly. Wrong scaling of speed as growing variable leaded to forecast that 'the speed of light seem to be achieved by 1982' (left plot on Figure 15). Using the same historical data and "envelop curve" as technique the forecast at the right plot of Figure 15 is more reliable. Plotted on a different scale these diagrams lead to a different sort of prediction.

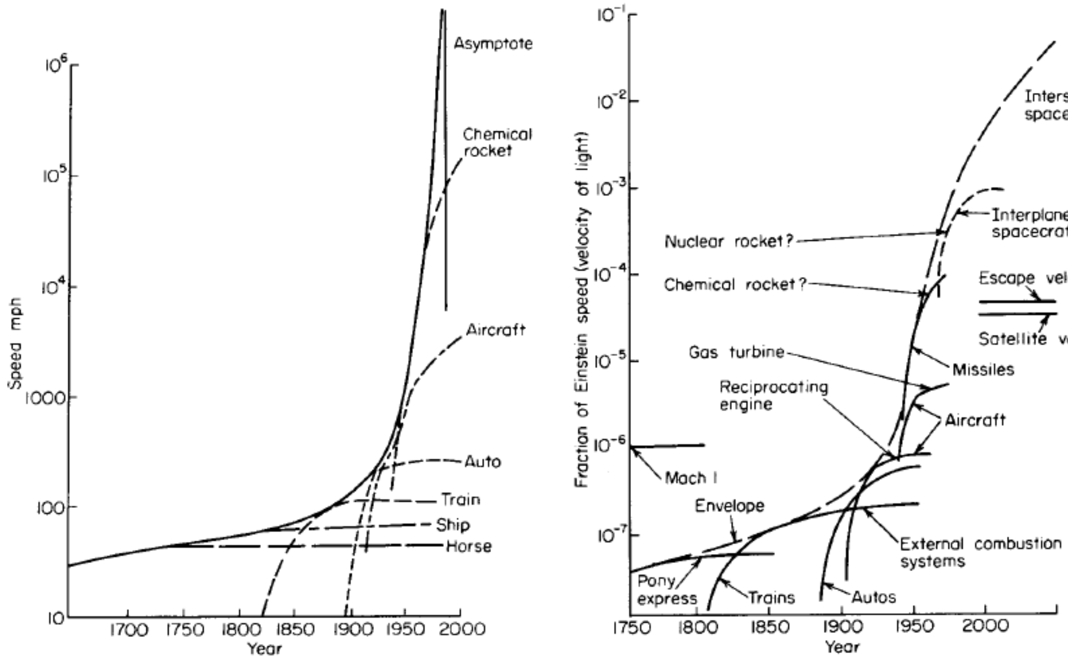


Figure 15. Two ways to scale growing variable. Source [3, p.21]. The forecast can be dramatically different, depending on the selected parameter for measuring the evolution of the system.

Figure 15 is taken from the book [3] about technological forecasting which G.Altshuller cited when he wrote his manuscript [26]. The issues linked with growing variable measurement and allocations are known a long time ago. Nevertheless, practice to draw S-curve by hand is in the habit of many researches until now. It is interesting to understand why so?

Extrapolation of trends using logistic S-curves is quantitative forecasting method based on data about past of system transformation. In practice of technological forecasting S-curves are used qualitatively to obtain rare insights and intuitive understanding of future changes. Thus, it is recommended to start with fitting S-curves on data and continue with qualitative analysis and interpretations.

Q6: What would we do with it?

The most interesting question we are working on is "How to forecast the future of emerging technologies using simple logistic S-curves, when there is no statistical data about?" In other words, "How to plot S-curve before system pass 'infant mortality threshold' (point α at Figure 7)?" When system passes α point of its evolution some data can be collected. There is still a question of data availability and the choice of an appropriate growing variable. However, before 'infant mortality threshold' there is no statistical data at all, because system does not exist out of laboratories. We are working on question "How to construct the logistic S-curve before having statistical data for growing variable trend?"

It was proposed to use causal method for approaching the question above. In the first experiment (2004-2005: project about forecasting the small fuel cell technologies) it was tested the hypothesis about studying problems (contradictions) as causal variable to foresee future evolution of technology [33]. Number of contradictions was applied as measurement to judge about technology maturity. This hypothesis was tested second time (2005-2006) in border of project about future of distributed energy generation technologies.

Nowadays (2006 - at present), we try to test an extension of original concept of 'contradictions as causal variables'. There are two basic assumptions behind: 1) any process can be considered as learning process [13] especially problem solving; 2) at the output of any learning process, there is knowledge acquisition issue. Therefore, it is proposed to measure the knowledge growth within transition from invention to innovation. In his book [23] Mensch presented data about 113 basic innovation history. The distance between invention (feasible prototype) and innovation (first production for market) for different technologies was different. For instance, for photography it was 111 years, for electricity production - 92 years, for dynamite - 23 years, for magnetic tape recording - 39 years, and for fluorescent lightning - 82 years.

The research question can be reformulated: *How to foresee time, place and peculiarity of transition from invention to innovation in advance?* The questions about forecasting of inventions and the mature technologies time of retirement lay out of scope of this description.

In order to better understand the main function of technological forecast the photography example can be considered. Photography was invented in 1727. Let us imagine that we are at 1790. The technological forecast question can be: When and where the photography will be commercialized? In other words: How long will be the distance from invention to innovation for emerging technology? (It was introduced as market product 48 years later in 1838).

According to result of research in organization and economic sciences, the transition from invention to innovation follows three consecutive stages [34, 35]: exploration (research in laboratory), experimentation (field tests) and exploitation (commercialization). The research assumption is: if to measure knowledge growth during these stages, it is possible to predict with logistic S-curves the beginning of commercialization (when system passes the α-point on its curve of evolution). It is proposed to apply as growing variable the amount of knowledge about emerging technology.

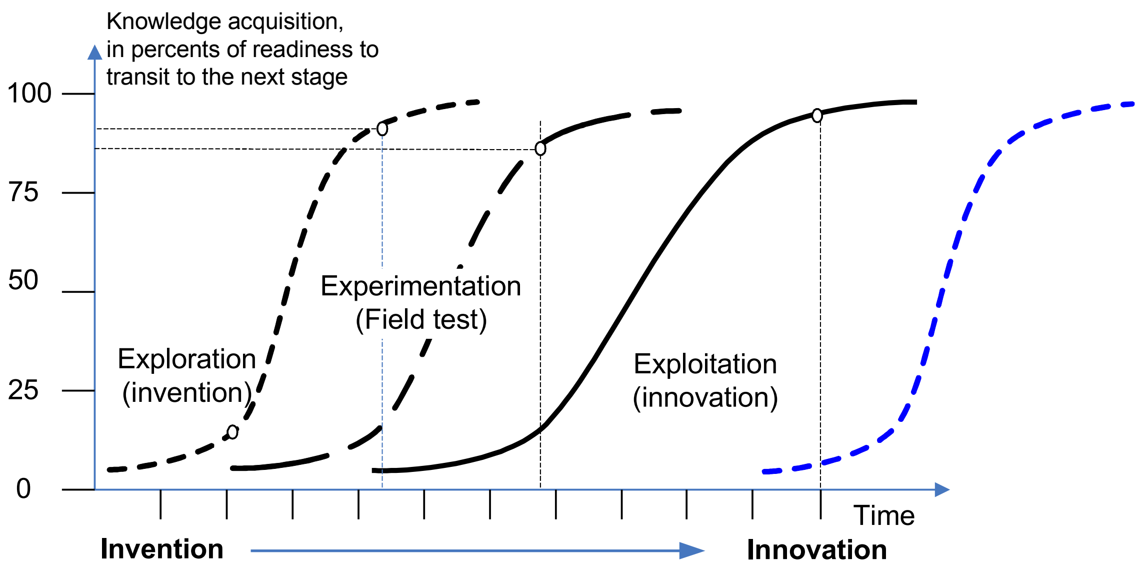


Figure 16. Growth of knowledge during exploration, experimentation and exploitation.

In order to manage fits of logistic curve, it is unavoidable to define the measurement units for knowledge. Despite many publications in artificial intelligence, economics, cognitive science, and pedagogy we did not find a relevant answer for question: "How to measure knowledge?" This question seems a stumbling block for conducted research. In fact, there are several feasible concepts how to measure information in particular cases [36, 37], but the question about knowledge measurement is still the open one.

It is proposed to apply *the network of contradictions as a guideline* for the process of knowledge acquisition. Among many others roles, the network of contradictions helps to differentiate signal and noise on the early stages of emerging technology development.

As a working concept it is adapted the relative ratio 'knowledge acquisition in percent of readiness to transition to the next stage' as an interim answer for measurement units (see Figure 16). One hundred percent represents sealing of knowledge acquisition for certain stage (e.g. exploration). Right dashed curve represent a new system at exploration stage. It is suggested that knowledge are accumulated during a time and when there is enough knowledge to decide about next stage, S-curve of next stage (e.g. experimentation) passes through α-point. It is supposed that when accumulated knowledge approach 90% of limit of growth, it is the time to take decision about transition to the next stage.

In practice, the experimentation (field test) stage can be launched far before exploration stage of knowledge acquisition reach 90% of saturation. A weak point of proposed assumption is fuzziness about when a new curve of knowledge growth substitutes the old one and how to distinguish these two curves. Nevertheless, example about clusters of discovery the chemical elements (Figure 9) and methodological advancement about bi-logistic growth models [9] provide us confidence about future results.

If we take into account that all technologies evolve under competition it becomes clear, why certain inventions will never reach the experimentation stage, when some of the inventions that pass through 70% of experimentation will not arrive at exploitation phase [35]. Reliable technological forecast should provide an explicit answer for the question which (?) technology will win a competition, when (?) it will happen and where (?).

The proposed working hypothesis about mechanism of knowledge acquisition is suggestive one and it should be checked through practice. It is supposed that at stage of exploration (E1), most of the knowledge is implicit at the beginning. At the end of the stage E1 knowledge are represented mostly in scientific papers and patents. At the experimentation stage (E2), needs in explicit knowledge increase, however it is necessary to protect the intellectual properties. Therefore, most of the knowledge at the beginning of E2 can be found in internal reports about field tests, in review, and in local patents. At the end of the stage E2, the international patents, publications in industrial journals increase in number, conference papers, and marketing articles are numerous.

* * *

What is proposed as working hypothesis for testing in coming future:

1. to measure knowledge growth by applying a network of contradictions as a guideline to differentiate signal and noise information;
2. to employ the concept of limiting resources from super-system for validation the network of contradiction for system;
3. to adapt the knowledge growth factor as an underlying cause of technology substitution mechanism.

1. Signal and noise information can be differentiated when one focuses its attention not on the existing technological solutions, but on the problems to be solved regardless to known answers. Network of contradictions is a technology to realize the basic principles of system thinking: "First, one should examine objectives before considering ways of solving a problem. Second, one should begin by describing a system in general terms before proceeding to the specific. [14]"

2. Application of simple logistic S-curves to represent growth of knowledge follows the same concept of 'limiting resources' from nearest super-system as it was implemented to study the evolution of technical systems. For instance, there is well known issue when at the certain stage, the new laboratory experiments do not provide additional knowledge about research topic. A typical answer for such an issue is to redesign experiments or to conduct a field tests in real conditions but not in laboratory. There is an open question for us what are the limiting resources in proposed example.

Analysis of limiting resources for constructed network of contradictions helps to review and to validate obtained map of problems through study how formulated problems are recognized in research and development societies. In the same time, study about limiting resources discloses future problems and technological barriers.

3. According to preliminary results of our research, knowledge growth mechanism is one of the major factors in the chain of technology substitution issues. The competition issue is the exterior side of technology substitution when knowledge acquisition is an internal force for surviving under competition.

What has been achieved?

The results of observation is based on 93 references[20]: 4 books, 6 books sections, 10 conference papers, 13 official reports, 9 interim research reports, 51 journal articles from Futures, International Journal of Forecasting, Technological Forecasting and

[20] In addition to the titles from TRIZ community.

Social Change, and others. The performed study shows that the simple logistic S-curve has been used extensively in the wide range of application. It produces appropriate outputs for technological forecast of large spectrum of technologies.

The working assumption we are trying to check in scope of research about methods for technological forecasting with logistic S-curves is: "efficiency of knowledge growth determines technology substitutions and technological competition mechanisms."

The basic working hypothesis to be checked: emerging technologies future can be reliably predicted by applying simple logistic S-curves of knowledge growth in framework of transition from invention to innovation[21].

How do we suppose to verify and validate the suggested hypothesis? Two times they were tested through forecasting projects with European Institute for Energy Research (EIFER, Karlsruhe). Interim results were reported. Three conference papers are presented and communicated. Developing approaches, techniques and method will be checked through practical forecast projects.

The ultimate test of the forecaster is an accurate and reliable forecast not the elegant or easily applied method. Theodor Modis, 2007

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[21] Consecutive chain of exploration-experimentation-exploitation.

Questions:

Nikolai Khomenko:
You presented that network of contradiction can be a tool to distinguish the difference between useful information and useless information. Right? Could you explain a little bit more, how it can be done?

Dmitry Kucharavy (DK):
We discussed yesterday [5] about this question. Thus, I would like to open some slides from yesterday tutorial to be constructive and short.

We construct a network of contradictions in order to have a guideline and to identify the appropriate information (appropriate to formulated problems). At the beginning many drawbacks seems like problems. This is the issue of 'perceived problems'. At the beginning of study, specialists say "we have plenty of problems". When we represent those 'problems' in form of contradictions many 'problems' disappear as soon it was just naming the same things by different words, or situation was perceived as problem due to the lack of information and communication between specialists. Afterwards, when we try to put formulated contradiction into the map of contradictions (in OTSM-TRIZ dictionary such form of contradictions is named: contradictions of parameters). Some of previously formulated contradictions disappear (through its inconsistency, reformulation, and integration with others contradictions) and new unobvious contradiction appear in order to fulfill the map.

These observed results lead us to the conclusion that map of contradictions can be useful for judging which information is appropriate and which one is not suitable for objective of forecasting.

See an example of contradiction map on the Figure 17. This map is based on the measurable critical-to-X features. These features were defined on the previous stages of forecasting. All elements which are the sources of problems are linked with critical-to-X features through couples of opposite requirements. For instance, Stack - Pressure inside has to be high in order to satisfy 3. Electrical Efficiency, but Stack - Pressure inside has to be low in order to satisfy 5. Maintenance intervals.

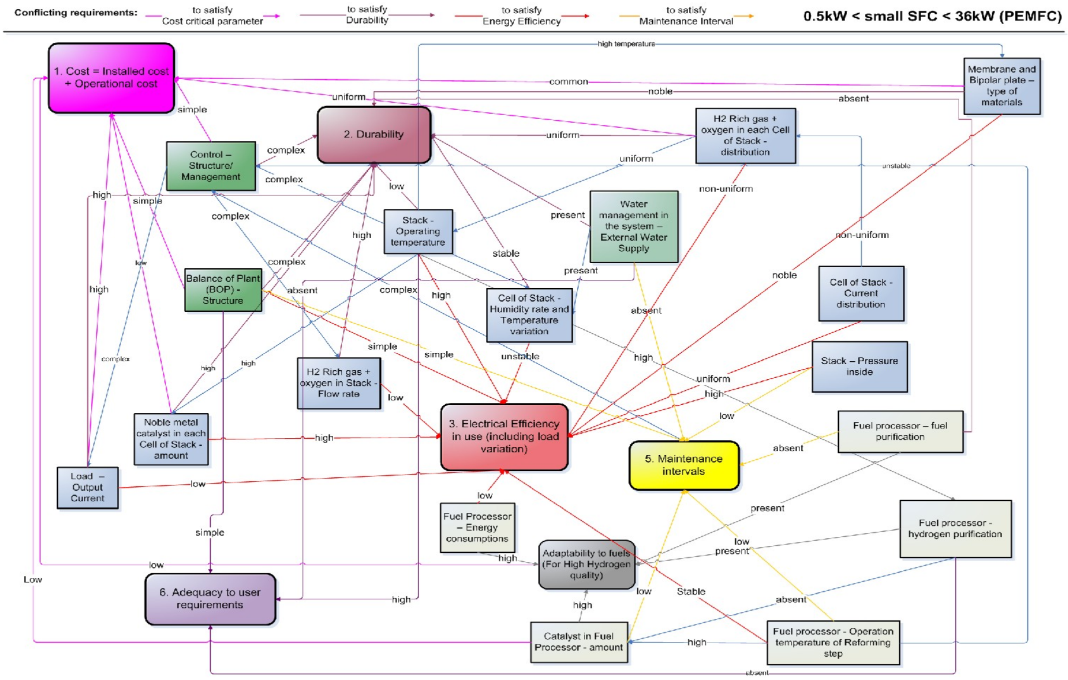

Figure 17. An example of map of contradiction for low temperature small fuel cell technologies. *Source:* [33] (Information provided courtesy of EIFER, 2005, Karlsruhe)

As soon the problems are defined in context of map, they can be applied to monitor growth of knowledge how this problem is solved. In other words, how future concept solutions and technologies answer for the formulated problem.

The final map (see Figure 18) represents the same set of contradiction with additional time axis. This axis represents integral estimations about speed of knowledge growth for identified research and development activities. Research and development activities were identified through monitoring of publications and reports. In order to select publications, the map of contradictions was applied. Monitoring of all unselected publications about small stationary fuel cell needs enormous human resources and time. There should be criteria to select relevant information (distinguish signal and noise). The mapped problems play the role of criteria to select relevant information.

When identified R&D activities were not linked with formulated problems, two variants were considered: either we missed a problem on the map, either we have irrelevant information. After several working sessions the map of contradictions was stabilized so well that we did not observe issue about missed problems on the map.

Nikolai Khomenko:
When you developed the network of contradiction you are talking about value and parameters. It is a kind of equivalent of physical contradiction. What is the contradiction of parameters[22]?

DK:
Speaking in terms of the dictionary of classical TRIZ, we constructed the map of physical contradictions. However, as soon we face with engineering and non-engineering contradictions during forecasting, the dictionary of OTSM-TRIZ is more suitable: such contradictions are named as 'contradictions of parameters'.

[22] The question on the record was not recognized exactly.

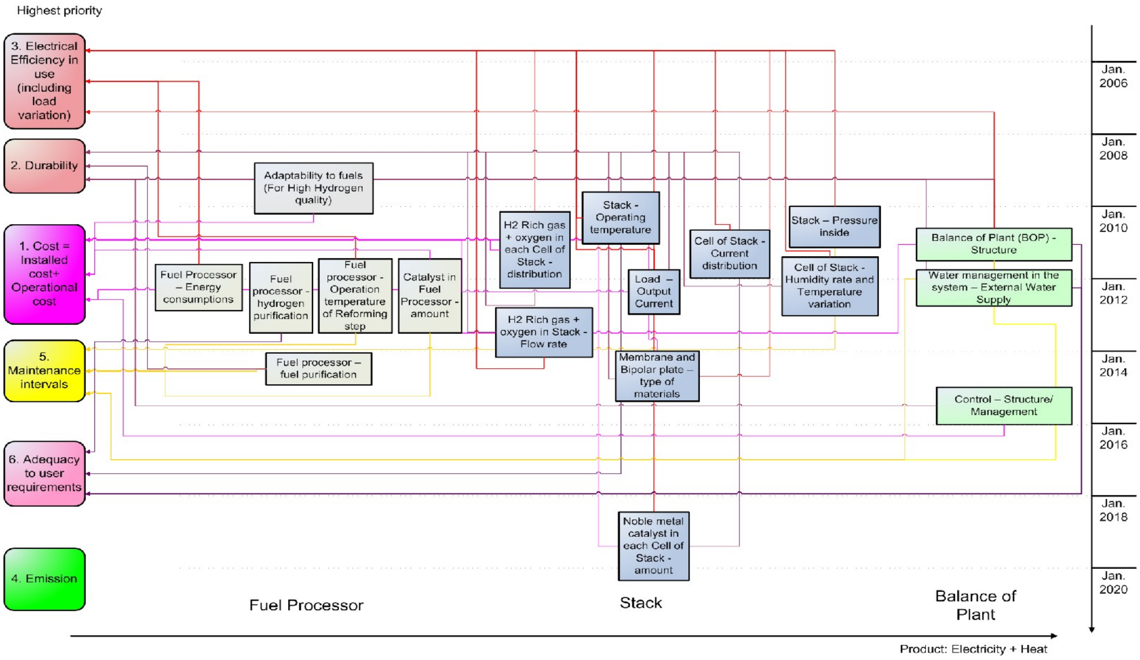

Figure 18. Map of contradiction for low temperature small fuel cell technologies with time scale. *Source:* [33] (Information provided courtesy of EIFER, 2005, Karlsruhe)

Question:
You presented S-curve with upper limitations about TRIZ-publications in English. How did you define the upper limits?[23]

DK:
The presented prediction about upper limits is based on the time series data from history of last 10 years publications (see Figure 7). The data about dynamic of publications in combination with simple logistic growth model [9] produces a particular shape of S-curve. In other words, fitting logistic to time series data using non-linear least-squares regression algorithm (Loglet Lab version 1.1.4 software) with minimum residuals outputs values of the three parameters of simple logistic S-curve. One among others is the upper limit κ (the asymptotic limit of growth).

When we look to the data with naked eyes, it is unobvious what will be the trend of publication in coming future. Assumption about logistic nature of growth process and the data from history of publication in combination with fitting technique disclose future upper limit of growth. First we try to fit S-curve to data. Second, using bootstrapping technique we try to minimize the residuals (i.e. errors - difference between S-curve and real data). In example with TRIZ-publications in English we applied so called 'naïve' method of forecasting (See Figure 5).

If to pose the question "What are the causes of publications dynamics?" - and to collect data about causes, another curves can be plotted using 'causal' method. Presented curve and the upper limit of TRIZ-publication in English has been obtained by 'naïve' method using fitting the simple logistic to time series data.

Comment: Using symmetric logistic curve…

DK: Yes. Right.
Why do we apply the symmetric logistic? Most of the reviewed reports and articles [8, 10, 11, 12, 19] stated that the simplest methods perform more reliable forecast in

[23] The question on the record was not recognized exactly.

comparing with complex and sophisticated mathematical models. In one of his interview INSEAD[24] Dean of Faculty and Professor of Decision Sciences, Anil Gaba summarized "complicated complex models don't actually predict real-life events" [38]. His colleague Spyros Makridakis, who spent his entire career looking at forecasting, is sure that "simple methods do at least as well as some of most complicated methods".

Another reason to apply the simple logistic S-curve was the availability of free software from Program for the Human Environment (http://phe.rockefeller.edu/LogletLab/). The Loglet Lab is a software package for analyzing logistic behavior in time-series data. Instead of complicated non-symmetric logistic the researches from Rockefeller University under leadership of Jesse H. Ausubel proposed to apply bi-logistics and multiple-logistics to describe systems with two or more growth phases.

Gaetano Cascini:

When you present the evolution in number you measured (e.g. number of published papers) you make it in time series (e.i. how many was published every year). How do you identify the intervals that will allow you to forecast? Why not to choose number of publications per month? Why do you apply 10 years period, but not 5 years period? Probably, the result of forecast will be different.

Of course, when you increase time delay, you reduce fluctuations (may be) and, probably the shape of the curve will be modified. Are there any suggestion for this issue?

DK:
We did this kind of experimentation for our curiosity. It is correct, the fluctuation increases for shorter time periods. However, the overall shape of fitted S-curve is the same. Even more, we tried to plot logistic curves separately for TRIZ Journal, TRIZCON conferences, and for ETRIA TRIZ future conferences. The obtained forecasts were similar. When we tried to fit bi-logistic or multiple-logistic to the data, it caused larger residuals (i.e. incorrect fit). In fact, during fitting logistic S-curve to data we work for reduction the distance (error) between the real data and logistic curve. All the forecasting power of S-curve study is based on the assumption that logistic curve represent the natural growth law.

Gaetano Cascini:

The second question is: When we analyze some data (e.g. number of patents in a particular domain) during a time, the growth process, as a rule, does not resemble the S-curve. My suggestion is: there is a synergy of different S-curves and other patterns of evolution. That is why the resulting curve to fit data has not S-shape. If we are talking about logarithmic curves, we cannot apply the superposition principle.

Comment DK: We are talking about logistic curves. However we can plot them in logarithmic scale as linear curves.

Gaetano Cascini: This is exactly what I was saying. If it is not true, just putting together different curves you think everything can be curved[25].

DK:
There are several questions can be recognized in your 'one question'.

[24] One of the world's leading and largest graduate business schools http://www.insead.edu/discover_insead/who_we_are/quick_facts.cfm
[25] The question on the record was not recognized exactly.

I do agree with your suggestion, that it is really an art to identify what is a growing variable for the question we would like to forecast. It is not easy at all. This is one of the points we need to find a formal procedure to deal with. This is one of the major causes why do we mix together frequently parameters that growth with different rhythms in accordance with different patterns. As result we obtain a misleading forecast.

On the other hand, we disagree about different patterns for law of growth (in original speech it was: "growing based on data"). Our observation and cognitive capacities are limited as soon we are human being. When we look at some data, depending on their nature (number of elements and so on) we do not agree a priory that it can be described by S-curve. However, when we try to fit curve to data (wow!) it fits data with so small residuals. Let us be not so faithful in suggestion that law of growth follows non-logistic curve before checking through rigorous fitting procedure. In other words, "Did you fit curve to your data? If yes, show me your fit and we can see together is it a new pattern to grow or some other issue."

I was fascinated how many times forecasting with logistic S-curves leaded to reliable forecasts. Four years ago, before studying literature, I could not imagine that dozen thousands of S-curve fits represent reality so accurate way.

Fitting S-curve on data does not mean automatically successful forecast. For instance, T.Modis published his book [39] in 1992. The second version of this book [13] was published 10 years later with detail analysis of fault predictions made in first one. What is interesting to learn, there were not so many faults. About 70% of presented forecasts are correct. The book is full of logistic curves fitted to data.

In close look, the famous law of ideality growth [15] is a corollary of logistic S-curve which represents law of natural growth.

In order to conclude the answer for the question I would like to propose, that it is essential to apply a quantitative way to construct S-curves. As soon we draw our 'S-curves' by hand, we do not present the trends, but our unverifiable hypothesis. It does not matter how these hypotheses are genius, as soon they are unverifiable, they are not reliable. As result they are not applicable.

Question:
1. Am I wrong or do you pose that TRIZ-publication in English can only decrease from now on?

2. What is your opinion about the second[26] Moore's law?

DK:

First question: In accordance with the results of fit S-curve to the available data, TRIZ-publication in English for selected sources will not grow the same way in coming future. Please look to the presented diagrams carefully. They are not so dramatic for coming two years. We can speculate "why so?" It looks like, as usually, we have a competition issue… In coming future we will verify together how the presented forecast is correct.

Second question: One of the roles of each forecast (it was discussed in scope of tutorial [40] in section "Why do we need to forecast?") is to increase awareness. Actually, the predictive power of Moore's law is based on the fact that 'the more widely it became accepted, the more it served as a goal for an entire industry.' There is a kind of self-

[26] The notion 'second' was not understood exactly.

fulfilling prophecy phenomenon. Last years, many companies struggle to keep up with Moore's law.

Initially the Moore's law was formulated as exponential growth. (Originally it was suggested that the number of transistors that can be inexpensively placed on an integrated circuit will be doubling annually.) Later in was corrected (towards 24 months for doubling. Different sources refer to 18 months for doubling the number of transistors.) Moore's law name is applied as a synonym to exponential growth especially in computer technologies. Exponential growth is a part of logistic natural growth. If we consider these facts it becomes clear, why this particular prediction became so famous.

According to the evolution of many generation of systems there is obvious, that system cannot evolve endless exponentially. The same is occurring with integrated circuit. The number of transistors approaches its ceiling, and trend changes from exponential one to logistic curve.

In accordance with what was described many years ago [3, 4, 15], the rhythm of changes from exponential growth to logistic one depends from how many resources will be sacrificed to keep up with Moore's law. The mechanism was well described by G. Altshuller in the book Creativity as Exact Science [15] and explained through many examples in multiple TRIZ-publications.

> *"...The emphasis of logistic curves analysis becomes not building or running the model, but interpreting it..."* adapted from [25]

Contact:

* Dmitry KUCHARAVY
LICIA / LGECO, INSA Strasbourg
24, Bd de la Victoire, 67084 Strasbourg, France
tel: +33 (0)3 88 14 47 10; fax: +33 (0)3 88 14 47 99
E-mail: dmitry.kucharavy@insa-strasbourg.fr

Dmitry KUCHARAVY is a research engineer of INSA Strasbourg - Graduate School of Science and Technology, France. He is a doctoral student at the University of Louis Pasteur (Ecole Doctorale des Sciences pour l'Ingénieur). His research interests are in Technology Forecasting of systems evolution, Theory of Advanced Thinking (OTSM-TRIZ), and Problem solving knowledge management.

Roland DE GUIO is professor at the National Institute of Applied Science (INSA) of Strasbourg, France. He worked 13 years in the area of application of operational research and data analysis techniques to production flow analysis and design problems. Since 2000, his main interest is developing holistic approaches, technologies and tools that support innovative design in the frame of the research team in innovative design at INSA.

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