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PROBLEM MAPPING FOR THE ASSESSMENT OF TECHNOLOGICAL BARRIERS IN THE FRAMEWORK OF INNOVATIVE DESIGN

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ABSTRACT
This paper discusses an approach that points out technological problems that may occur whilst designing emerging technologies. The shape of the problem maps, which are obtained as an output of the proposed approach, is compatible with inputs of OTSM[1] or TRIZ problem solving processes used in innovative design. One of the standard ways of gathering knowledge and information (qualitative and quantitative) about new technologies is to elicit them from experts. Existing approaches may produce some biased knowledge. Indeed, a result of this approach is either over-optimism about emerging technologies or missed opportunities (stemming from pessimistic evaluation). We propose to reduce bias through a problem mapping approach that extracts and organizes expert knowledge in the shape of a network of interlinked contradictions. First, an overview of forecasting methods which apply S-shaped curves is presented. The concept of the S-curve being shaped by resource limitations is discussed. Some reasons behind the complexity of assessing resource limitations are proposed. Secondly, the concept of problem mapping is introduced. Some features of the practice of problem mapping are discussed. The third part examines how problem mapping can be purposefully applied for assessing technological barriers using examples from emerging energy conversion technology. Finally problem mapping is considered from the viewpoint of knowledge management, inventive problem solving, and decision making within the context of studying future technology and innovative design.

Keywords: Technology Forecast, Laws of Technical systems evolution, Map of Problems, Resource limitations, OTSM-TRIZ

1 INTRODUCTION

"If one does not know to which port one is sailing, no wind is favourable". Seneca

Any technical system (product of process) is designed in order to satisfy some social and economic needs. As soon as the existing technical system (TS) answers certain needs, the necessity for a new system generally appears as a result of two causes: the appearance of the next generation of socio-economic needs and the reduction in the resources used by the existing TS when operating [1]. In order to determine a direction of future technology development, it is necessary to have credible knowledge about future quality standards. Such knowledge may be described by the means of criteria that have to include a clear image of the technological capabilities that will satisfy these needs. These criteria can be drawn from a relevant vision of future designed systems in their environment. One of the issues of technological forecasting is obtaining a relevant vision of the future TS and of the

[1] Theory of Inventive Problem Solving (TRIZ is the Russian acronym usually applied for) was developed mostly to address the engineering problems. At the end of the 1970s founder of TRIZ G.Altshuller anticipated further evolution of TRIZ towards a General Theory of Powerful Thinking, which will be useful to deal with non-engineering problems and complex cross disciplinary problems as well. At the beginning of the 1980s G.Altshuller initiated research to develop this theory. OTSM is the Russian acronym usually applied to indicate the General Theory of Powerful Thinking. For details see paper of N.Khomenko et al. [18].

problems that may occur during its development and during its life cycle. This needs to be done early enough in order to be able to answer the arising demands on time and reduce risks of possible threats and wastes. To some extent, the technological forecasting approach presented in this paper contributes to design-to-cost tools for the design of new generations TS. There are still several problems to overcome to fulfil the demands of these methods.

In efficient innovative design the critical questions addressed in technological forecasting are: How to improve technical credibility, visionary capacity, certainty and the resolution of the technological forecast? How to increase the reliability, accuracy, repeatability and efficiency of the forecasting process?

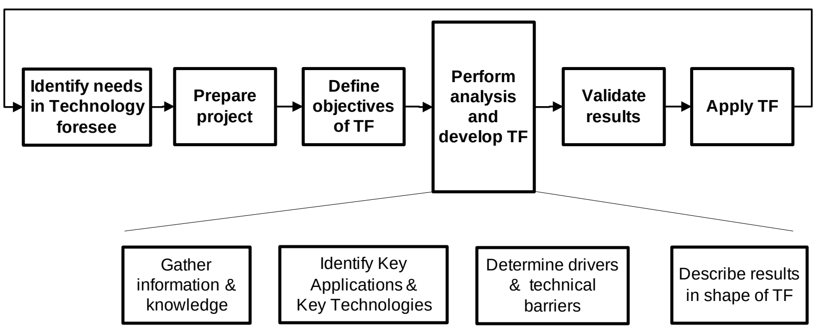
There are already general contributions that have been provided on the way to answering previous questions. For instance, in [2] J. S. Armstrong tries to capitalize the principles of the forecasting process. In [3] S. Makridakis collected the proven methods for forecasting the future for different purposes. The American Council for the United Nations University provides in [4] a detailed discussion about methods that are applicable for the prediction of the evolution of complex systems. In [5] M.Godet and al. present a set of methods to improve forecasting by using scenarios. There is interesting empirical knowledge described as well in the papers [6], [7], [8]. All the forecasting methods are candidate neither for technological forecasting nor for technological barriers forecasting. The next sections of the introduction provide the basics concepts required to understand and pose the problem of assessing technological barriers.

1.1. Quality of technology forecasting

According to several sources of information the main function of technology forecasting (TF) is to lead the decision making process towards profitable solutions with minimum uncertainties. For instance, Kostoff, R.N. and Schaller, R.R. [9] define the main function of technological forecasting as providing a consensual vision of the future science and technology landscape to decision makers. As a consequence, a high quality forecast of a TS should fit several characteristics: it should be accurate, credible and visionary. It should also portray the evolving relationships with adequate breadth and depth. Moreover it should provide a comprehensive description of the evolution and relationship of most critical sciences and technologies in the past, present and future as well as a high degree of certainty, reliability and objectivity (bias-free).

1.2. Forecasting process

During the last decades, despite multiple attempts to formalize the medium and long-term technology forecasting process, most of the authors agree that it needs to become much more formalised [10] and reproducible. Our research equally contributes to this goal.



Key: TF: technology forecast

Figure 1. Outline of Technology forecasting process

The main phases of the technology forecasting process are presented in the first line of Figure 1. The method proposed in this paper, concerns the sub-phase "*Determine drivers & technical barriers*" of the phase "*Perform analysis and develop TF*" which consists of the four stages given on the second line of Figure 1.

Frequently, the results of technology forecasts are described in a shape of science and technology roadmaps [11].

1.3. What makes forecasting difficult?

Within the framework of the present research we aim to identify the key difficulties and problems for each stage of the phase. First, the problems and difficulties were collected through reviewing literature, the practice of forecasting and by informal interviews of practitioners. Secondly, the collected information was structured in accordance with the four sub-stages of the phase “Perform analysis and develop TF”. The third step saw the problems reformulated in the form of contradictions [12, pp.26-30]. Finally the generic problems were named and questions for each stage were formulated in order to summarize the set of contradictions for each stage [15].

The critical question for the stage *Determination Drivers and Technical Barriers* was formulated the following way: How to assess the advantages and shortcomings of emerging technologies before having experienced them? The problem was named as 'Preconceived limitations, biases, personal and organizational agendas of the experts' due to the underlying problem connected to this question. In fact, the question is closely linked to the source of knowledge about emerging technologies. An instructive example can be found in [8]. In order to decrease risks and make a trustworthy assessment, we should have knowledge; however, we do not have the required knowledge, because the technology is emerging.

In practice, when working with experts to explore the future of a specific technology, the level of optimism depends on many factors where personal bias plays a significant role. The experts on competitive technologies (alternative solutions) will emphasize the strong points of their own solutions and unconsciously tend to diminish the weak points. How to bypass such biases and personal agendas? Frequently the phenomenon 'Solution looking for its problem' takes place in the mind of specialists. The method presented in this paper aims at decreasing the bias of experts during the *Determination of Drivers and Technological Barriers* stage of technological forecasting.

1.4. S-shaped curves to describe the evolution of TS

In order to perform quantitative and qualitative forecasts about TS, models of their evolution in time were required. By analysing historical data, it was found that population growth and other “main indexes” of a given type of TS can be fairly described with an S-Shaped curve, which is also called sigmoid function, sigmoid curve or standard logistic function. It should be noted that this type of curve has been previously introduced in many other scientific domains in order to describe the evolution of population growth. Several mathematical models of this type of curve has been proposed. The logistic equation as a model of population growth was first introduced by Belgian mathematician Verhulst, Pierre-Francois (1804-1849) in 1838 [14]. But one of the most frequently encountered models in statistics, economics, biomathematics and in many technical domains is the special case of the logistic function called S-curve.

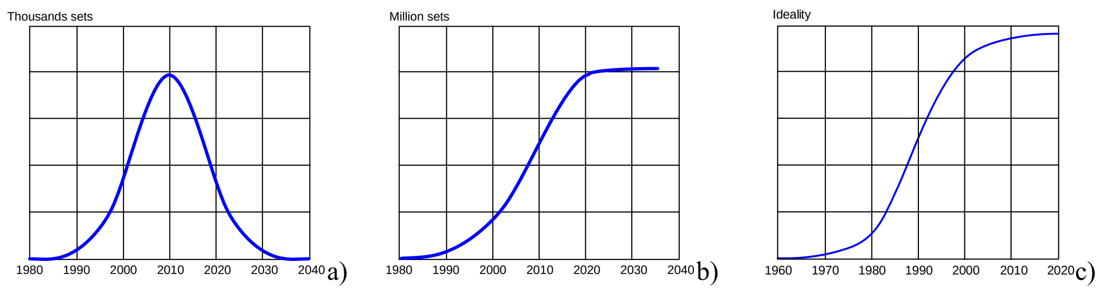


Figure 2. Three curves to describe the evolution of technical systems

Figure 2a presents the evolution in time of the number of sales of a given TS. This curve is close to a Bell-curve. Figure 2b represents the cumulative sales deduced from graph 2a.

Within the research of the Theory of Inventive Problem Solving (TRIZ) an S-curve model was employed to study technical systems evolution [12]. Analysis of technical systems evolution in accordance with the S-curve model gave the opportunity to describe a concept of three levels of resource limitations during technical system evolution: first level – limitation of working principle (limits of system's resources), second level – limitation of economic rationality (limits of available resources from the environment), and third level – physical limits of resources in the super-system (e.g. limitations of fossil resource, limitations of available area, limitations of renewable resources –

clean water). In the scope of our research the most interesting concept is multi-level resource limitations assessment (see Figure 3). It is interesting to notice, that a similar concept was described as a *Law of the Minimum* by German geochemist Justus von Liebig (1803-1873) in 1840. The Law of the Minimum states 'that growth is controlled not by the total resources available, but by the scarcest resource'. In chemistry such a concept is known as a rate determining step, in management as a critical path. We shall use this assumption for our study. More information about it is given in section 1.6. Graph c) of Figure 2 ordinate is a compounded index named "Ideality" in TRIZ [12]. It is assumed that this index follows also an S-curve, which describes the efficiency of the applied resource growth over time.
S-curves can be used for quantitative and qualitative analysis of TS evolution a posteriori. Attempts to use them in the scope of forecasting were made. There are difficulties to use them in the framework of forecasting. First we should be able to define a priori what are the "main indexes" of a TS. Second, in order to fit a priori the whole S-curve to a given mathematical model of an S-curve relevant points of the S-curve should be known in advance. The issue is how to get them. When the "main index" is known and when some points are already known from the past it is possible to "extrapolate" a few points in the near future. In technological forecasting and in innovative design we are often faced with alternative technical systems. The situation of evolution of 2 TS that compete is represented in figure 3 (system A and B).

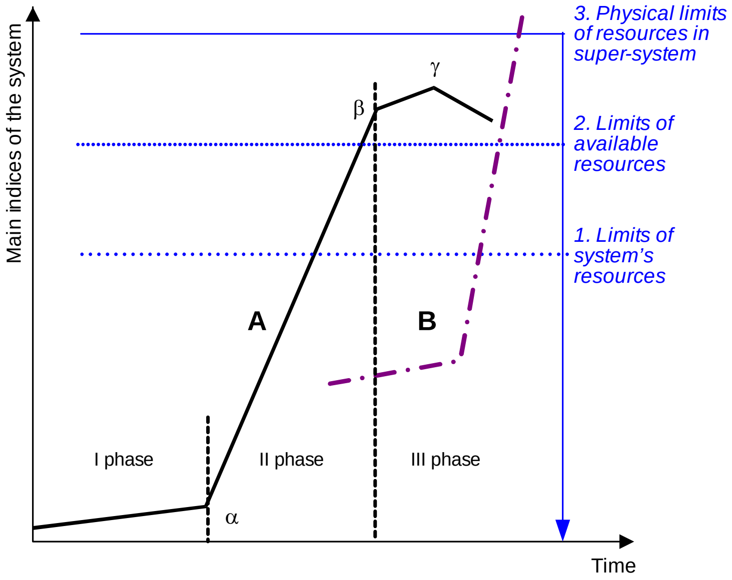


Figure 3. S-curve to study evolution of technical systems

1.5. Application of S-curves

In order to see the particularities of S-shaped curves when applied for technology forecasting, it is interesting to overview their application in future-oriented studies. The observed application of S-curves is summarized in Table 1.

Table 1. Some applications of S-shaped curves

Method name:	Name & Application:
Trend Impact Analysis [4]	S shaped curve[2]. For extrapolation of previously collected data
Curve fitting technique [4]	S shaped curve[3]. For forecasting the critical variables within of State of the Future Index (SOFI) method
Decision Modelling based on Fisher and Pry model (1971)	S-shaped curve[2]. For examining market, technological, social substitution dynamics
Statistical Modelling in border of time-	Gompetz curve,

[2] Quantitative nature
[3] Qualitative and quantitative nature

Method name:	Name & Application:
series analysis as a part of curve fitting [2, pp.577-595]	S-shaped curve[3]. For trend extrapolation
Text Mining for Technology Forecast [14, pp.194-197]	Growth curve[2]. For analysis of annual publications, to prove informative trends
Life Cycle Analysis in border of strategic analysis	Life curve of product[4]. To identify the stage of a system's evolution
Theory of Innovation Diffusion [16]	S curve of Cumulative Penetration or Sales[3]. For studying the technology adaptation dynamic
Emerging issues analysis [17]	S-pattern growth curve[4]. For identifying the issues before they reach the trend of problem phase for engineering and non-engineering fields

A preliminary study of the application of S-shaped curves shows that they are most often applied for analysing past data in order to disclose trends and for proving known trends. They are also applied in the framework of various extrapolation techniques. Most S-curves are constructed using quantitative approaches. However, qualitative analyses using S-curves are widely applied as well. It is necessary to notice, that a reliable technique to scale S-curves in time for qualitative analysis has not been found within the scope of our study. For mixed qualitative and quantitative studies the timing of S-curves is performed as result of collected data patterns in the framework of time-series analysis.

1.6. Assessment of resource limitations

In the scope of TRIZ research it was confirmed that an S-curve can be employed for depicting the evolution of every technical system. Therefore the evolution of the system can be presented in three phases: childhood (before α), adolescence & fast growth (between α and β), and maturity (after β) & declination (after γ) (see Figure 2).

Within the second phase a technical system, A, faces the first limits of the system's resources. Further evolution is possible thanks to extensive spending of environmental resources without recovering them (e.g. internal combustion engine started to pollute the environment many years ago). Close to the point β the technical system, A, confronts the limits of the available resources (e.g. there is not enough parking area for cars in populated cities). A new system, B, takes the place of system A, since system B spends limited resources in a more efficient way, or applies other resources to perform the needs (e.g. motor-cars have more horse-power per m^3 and occupy less space then horse driven cars). System A will never reach the third level of physical limits. According to laws of thermodynamics it is impossible to operate a system without spending some resources.

Knowledge about critical resources and their availability can assist bias free technological forecasting. In engineering practice identified resources can be measured and calculated. For instance from a technological viewpoint every TS consumes a certain amount of space, substances, and energy. There is a fixed amount of available space, proven reserves of fossil resources, metals and other substances. The energy available for the application can be calculated as well. Unfortunately, from a social viewpoint, resources of time can be computed whereas resources of knowledge can mostly only be evaluated qualitatively.

What are the reasons of the complexity of assessing resource limitations? There are several causes:

- One among others is a fact that at different stages of a system’s evolution, different resources can be identified as 'scarce resources'. For instance, at a certain stage it can be the size of a machine, at the next stage it can be energy efficiency, at a third stage it can be byproducts, dangerous waste products and other tailings. This group of reasons was named: Dynamic nature of limited resources.
- In order to be consistent, it is necessary to take into account not only the technological resources of the analyzed system, but also economic resources, social resources and environmental resources. How to measure and unify all these resource limitations? This group of reasons was named: Multiple contexts compatibility.
- In order to calculate scarce resources, data should be collected. The problem of Noise and Signal, discussed above takes place here as well.

[4] Qualitative nature

- For emerging technologies, when the analyzed system is in the exploration phase [8] of its development (before point alpha on the S-curve) it is necessary to work with specialists and experts to overcome knowledge shortages. The problem of preconceived limitations, biases, personal and organizational agendas of experts has to be secured.
- Usually the analyzed system is considered as a part of a super-system. Often the super-system is named 'environment'. In order to identify a system it is necessary to define its boundaries, properties, and its interaction with the environment. Aren't we making an artificial boundary? On the other hand, the forecasted system draws resources from the nearest super-systems. In order to identify scarce resources it is unavoidable to distinguish the dynamic of the relationship between the system and its environment. According to laws of technical systems evolution from TRIZ, system boundaries change over time (law of Transition to the Super-system). This group of difficulties was named: Dynamic of necessary and sufficient description.

The presented list of causes of complexity in assessing resource limitations is not a complete one. Nevertheless the presented reasons, according to our study, seem the most critical to address. How do different forecasting methods manage the established difficulties?

Despite many criticisms, one of the most popular methods for medium and long-term technology forecasting is the Delphi method and its versions. Many improvements and modifications have been proposed since the 60^{s}, when the method was developed in the RAND Corporation by Olaf Helmer, Norman Dalkey, and Nicholas Rescher [4]. Usually the Delphi method is presented as a systematic interactive forecasting method based on independent inputs of selected experts.

An interesting review of Delphi method pitfalls as well as many references on criticism and modifications of the Delphi method can be found in the paper of P.Tapio [21]. The paper discusses eight pitfalls and how clustering can help to bypass them: a biased selection of panelists; disregarding organization; forgetting disagreements; ambiguous questionnaires; oversimplified structured inquiry; feedback reports without analysis; forgetting the arguments; lack of theory.

Another paper of A.Kameoka et al. [6] presents experience and some results of Delphi method application on the level of industrial strategy development.

According to our study, there have been many cases when the method produced poor results. Nevertheless, the Delphi method includes some mechanisms and techniques for decreasing the impact of panelist biases and for considering multiple contexts. Unfortunately, the problems of Noise and Signal, dynamic nature of changes and the high cost of conducting a Delphi survey reduce accuracy, visionary capacity and applicability of the method.

2 PROPOSED APPROACH TO PROBLEM MAPPING

The target of this research is to improve the process of technological forecasting and also the quality of the forecasts produced. Most of the literature reviewed discusses various improvements in forecasting practice and how they influence the quality of the forecast [2, 3, 4, 5]. In order to deliver practical results we expect to follow both objectives:

1. To increase the reliability, accuracy, repeatability and efficiency of forecasting for proposing cost effective and easily applicable approaches.
2. To improve the technical credibility, visionary capacity, certainty, and resolution of technological forecasts for reinforcing the support of decision making.

As a preliminary solution of the problems discussed above the network of contradictions analysis, adapted from OTSM-TRIZ technologies was tested [18]. This approach maps the problems of the analysed technology using the syntax of contradictions and the specific structure of a graphical description. There are two types of nodes. The first type of nodes (N1) describes critical-to-X features. The second type of nodes (N2) presents elements responsible for problems and their features that must obtain the opposite value. Links are used to describe the opposite values of features. Links can connect N1 with N2 and N2 with N2. Links between N1 and N1 do not contribute to the assessment of resource limitations but help to understand cause-effect relationships.

Links on the map can be placed only if the opposite value of features are described. This simple rule contributes significantly to decreasing the number of non-appropriate links and to overcoming personal biases of experts.

The approach was tested to study the technological future of small stationary fuel cell technologies for the European market and to perform a technological forecast of distributed energy generation technologies for the German market. These two studies were performed in regular close collaboration

with the European Institute for Energy Research (EIFER), Karlsruhe in the period from September 2004 to December 2006.
Why is it crucial to identify and analyse problems prior to existing solutions for technological forecast? From the viewpoint of socio-economic needs it does not matter what is the technology which answers the demand: fuel cell, photovoltaic or wind power generators. The real questions is will it be possible to satisfy changes in energy demand? If it is not certain, what are the alternative pathways (technological and non-technological) from the existing situation to the future state? Therefore, before judging technologies, it is necessary to understand where the problems come from and which problems are to be solved in the specific situation.
Figure 4 represents the outline of the process performed for the two studies in collaboration with EIFER, Karlsruhe.

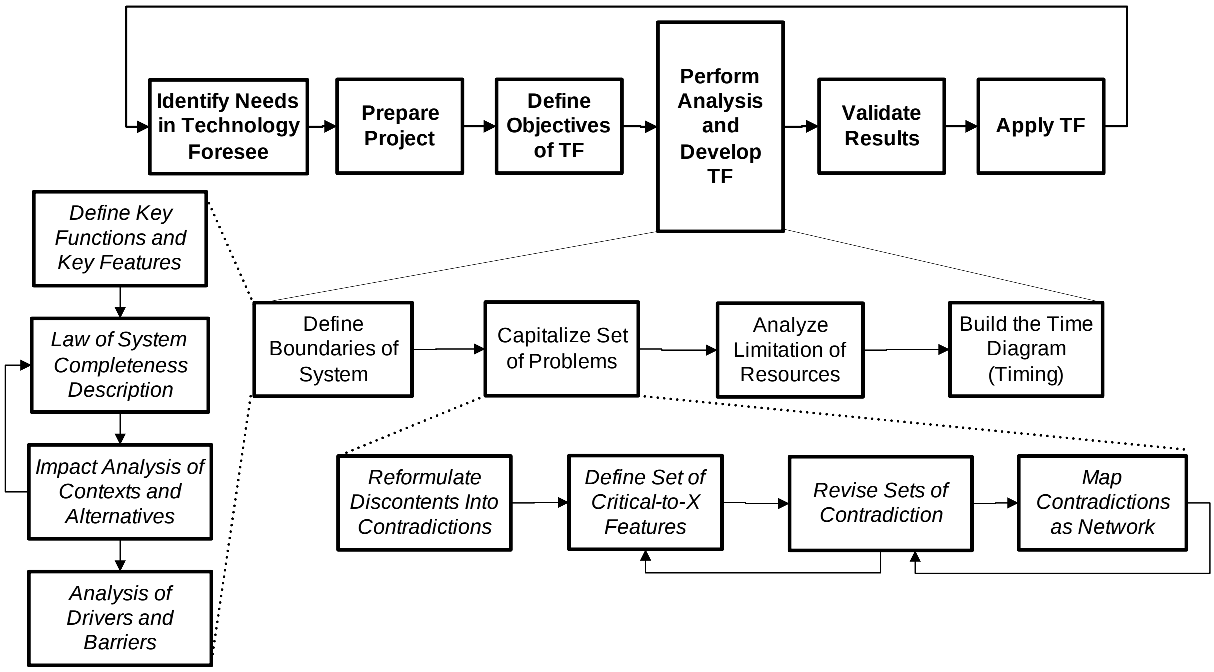


Figure 4. Outline of the forecasting process tested in practice

The definition of a system's boundaries is performed using laws of technical systems evolution from TRIZ and the results of the definition of the main functions and key features of the system. The defined functions and features represent socio-economic needs. From a set of laws of TS evolution, the law of system completeness, the law of energy conductivity and law of harmonization are applied. Impact Analysis of Contexts and Alternatives in combination with Analysis of Drivers and Barriers help to define system boundaries more precisely and refine the collected information.
At the next stage the set of problems from the explored technology is capitalized. Rules and interactive mechanisms of contradiction formulation give the opportunity to take into account the drivers and the barriers in compact and reusable form. The knowledge management function of contradictions definition is important for practical forecasting.
The capitalization of problems through the definition of contradictions helps the working team with removing bias from the gathered knowledge. The process of problem reformulation generates additional, usually unexpected, viewpoints of the explored system and discloses non-obvious problems. On the other hand, several separate problems can be combined into one when the contradiction 'language' is applied in the proper way. Self-organization of the mapped problems is an interesting secondary effect. It is necessary to notice, that problem mapping using contradictions requires a high level of expertise in the analysed technological domain. This requirement was recognised as valuable for increasing the competence of specialists in emerging technologies. However, it can be a cause for slowing down the forecasting process when the required expertise is not available or the working team reaches the limits of its knowledge.
An example of the resulting network of contradictions for low temperature (PEMFC) stationary fuel cell (SFC) below 5 kWe power is presented on Figure 5. The network was constructed for six critical-

to-market (CTM) features. How to read concepts on the map? For instance, 'Current distribution inside cell of stack' (central block at right side on Figure 5) has to be uniform, in order to satisfy the electrical efficiency in use (CTM#3); but it has to be non-uniform, in order to satisfy distribution of hydrogen rich gas and oxygen inside cell of stack (which is tightly linked with CTM#1, #2 and #3). 'Electrical efficiency in use', 'Durability', 'Maintenance intervals' are the critical-to-market (CTM) features #3, #2, #5 accordingly (#1 is not shown on Figure 5).

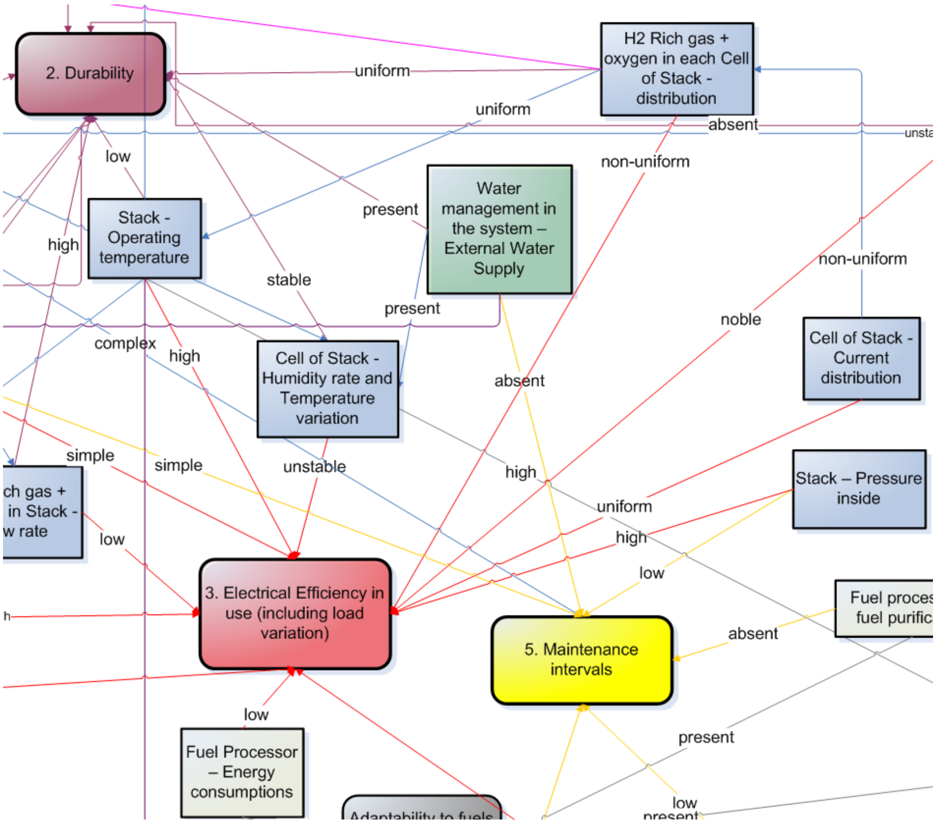


Figure 5. Fragment of network of contradictions for low temperature SFC (Information provided courtesy of EIFER, 2005, Karlsruhe)

3 ASSESSMENT OF TECHNOLOGICAL BARRIERS USING PROBLEM MAPPING

Technological barriers are a problem; they are limits imposed by the impossibility of applying a certain technology to meet the specific socio-economic needs. Technological barriers can be caused by environmental, social, economic or technological issues. As soon as any technology requires a set of resources to operate, the limitation of resources is the root cause of incapacity of the technical system to meet quality standards. That is why it is crucial to foresee future technological barriers and how they can be approached in order to forecast the evolution of certain technologies.

The interactive nature of mapping the contradictions as a network requires a regular revision of the collected set of contradictions and set of critical-to-X features in order to keep the consistency of the analysis and processed knowledge. This mechanism contributes to a bias-free assessment of technological barriers. In practice, after several reviews the resulting map can look quite unexpected for working team members. The process of map construction contributes to a consensus within the working team about the subject of study as well.

For example, according to the aim of the study where small SFC are critical-to-X features, a set of critical-to-market features was formulated. When critical-to-market features and their values were defined, the large gap between the existing cost of SFC and required value of this feature was identified (see Figure 6). While mapping the contradictions one asks 'What are the problems that prevent us from closing the gaps?' If in the network of contradictions, the gap on the Cost axis is not presented by an adequate problem value, it is a warning sign of the inconsistency of the analysis. Critical-to-X features analysis and the network of contradictions should be harmonized.

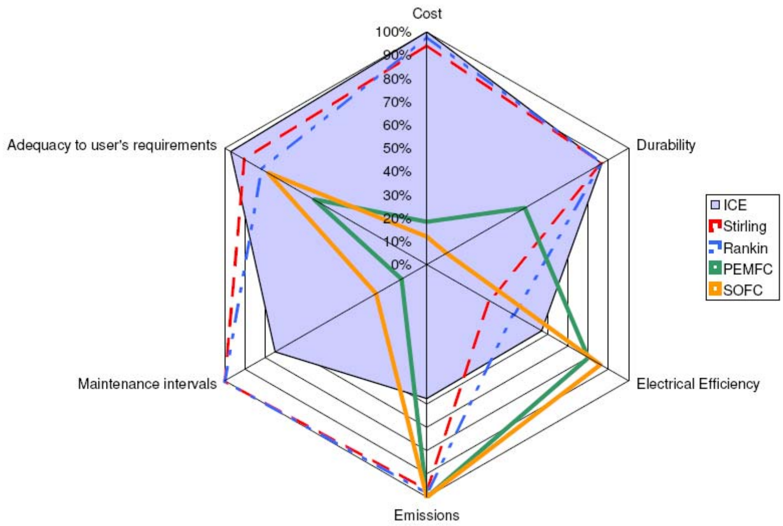


Figure 6. Representation of critical-to-market features in a radar diagram (Information provided courtesy of EIFER, 2005, Karlsruhe)

At the third stage (Analyse Limitation of Resources, see Figure 4) the limited resources for the defined network of contradictions are examined. Limited resources in a technological context can be described through the shortage of certain substances, inadequate flow of energies (fields), restrictions of space and limitations of time. In order to overcome the limitations, the identified problems should be resolved and limitations of resources should be overcome. In practice, it takes time to develop concepts, to design a solution, to explore the obtained solutions, to perform field tests and to diffuse the proposed solution [8, 16]. Assessment of the required time for resolving the mapped problem is a result of the third stage. Available information about ongoing research projects and development of new products is applicable at this stage. However, for both studies the discussed approach produced several problems which were not considered by any R&D activities. It verified once again the advantages of a system approach for forecasting technological barriers.

At the fourth stage (Build the Time diagram) a time diagram for the constructed network of problems is composed using results from the third stage. The time diagram can be considered as a technological roadmap for the explored technology on its way to market.

Let us illustrate the limitation of resources analysis using the example of low temperature (PEMFC) small (below 5 kWe power) stationary fuel cell. First, the contradictions are extracted from the network in formalized form: element, feature and the opposite values of features. Second, limited resources for the formulated problems are assessed. Results can be collected in a table. Third, R&D activities are identified for each “problem-limited resource” pair .

For instance, there is a problem extracted from the network of contradictions: applied materials for membrane in stack and for bipolar plate must be noble and must be common. For this problem we are limited by substance resources: nafion and graphite bipolar plate. In order to see how and when the identified problem can be solved, R&D activities were explored to address the problem. The European projects AUTOBRANE: Nonfluorinated membranes and PAN-H were identified: metallic bipolar plate as most representative. The planned duration of these projects is 5 years. This is the planned time for designing a solution. Forecasters assumed the successful completion of the projects. Duration of field tests and prototyping before commercialization was assessed by experts of EIFER as 3 years.

The total time for commercializing the solution of the problem was assessed as 7 years and 6 months. As soon as the exploration is underway, field tests and the beginning of commercialisation can be done partially in parallel the total time, for diffusion is not simply the total sum. For details about exploration, field tests and the beginning of commercialisation see E.Schenk [8].

Example of a resulting map of problems (for low temperature small SFC) is presented in Figure 7.

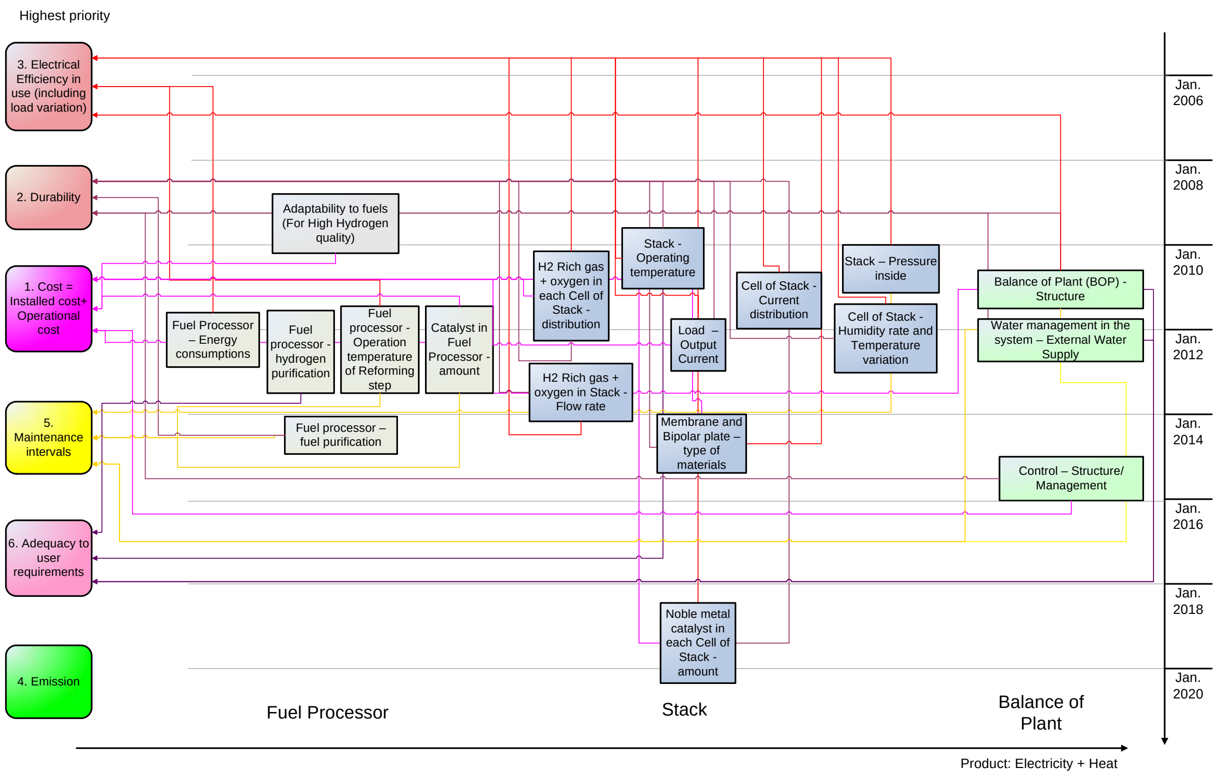


Figure 7. Example of a network of contradictions in a time scale
(Information provided courtesy of EIFER, 2005, Karlsruhe)

The strong point of such a map is that it allows forecasting of the technological future of the explored technology and monitoring changes of the speed of evolution. At the same time it represents contradictions to be solved on the way to arriving at adequate values of critical-to-X features. Unfortunately, the presented map was constructed just for the technological context so it mostly depicts the engineering problems. Each box on the map portrays a specific technology barrier. Every problem (contradiction) in turn, can be decomposed and described as a set of sub-problems at several levels of details.

4 CONCLUSIONS AND DISCUSSION

Two studies of the future of new energy conversion technologies performed in the period from September 2004 to December 2006 using the concept of limited resource assessment showed valuable results on the level of technology forecast as well as on the level of the forecasting process. According to the feedback received, problem mapping and the assessment of limited resources, when integrated into the technology forecasting process, assist:

- in the assessment of technology barriers and opportunities in a bias-free way;
- in the accumulation of knowledge about limited resources in a structured way;
- in the recognition of the alternative pathways from present to future technologies independently from existing solutions.

From a knowledge management viewpoint the systematic approach, with a given analysis grid using contradiction models, helps to focus only on significant problems. It provides considerable support for handling the problem Signal-Noise and for keeping the consistency of the forecast.

The proposed approach helps to discover new problems and to organize knowledge in accordance with them. The resulting networks of problems on the one hand accumulate and structure knowledge of experts, on the other hand, construction of maps of contradictions contributes to the reduction of experts' biases.

From an inventive problem-solving viewpoint assessment of technological barriers produce the output of a system vision of problems surrounding the analysed technology. Previously invisible barriers are clarified. Resulting maps can be applied to define the priorities in research and development programs. A system vision of technological barriers enlightens the key problems to be solved. As a result, many related problems can be reduced thanks to solving one key contradiction.

In practice, it was observed that constructing a network of contradictions helps members of the working team to develop their level of expertise incredibly quickly. This takes place as soon as knowledge acquisition is combined with structuring the network. This process produces a system effect when experts are forced to study new limitations.
From a decision making viewpoint, the tested approach showed better comprehension of stakes and links between technological advances and the market. A description of the results in the form of a timed network of contradictions brings a clear picture of challenges and time required. Resulting maps for different emerging technologies are comparable and synthesise a lot of knowledge in a bias-free way.
Networks of contradictions can be applied for monitoring the evolution and rhythm of development for the targeted technology in the future. Development of the forecast in close cooperation with forecasting specialists, researchers in emerging technologies and the customers of the forecast gives not only credible results, but it supports building customized methods.
There are considerable remarks, which were collected within performed studies.

1. The proposed approach requires a high level of expertise and lead to the edge of available knowledge.
2. The proposed forecasting process takes a lot of time and human resources to be performed in the correct way.
3. Contradiction analysis is difficult to perform due to the specificity of contradiction models applied in OTSM-TRIZ. It is preferable to have preliminary experience in problem solving using contradiction analysis before beginning forecasting.
4. One of the weak points is that we have only technical problems (barriers) on the maps.
5. Definition of the objectives of the technology forecast and the scope of study should be done carefully and precisely.
6. It is difficult to put into practice the assessment of limited resources for emerging and ongoing technologies in parallel. The procedures of assessment are varying and it complicates the problem.

There are also several general questions and remarks of which we had no clear vision until now.
It became evident that by using just a technological context it is impossible to provide a reliable technology forecast. It is necessary to find a way of integrating knowledge and different models from economic, social, technological and environmental contexts. This issue become especially critical to forecast new-to-the-world technologies in the framework of medium and long-term forecasts.
For different contexts, the importance of different critical-to-X features can vary. Thus, for instance, time to market from a technological context can be predicted as January 2013, when in accordance with the social context, time to market will have a value of July 2015. How to integrate predictions from various contexts?
For medium and long-term forecasts faced with a fast-changing environment, the critical question is 'How to manage the transformation from quantity to quality issues (a law of evolution known from dialectics)?'
In this paper we present ongoing research. Whilst working towards the next generation of forecasting methods we aim to improve efficiency, transparency, and the length of time-horizons. Reliance on technology forecasting is unavoidable if we are to design the required solutions at the needed time in the needed place for real threats and opportunities rather than for probable or believable ones.

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