PROBLEMS OF FORECAST[1]

Dmitry KUCHARAVY
dmitry.kucharavy@insa-strasbourg.fr
Roland DE GUIO
roland.deguio@insa-strasbourg.fr

LICIA team, LGéCo,
INSA Strasbourg
Graduate School of Science and Technology,
24, Bd de la Victoire
67084 STRASBOURG Cedex, FRANCE

Abstract
The ability to foresee future technology is a key task of Innovative Design. The paper focuses on the obstacles to reliable prediction of technological evolution for the purpose of Innovative Design.
First, a brief analysis of problems for existing forecasting methods is presented. The causes for the complexity of technology prediction are discussed in the context of reduction of the forecast errors. Second, using a contradiction analysis, a set of problems related to technology forecast is proposed. Third, the paper examines how some knowledge from the Theory of Inventive Problem Solving (TRIZ) can be applied in response to forecasting problems. Fourth, conclusions are drawn about the perspectives for reliable technology forecasting. All of these reflections are supported by the research experience gained in the project with the European Institute for Energy Research (EIfER, Karlsruhe).

Keywords: Technology Forecast, Laws of Technical systems evolution, Analysis of Contradictions.

1. Introduction

Let us start with an idea that "…Any system which depends on human reliability is unreliable[2]…" Why is reliable technology forecast so urgent today? The Problem might be formulated in the following way: If technology forecasting practice remains at the present level, it is necessary to significantly improve the efficiency of design to make it possible to develop adequate technologies in a short period in response to new demands (like Green House Gases - GHG Effect reduction or covering exploded nuclear reactor); If technology forecasting is more efficient, it is possible to develop an adequate technology for coping with the new requirements without being in a hurry (if GHG Effect could have been predicted 50 years before it appeared). Thus, in order to survive in a highly technological environment, an efficient engineering design and production are not enough. The absence of efficient and reliable forecast limits decision makers and the pace of changes.

What if we look at technology forecast from the problem-solving viewpoint? Let us assume that a problem situation can be defined as a difference between the actual state and the target situation (objectives). In other words, *Problem = Target situation – Actual state* (or *Target situation = Actual state + Changes*, where Changes include Typical solutions and Problems). Where do objectives come from? They come from the vision of future. When a certain technical problem is discussed, the vision of future appears as a result of a technology forecast. Even if the formal forecasting was not performed the intuitive one was done.

What is a problem origin in such reasoning? The target situation seems unreachable. However, what if the vision about future is wrong? The Problem could be defined in the

[1] Article was prepared for ETRIA TRIZ Future 2005 (Graz, November 16-18, Austria) conference. Last update: November 28, 2005

[2] Merphy's laws (Gilb's Laws of Unreliability)

wrong way. It is a common place today that a solution fails more often because a wrong problem has been chosen rather than because a wrong path to the right problem was followed. "…We suffer more from the good solutions for wrong problems, but not from weak solutions for right problems…" [Russell L. Ackoff – an American scientist in operations research and systems theory; iconoclastic management authority, advocates a ‘‘systemic’’ approach to innovation]

Why do we need a reliable technology forecast? From the technological viewpoint, it is required for setting priorities for research and development; and definition of the right problems instead of approaching whole of believable. From the social standpoint it is essential for assessing and managing threats of emergent technologies and new scientific discoveries in advance as well as an for adaption of social institutions, such as educational system, for coming changes. From the business environment context it is substantial for efficient management of intellectual property and for extension of technological competitiveness of products, processes, and services.

This paper seeks to discuss a set of problems related to a reliable technology forecast.

1.1 Specific terms definition

Let us define the specific terms that used in this paper:

Event is a physical effect (changes), that occurs in a particular place of space, at a particular point in time. An Event can be defined by several features, such as physical content of changes, location in space and time (What? Where (How large)? When (How long)?). In order to unify the applied descriptions, the ENV (Element-Name of Feature-Value of Feature) model is used to describe Events. For details about the ENV model, see Khomenko [1]. According to the ENV model physical contents, place and time are considered and described as features.

Time is an artificial concept (method) to put in order the observed events and to measure relative duration of processes. Discussion of the epistemology of time is beyond the scope of the given paper.

Present is a set of events that occurs in a particular place of space.

Future is a set of events that may be affected by some events in Present. One of the crucial questions of any forecast can be formulated as follows: "How to recognise which events in present will influence the future and which ones will not affect it?" Another critical question is: "How to foresee uncertainties that will affect future as well?"

Past is a set of events that may influence the events in Present.

1.2 Technology forecast

The difference between forecasting methods and forecast results (model description) is presented in Table 1.

Table 1
Features of forecasting (process) and forecast (results)

Forecasting (process)	forecast (result)
▪ Cost effective in practice o profitability (computer, human resources, etc.); o timeless in providing forecast. ▪ Flexibility in application ▪ Easy in using available data ▪ Transparency ▪ Operability o easy-to-implement; o easy-to-use; o sensitivity for input data; o easy-to-develop or universality (e.g. using extensions without changing the main procedure); o stable in time. ▪ Reliability ▪ Ability to identify: o future technology developments, and o their interactions with society	▪ Accuracy. ▪ Improved decisions (as a result of application). ▪ Ease of interpretation (in order to understand results and origins). ▪ Ease to update. ▪ Intelligibility. ▪ Readability. ▪ Confidence. ▪ Validity. ▪ Describing a technology at some time in the future o Emergence; o Performance; o Features; o Impacts; ▪ Consists of: o emerging technology characteristics, o development pathways; o potential impacts on social and business environments. ▪ Explains interactions between: o events. o trends, and o actions. ▪ Does not include personal bias (bias free).

Researchers in the field of future technologies differentiate between technology forecasting, technology foresight, technology intelligence, technology road mapping, and technology assessment [5]. The given paper mainly deals with the technology forecasting. For instance, a forecast usually answers the question "What will happen?" while a plan describes "What should happen". There are dozens of different definitions of technology forecast in literature [some of them can be found in 2, 3, 4, 5]. In the context of the present research we use the following definition: "Technology forecast is a comprehensible description of emergence, performance, features, or impacts of a technology in a particular place of a particular point of time in the future".

Often, scenarios building methods lead to a hierarchical set of descriptions about future events. The number of possible events described increases exponentially with the number of levels. From the practical viewpoint, time limitations do admit to analyse multiple alternative. That is why we intensify the initial situation and propose not to admit to have any "IF" in a forecast description. Consequently, scenarios methods are not considered to belong forecast methods.

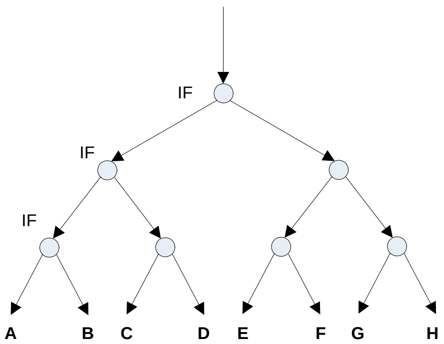

Figure 1.2.1. Multiplication of scenarios

In order to be precise with a technology forecast the system approach is inevitable [2, 12]. Using a Multi-screen analysis different levels of details can be recognized for any technology forecast:

1. sub-micro (technology, product, process)
2. micro (company, group of companies)
3. industry (competitors by the same product, competitors by the same function)
4. macro (financial, economic community, country)
5. super-macro (environment, demographic, etc.)

Such a list can be expanded in both sides. What complicates a technology forecast is interconnections between all these levels. It is evident that an efficient forecasting process has to provide a means for a simultaneous work on several levels.

We propose to define the *efficiency of technology forecast* as a ratio between a *reliable forecast* and *aggregated expenses* necessary to perform forecasting, where a reliable forecast is characterized by accuracy of forecast and transparency of the forecasting process while aggregated expenses include resources spent on development and communication of forecast results. This working model of technology forecast efficiency is introduced in order to make it possible to measure the difference between "good" and "not so good" forecasts while comparing two forecasts about the same question.

2. Review of forecasting practice

2.1 Existing forecasting methods

Existing forecasting methods can be classified in various ways.

In Principles of Forecasting, edited by J.S. Armstrong [4] all forecasting methods are classified into ten categories. The methodological tree starts from the division of all methods into two categories: Judgmental and Statistical. The proposed classification helps to choose an appropriate method or combine several methods for particular objectives and conditions.

In scope of research about Technology Future Analysis [5], fifty-two methods (including TRIZ) are classified into qualitative (soft) and quantitative (hard) as well as grouped according to nine "families": Creativity, Descriptive and Matrices, Statistical, Expert opinion, Monitoring and Intelligence, Modeling and Simulation, Scenarios, Trend analysis, and Valuing/Decision/Economic. Each method can be considered as Normative (beginning the process with a perceived future need) or Exploratory (beginning the process with extrapolation of current technological capabilities). Such classification is supposed to serve the choosing and combination methods in accordance with particular situation conditions. The idea of Directed Evolution [7], which is well-known in the TRIZ society, belongs to Normative forecasting.

In his classical book [3] Markidakis and co-authors subdivide fifteen groups of forecasting methods into five categories: traditional time series methods, advanced forecasting methods, approaches to long-term forecasting, major statistical combination methods, and judgmental forecasting.

Some practitioners [8] categorize forecasting methods according to different ways people view the future. Five groups are distinguished: Extrapolators, Pattern Analysts, Goal Analysts, Counter Punchers, and Intuitors for twenty-four different analyses. This classification helps to customize set of methods to initial vision of forecast users about technology future and forecasting.

(Technology forecasting using TRIZ and concepts based on works of G.Altshuller are discussed below in section 3.1.)

The review of the existing methods for forecasting shows that single method is never used for practical technology forecast. The necessity for a combination of methods become apparent when formulating generic conflicting requirements for any method of analysis: the

Method should be short and simple, in order to be easy-to-learn, easy-to-apply, easy-to-integrate into super-systems (e.g. planning and decision making processed for forecasting); BUT the Method should be redundant and complex, in order to be reliable, to have one universal method instead of multiple, in order to decrease the probability of application mistakes; and to secure achievement of the initial goals.

From the TRIZ viewpoint, one of the typical solutions for a conflict "complex vs. easy" is performing segmentation and then building a new system from the segmented parts in accordance with the requirements of a specific situation. Thus, it seems obvious that at present combinations of several methods are preferred to a single one.

It is not evident however, how a combination of methods influences the technology forecast errors. Normally, methods are combined in order to reinforce the weakness of one method by the strength of another. However, when several methods are combined, new forecast errors can appear as a result of the synergy effects. At present, the question of measurability of forecast errors arising as a result of an integration of several methods remains unanswered.

In order to review the existing technology forecast methods in a holistic and systemic way we propose to classify all forecasting methods from the point of view of a problem solving approach by indicating which problem or a set of problems a given method addresses and aims to resolve.

In order to illustrate our point better, let us consider a method of Role-playing [4, p.p.15-30] that is used to forecast decisions. Using the same data, depending on a given role ("cost analyst" or "feasibility analyst"), a forecaster can obtain different forecast results. Moreover, Role-playing works on simulation of interactions between roles A and B, when several participants try to simulate decision making in order to forecast a decision.

Which problems are solved by this method? It is necessary to note, that there are many problems that remain unsolved and eventually influence the accuracy of such a forecast. Nevertheless, the evident advantage of Role-playing is that it applies a mechanism decreasing subjective biases of forecasters: Forecaster should have personal inclinations, because he has subjective opinions; BUT Forecaster should not have personal inclinations, because they decrease the accuracy of a forecast.

Another interesting point is that Role-playing works with interactions, rather than with subjects. In accordance with a systemic approach (a Multi-screen scheme of thinking, or the so-called System operator) a forecast will be more efficient when interactions rather than just separate objects are taken into consideration. It is quite obvious that in order to forecast a future of some transportation technology, it is inevitable to analyze interactions of such technology with present and future social, environmental, and economic contexts. Role playing offers no formal mechanisms for performing systemic thinking; nevertheless, its primary focus is on interactions: forecaster has to analyze interactions between objects, in order to improve the accuracy of a technology forecast; BUT forecaster has to analyze separated objects, because interactions appear when objects start to act and react.

Thus, Role-playing offers a concept solution to the two problems in a network of problems dealing with a technology forecast. Further on, we will describe this network and categorize the existing forecast methods according to the problems from the network.

2.2 Technology forecast errors

In order to be confident about a technology forecast, one crucial question should be answered with certainty, "How can one distinguish between valid and invalid forecasts?" Or, in other words, "How to measure errors and accuracy of forecasting results?"

When reformulating the above question in the form of conflicting requirements, we arrive at the following contradiction: the Difference (between valid and invalid forecasts) should be measurable, in order to evaluate the technology forecast with minimum bias; BUT the Difference cannot be measurable, because forecasted events will happen in future.

One of well-known definitions [4] proposes to identify a forecast error as the difference between the forecasted value (F) and the actual value (A). The accuracy of forecast is used as an optimist's term for forecast errors. Regarding the definition of forecast given above (section 2.1, 2.2), the value of technology forecast is presented through event, time, and place characteristics. Thus, an invalid forecast may be a result of a mistake in terms of event (what happened?), time (when?), and place (where?). In a general sense, in order to judge a technology forecast it is necessary to be able to measure both a forecasted value and a real value. The difficulty arises only because these two values are separated in time.

What typical solutions exist for improving accuracy of technology forecasting? In case of a short term forecast, when qualitative methods are used, recalculation can be performed several times and the resulting model can be tuned in an interactive mode to better fit the reality. The interactive techniques for tuning forecast equations are well known in data mining area.

In case of a long-term technology forecast, it is interesting to consider the experience of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) [9]. Starting from the early 1970s, MEXT has been conducting a regular Delphi survey every 5 years. Surveys have involved more than thousand experts (last two survey involved more than three thousand) and aimed at forecasting long-term trends in various fields of technology with forecast time horizon of thirty years. Thus, the technology forecast is updated regularly (every 5years) to decrease errors. It is necessary to note that the applied methods are regularly modified as well in order to reduce errors of technology forecast.

Both examples we consider use a similar solution concept: to forecast, to wait for the forecast time to come, and to compare the forecasted value (F) with the actual value (A).

The second example shows us a much more expensive way for improving forecast methods with the purpose of evaluation of the validity of a technology forecast. Such an expensive way is not acceptable for most of the technology forecast demands. Thus, the question about the difference between valid and invalid forecasts needs to be answered mostly for medium and long-term technology forecasts.

There are many qualitative ways for performing forecast evaluation. For instance, it was proposed [6] to use a set of characteristics such as: market impact, market timing, predicted use, and social impact. The market impact can be evaluated as strong, moderate, weak, or virtually none; the market timing can be on target or optimistic; while predicted use can be characterised as mostly right, mixed, right, mostly wrong, wrong; etc.

Such quantitative evaluations appear easy-to-use, however they lead to the same problem: forecasted events should happen in order to perform a definite evaluation of a forecast.

2.3 Problems of technology forecasts

In order to build a network of problems, the initial set of problems should be collected. For the purpose of the present research, it was decided to group the problems according to four stages of a technology forecast life cycle: Design stage; Developing stage; Application of a forecast stage and Retirement-and-Update forecast models stage.

In order to focus on the most difficult technology forecast problems the literature review and practical case study were performed. According to literature [for example 2, 10] and the practice of forecasting a technological future of a new product, most mistakes are made in medium and long-term forecasting dealing with pioneering and new-to-the-world technologies.

Let us try to define what is meant under "a new product"? Crawford's list [11] distinguishes six types of new products:

- cost improvement (reduced cost versions of a product for the existing market);

- product improvement (new versions of existing products, targeted at the existing market);
- line extension (innovations added to the existing product lines and targeted at the actual market);
- market extension (taking existing products to new markets);
- new category entry (new-to-the-company product and new-to-the-company market, but not new to the general market);
- new-to-the-world (radically different products).

For practical use of a technology forecast it is proposed to distinguish four types of new product/technologies:

- new version of a product (e.g. a new bicycle without a chain, with a new lighting system, with a new break system; high capacity small batteries; low price small batteries);
- new market penetration (e.g. German bikes to the Russian market; high capacity batteries for toys);
- new family of products (e.g. mountain bikes; fast rechargeable batteries; noise-cancelling headphones);
- new-to-the-world (e.g. a new personal transport instead of bicycle; a small stationary commercial fuel cell).

Another issue to define is the difference between short-term and long-term forecast. It is proposed to use the life cycle of a product/technology as a unit for measuring the difference between short-term, medium-term and long-term forecasts from the market viewpoint. For instance, if the life cycle of computer mouse is determined as 24 months, a short-term technology forecast for computer mouse has time horizon below 36 months, while a long-term forecast will exceed 48 months.

However, when the life cycle is reduced as a result of changes in the nearest super-system, the definition of a short-term forecast for a certain product could be changed as well. For instance, cathode ray tube (CRT) displays have the life cycle of about 8 to 10 years. However, increasing prices for office and living space in combination with electricity price rise lead to replacement of CRT displays and TV sets by slim and energy efficient products faster than an old fashion CRT really stops functioning.

Short-term and long-term forecasts have different duration in time for production and for service companies. For instance, industrial companies have longer time horizons for new product forecasts (on the average 34 months) than consumer firms (18 months) [10].

The problems presented below are pertinent to medium and long-term forecasts of a new family of products and new-to-the-world technologies. The literature review reports that for the first two groups of new products when a short-term forecast is formal quantitative methods in combination with a proper management of forecasting projects gives an adequate accuracy of forecasting.

Due to the format of the given paper, it appears impossible to focus on all the stages of a product life cycle. Therefore further on we will focus on two stages only, namely those of Forecast Design and Forecast Model Development.

Design of forecast stage can be subdivided into three major steps: problem formulation, information gathering, and selection on an appropriate method(s).

It is difficult to overestimate the importance of forecasting problem definition. The answer usually depends on the question. The way the problem is defined determines the whole forecasting process. For example, a question such as "When technology 'A' will reach the commercial level?" already assumes that the technology will succeed. A new product forecast is usually connected with many limitations, such as a shortage of data, a limited time for an analysis, general uncertainty surrounding a new product, no marketplace for a new product etc.

Many questions appear at the step of problem formulation: How to find the right problem? How to purge one's mind from existing theories and predilections? How to structure a forecasting problem? What are the evaluation criteria for measuring the accuracy of an answer to the formulated problem? Normally there are conflicting requirements hiding behind each question.

One of the primary contradictions at this step can be defined as follows: Problem has to be formulated precisely to be able to use the forecast results for decision making; BUT Problem has to be formulated approximately, in order to avoid predilection and the influence of dominant concepts.

At the step of information collection frequently occurring complaints are "not enough data" or "no data yet". A list of generic questions for this step may looks as followings:

- What data are to be collected?
    - How to prove the validity of the collected data?
    - How to be sure about the reliability of the data?
- Why do we need to collect data?
- How to use existing (subjective) data most effectively?
- How to incorporate the existing ideas into the picture after the data collection?
- How to interpret the collected data?

One should be aware that the problem of signal-noise often hides behind the so-called lack of data. If we assume that all data are available, the time necessary for data processing will increase dramatically. Thus, we face the following problem: How to recognize events in present and past that will influence the forecasted future? In other words, how to collect "signal-data" and avoid spending time and resources on "noise-data"?

At the step of an appropriate method selection the following questions may appear:

- How to know about most efficient methods for a particular situation?
- How to select right method(s) out of a set of methods?
- How to evaluate the selected methods or how to be sure about the chosen techniques?
- How to apply the selected methods in the most effective way?

One of the contradictions that appears at this stage relates to specific competences: in order to make the right choice of a method(s) it is necessary to be a specialist in all known forecasting methodologies, BUT it is necessary to be a specialist in a particular domain of knowledge, in order to be able to perform forecasting and to valuate the obtained results.

The stage of Forecast Model development can be presented through three basic steps: method(s) implementation including evolvement of the forecast models, evaluation of the applied methods, and evaluation of the forecast models.

Most of forecast problems are concentrated at the step of methods implementation. Some problems are generic and appear when facing such questions: How to assess uncertainties? How to keep forecasting methods simple? How to perform a realistic representation and link obtained results with contexts (super-systems)? How to reach an agreement in a working team that consists of specialists with various competences and different visions? Which reasoning, causal or naive[3] will be appropriate for a particular forecast?

Another group of problems is linked with the nature of selected methods. For qualitative methods most critical queries to satisfy are the following: How to measure (to be objective) with qualitative criteria and expectations of different experts? How to frame questions to experts in order to avoid misunderstandings and biases? How to combine diverse quantitative criteria and forecasts? How to scale in time quantitative proposals of forecasting? It is necessary to note that judgmental methods are usually limited by what people perceive as feasible that depends in fact on their shared beliefs and their restricted imagination.

[3] Naïve model – a model that assumes things will behave as they have in the past. [4]

For quantitative approaches many problems are generated by the following questions: How to match models with underlying phenomena? How many parameters will be enough to provide a useful result for a certain time horizon? How to present new quality results (unknown novelty) using quantitative output of models? Limitations of quantitative approaches come indirect way through boundaries of applied models and are similar to limitations of statistical methods.

Combination of quantitative methods with qualitative ones, as well as performing qualitative forecasting with a support of quantitative approaches helps to improve the accuracy of forecasting [3, 4, 9]. At the same time, it generates another complex bunch of problems and consumes a lot of resources. One of practical ways to improve the reliability of a forecast and to avoid large errors is a combination of forecast results obtained by various methods (combination at the level of results). However, such a combination requires extra time and decrease prediction probability of uncertainties. A valuable forecast presents an event that seemed improbable at the time of a forecast, but was proven by reality.

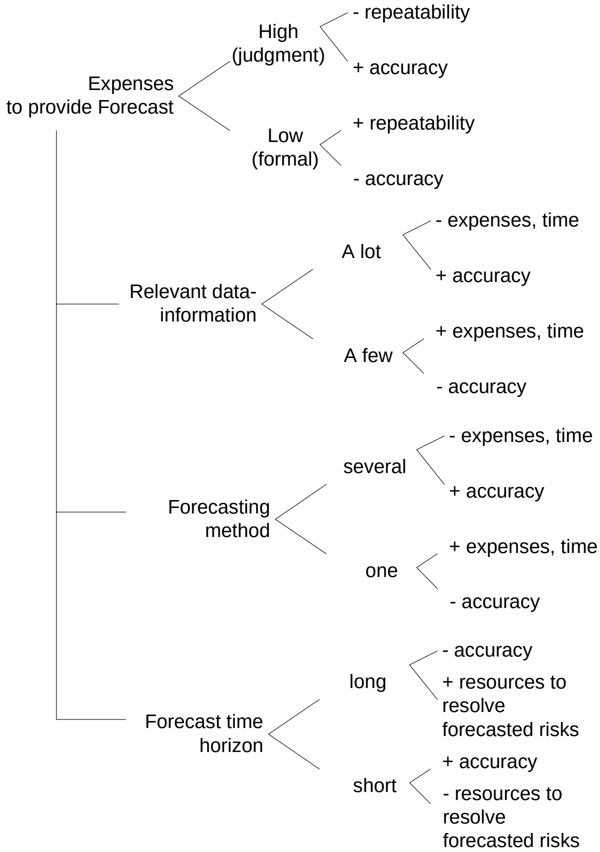

Figure 2.3.1. Prototypes of contradictions surrounding the accuracy of a forecast

The step of evaluation of applied methods plays an important role, especially for a technology forecast. If the applied method(s) is not transparent or it uses some hidden assumptions, the results of forecast have minimal value even if they can be proven by reality in the future. Thus, simple methods are often chosen, even if they provide less accurate results. In order to be evaluated, it is necessary to disclose a method completely, but in order to understand method fully, it is necessary to spend a lot of time and effort. Applied method(s) should be tailored to the forecast problem, but they have to be tested before in practice. In order to realize a complex of problems related to method(s) evaluation see *Table 1. Features of forecasting (process) and forecast (results)* above.

In order to structure the collected problems, it is necessary to disclose contradictions that lie behind of the questions described above. Figure 2.3.1 presents a fragment of the associated contradictions.

3. Field experiments

3.1 TRIZ and forecast

One of the authors of this paper has dealt with TRIZ and OTSM-TRIZ (General Theory of Advanced Thinking) for more than fifteen years. It seems evident that first forecast practice was based on the ideas of G.S. Altshuller [12, 13] and other researches from the TRIZ society [14, 15, 16]. Some of those ideas appeared in the English language publications as translations or rediscoveries after 1991 and they continue to be under development in the international TRIZ society.

It is evident that a new innovative solution is normally developed as a result of problem solving. Such a solution requires time and effort to be implemented in practice. As a result, solving an inventive problem causes technology evolution. As soon TRIZ and its posterior generations are based on the objective laws of technology evolution, these laws can be purposefully applied to foresee the technological future. (Discussion of the laws of evolution discovered in the context of TRIZ research remains beyond the scope of this paper.)

Most of the observed publications about TRIZ technology forecasting speculate about the S-curve of system evolution, ideality, multiple technology trends (patterns) and laws of technical systems evolution. On a closer examination, the law of increasing ideality of technical systems is nothing more than a sequent of analysis of several S-curves for several generations of a system (to measure time, to move load – transportation; to deliver information, etc.).

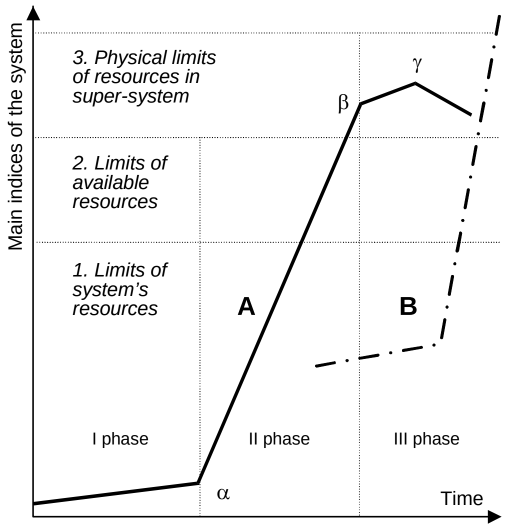

Figure 3.2.1. S-curve of Technical System evolution

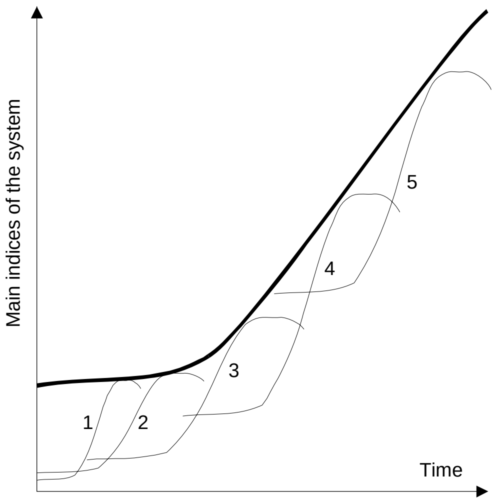

Figure 3.2.2. Superposition of several generations of evolution lines

The inherent meaning of the S-curve becomes evident when the reason for such a shape of system evolution is clarified. *Limitations of resources drive system evolution*. As soon as resources expire, a given system has to be replaced by a new generation of system. This next generation will spend fewer resources of space, energy and substance for satisfying the needs.

When applying the S-curve for technology forecast, one comes across a number of questions. Let us consider some of them: How to define the main index of an analyzed system in a computable way? How to scale the S-curve in time? How to accurately define the position of the analyzed system on the S-curve? It is interesting to notice that some of these questions considered in the context of the research dealing with genetic algorithm development [17].

One of the authors of this paper successfully applied the S-curve analysis in combination with resources and contradiction analysis for forecasting the future of a technical system at the end of 1999. As was proven later that the results of the forecast with a time horizon of three years corresponded to reality with quarter accuracy and forecast was right for three countries out of five forecasted. This experience gave an over optimistic viewpoint for the applied approach. Several express forecasts performed in the period from 2000 to 2003 just reinforced this optimistic viewpoint.

3.2 New product technology forecast

An improved approach was tested in 2004 for forecasting the future of Stationary Fuel Cell technology in framework of a project with European Institute for Energy Research (EIfER, Karlsruhe, Germany). The results of first phase of the project were recognized as unsatisfied. Among other reasons, an analysis of causes for failure showed drawbacks of the applied forecasting methodology. It was concluded that the methodology which was successfully applied for technologies in the second or third phases cannot be applied to a technology in the first phase of evolution (before point α on the S-curve). In addition, it was required to improve the transparency of the forecasting methodology.

The project dealing with Forecasting of Stationary Fuel Cell technology was redesigned and restarted. Using the results of the first phase of the project, the initial forecast problem was reformulated and divided into three questions:

1. What will be the Evolution of the market penetration for Stationary Fuel Cell (SFC)?
2. What will be the evolution of the SFC in comparing to competitive technologies?
3. What is the best path towards the ideal system of SFC?

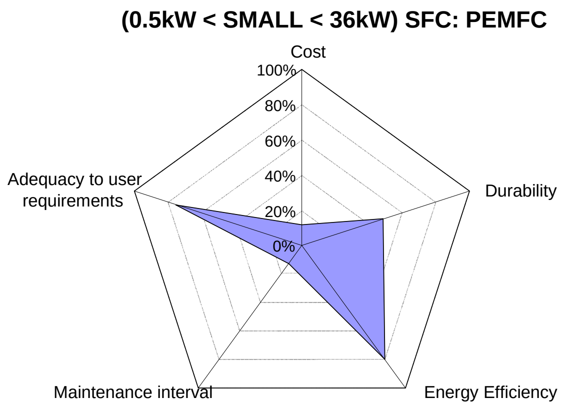

Figure 3.2.1. Example of results for critical features analysis for Proton Exchange Membrane Fuel Cell (PEMFC)

It was assumed that all questions would be answered for a fixed market (countries and regions) (Where?); for three power ranges (What?); for a time horizon: up to 2050 (with a nonlinear scale of time). (When?)

At the next step, a set of critical features was formulated in accordance with the rules of ENV modeling [1]. In order to estimate a gap between the required values of formulated features and the actual ones, an analysis of best samples was performed. The results of the analysis were presented in the shape of radar diagrams (see Fig. 3.2.1) for alternative technologies vs. required values of critical features.

In order to estimate limitations of resources a network of contradictions [18] (Map of Problems) was developed in accordance with required values of critical parameters. An analysis of the network (see Fig 3.2.2) in accordance with resources limitation support timing of technology forecast and answering for some of the formulated questions. On the other hand, such a map of problems supports the monitoring of new technologies impacts to the market capacity of small SFC. Every new patent of the project result can be associated with a problem from the map and the impact of such novelty can be examined in a systemic way.

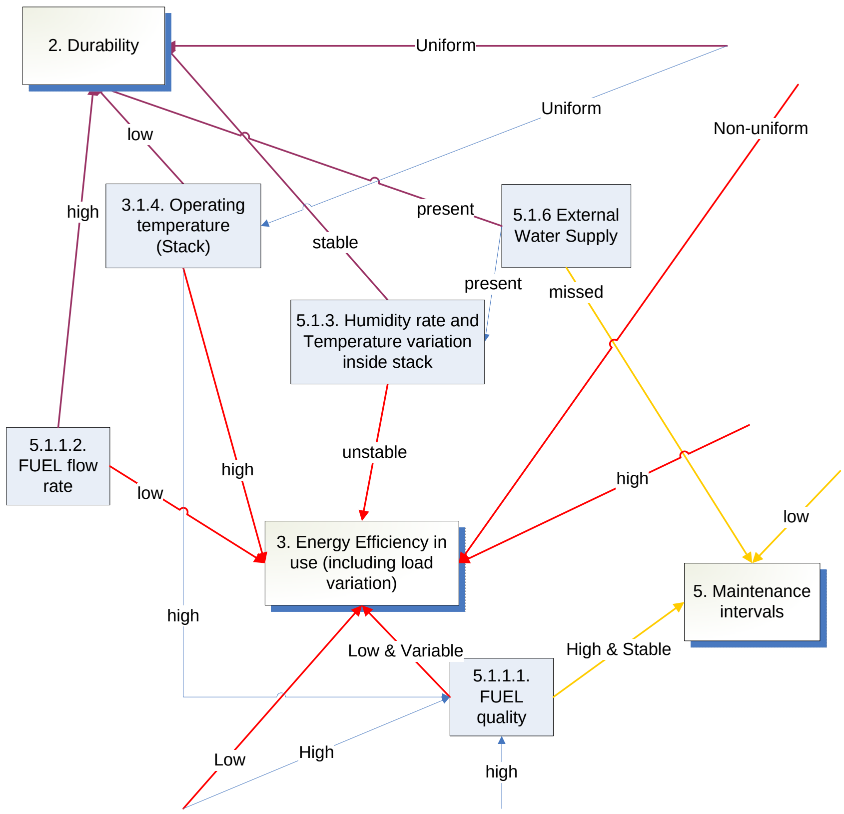

Figure 3.2.2. A fragment of the contradiction network for a small SFC (PEMFC)

Results of the second phase of the project were reported in June 2005 with a positive feedback. It was decided to continue the project in order to build comprehensive answers to the formulated questions.

4. Preliminary results

The results of the present study should be considered preliminary. These results offer the following:

1. Despite many existing methods, medium and long-term technology forecast of a new family of products and new-to-the-world technologies is not accurate enough to validate expenses for forecasting. The accuracy (mostly timing and social impact) of obtained technology forecasts is usually far from required.
2. Most currently applied methods aimed to satisfy the needs of a long-term technology forecast are modifications of Delphi surveys and scenarios building. Often they are applied in combination.
3. Knowledge extracted from the Theory of inventive problem solving (TRIZ) and its posterior generations can contribute to the accuracy of technology forecasting, but it should be done carefully taking into account the peculiarity of a forecast problem.
4. Complex forecasting methods do not necessarily provide more accurate forecast results than simple methods. Simple methods are less subjected to data inaccuracy than complex ones, while implementation expenses for simple methods are lower. As a result, the efficiency of simple forecast methods is higher.
5. The choice of a forecast method(s) mostly depends on data availability. A formal method(s) is reproducible, however it does not work well with qualitative parameters.
6. The efficiency of an existing forecasting method depends upon a forecasting horizon. Increasing the time horizon of a forecast dramatically decrease the efficiency of methods.

7. The efficiency of forecasting depends not only on applied method(s) but also the management of the whole forecast process. Effective method(s) can lead to poor results if project management is careless.

5. Concluding remarks

This paper aimed to demonstrate a set of problems that need to be solved on the way to a reliable technology forecasting. The collected set of problems should be structured in the shape of a map of problems and this map should be validated through further research.

It is also necessary to improve the transparency of a forecasting technique(s) in order to improve the applicability of proposed ideas and approaches.

The efficiency of next generation forecasting methods should suffer less from increased time horizons. It is necessary to propose a mode for description of uncertainties in a comprehensible way in order to communicate them and to be prepared for real threats rather than only for probable or believable ones.

6. Acknowledgements

We wish to acknowledge the European Institute for Energy Research (EIfER), Karlsruhe for support of the research on Technology forecasting. We also would like to thank our colleagues from LICIA team of the Laboratory of Engineering Design (LGéCo, INSA Strasbourg) for their questions and discussions that helped to clarify many points presented in this paper. Alexander Sokol provided a lot of corrections and advices about language and readability of this version of paper.

7. References

1. Khomenko, N., Materials for seminars: OTSM-TRIZ: Main technologies of problem solving, in “Jonathan Livingston” Project. 1997-2002: Minsk-Pyungtaek-Toronto.
2. Schnaars, S.P., Megamistakes: forecasting and the myth of rapid technological change. 1989, New York: The Free Press. 202.
3. Makridakis, S., S.C. Wheelwright, and R.J. Hyndman, FORECASTING: methods and applications. 3rd ed. 1998: John Wiley & Sons, Inc. 642.
4. PRINCIPLES OF FORECASTING: A Handbook for Researchers and Practitioner. 1st ed, ed. J.S. Armstrong. 2002, Boston / Dordrecht / London: Kluwer Academic Publishers. 849. http://hops.wharton.upenn.edu/forecast/
5. Porter, A.L. et al., Technology futures analysis: Toward integration of the field and new methods. Technological Forecasting and Social Change, 2004. 71: p. 287-303.
6. Schnaars, S.P., S.L. Chia, and C.M. Maloles III, Five Modern Lessons from a 55-Year-Old Technological Forecast. Product innovation management, 1993. 10: p. 66-74.
7. Zlotin, B. and A. Zusman, Directed Evolution. Philosophy, Theory and Practice, ed. V. Roza. 2001: Ideation International Inc. 104.
8. Vanston, J.H., Better forecast, better plans, better results. Research Technology Management, 2003: p. 47-58. http://www.tfi.com/rescon/five_views.html
9. Kameoka, A., Y. Yokoo, and T. Kuwahara, A challenge of integrating technology foresight and assessment in industrial strategy development and policymaking. Technological Forecasting and Social Change, 2004. 71: p. 579-598.
10. Kahn, K.B., An exploratory Investigation of new product forecasting practices. Journal of Product Innovation Management, 2002. 19: p. 133-143.
11. Crawford, M. and A.D. Benedetto, New product management. 7th ed. 2002, Irwin: McGraw-Hill. 588.

12. Altshuller, G.S., About forecasting of technical systems development., in Seminars materials. 1975: Baku. (in Russian)
13. Altshuller, G.S., CREATIVITY AS AN EXACT SCIENCE. Cybernetics. 1979, Moscow: Sovietskoe radio Publishing House. 184. (in Russian)
14. Altshuller, G.S., et al., SEARCH FOR NEW IDEAS: from insight to technology (theory and practise of inventive problem solving). 1989, Kishinev: Kartya Moldovenyaske Publishing House. 381. (in Russian)
15. Zlotin, B.L. and A.V. Zusman, Laws of Evolution and Forecasting for Technical Systems., in Methodical recommendations. 1989, STC Progress in association with Kartya Moldovenyaska: Kishinev. p. 114. (in Russian)
16. Salamatov, Y.P., System of The Laws of Technical Systems Evolution, in Chance to Adventure. 1991, Karelia Publishing House: Petrozavodsk. p. 7-174. (in Russian).
17. Goldberg, D.E., The design of innovation: lessons from and for competent genetic algorithms. Genetic Algorithms and Evolutionary Computation. 2002: Kluwer Academic Publishers. 248.
18. CAVALLUCCI, D., N. KHOMENKO, and C. MOREL. Towards inventive design through management of contradictions. in 15th International CIRP Design Seminar. 2005. Shanghai, China.