Contradictions in the domain of technological forecasting

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Problems are more important than solutions.
Solutions can become obsolete when problems remain.
– attributed to Niels Bohr[a]

Introduction

Decision making about future technologies like founding into research, purchasing new equipment or investing into human resources needs a forecast about future socio-technological changes. Technological forecasting as a regular practice started to grow from the 1950s[1]. Forecasting and roadmapping of technologies started to grow in importance from the middle of 1990s[2] due to increased complexity of science and technology management. Forecasting and roadmapping of manufacturing technologies are more and more demand from industrial companies and research institutions due to the high investment cost into modern technologies and the rapid pace of technology changes in the beginning of 21st century.

Within the development of the FORMAT methodology, we try to keep control on accuracy, reliability and practical applicability of a technological forecast for manufacturing companies. Meanwhile, the request of an easy to use forecasting methodology when developing a technology forecast is in the focus of our research[3].

It is necessary to notice that a study conducted in the framework of the FORMAT project, showed that most of forecasting methods work on the level of socio-technological changes[4]. The results of those forecasting methods are useful for economic decisions, or for strategic planning and decision making at regional and country level. However, these methods miss to provide specific information for industrial and R&D companies. Besides, short-term forecasting practices based on statistical methods are today well integrated into quality management approaches and are supported by statistical software packages, which are widely applied.

Fulfilling the gap between methods for socio-technological changes and short-term forecasting methods is a vital request in the beginning of 21st century for supporting decision makers with information about distant technological changes. This kind of knowledge of the future can facilitate effective decisions and the planning of resources allocations in the Research and Development of modern companies and institutions.

Technological forecast describes the future characteristics (WHAT?) of machines, products, and technologies which will be used in the future society. The description is connected with a time horizon (WHEN?) and a geographical region/market (WHERE?). Technological forecasts are widely applied for strategic planning, decision making and during early R&D stages.

Different approaches

There are many different classifications of the forecasting methods proposed by numerous research groups. One of the most generic classifications suggest distinguishing methods for exploratory (exploration of possible futures) and normative (target projections) forecasts. In fact, these two

[a] Niels Henrik David Bohr (1885 – 1962) was a Danish physicist who made fundamental contributions to understanding atomic structure and quantum mechanics, for which he received the Nobel Prize in Physics in 1922.

directions are complementary and they are often useful in combination. Another dimension of generic classification suggests recognizing two big groups of forecasting methods: trend extrapolation (based on quantitative information) and judgmental (using qualitative sources of information). Both groups have strong and weak points, thus in practice they are used in combination as well.
More detailed study about existing method for forecast was performed within FORMAT project and reported in Technology Forecasting – State of the art update[4].

We defined forecast as a process for getting prescient knowledge. Forecast is not merely information about What, When, Where (sometimes also Why and How) things will change. Knowledge is not equal to information[5]. Whatever method is applied there is always an inherent contradiction, rooted on definition of knowledge which is acquired from past experience by learning. That is why most of the people are skeptical about reliable forecast: How to learn about the future when knowledge comes from the past?

By using recent data, information, and knowledge about changes, the forecast has a limited accuracy for longer time horizon[6]. In order to improve reliability of a long-term forecast, it is necessary to identify a specific type of knowledge that can be useful for getting prescient knowledge. Our working hypothesis (see our epigraph): the knowledge about problems can be purposefully applied for predicting distant future.

> The study of **technology** concerns what things are made and how things are made.
>
> **TECHNOLOGY** = HARDWARE + SOFTWARE + ORGWARE
>
> *Hardware*: Manufactured objects (artefacts)
>
> *Software*: Knowledge required to design, manufacture, and use technology hardware
>
> "*Orgware*": Institutional settings and rules for the generation of technological knowledge and for the use of technologies
>
> [http://webarchive.iiasa.ac.at/Research/TNT/WEB/Page10120/page10120.html?sb=5]

When looking carefully on the history of the socio-technical systems evolution using problem-oriented thinking, it is noticeable that major problems have not been changed from the time of the Pyramids. Certainly, many socio-technical solutions, technologies and technical solutions we use today are really different from the past. Our research results since 2004 support the idea that systemic knowledge about problems is useful for producing a reliable technological forecast.

Here below, it is described how we organize knowledge about problems in the perspective of building a forecast and for developing science and technology roadmaps. There are also some practical questions of managing knowledge of a team of analysts and to be efficient when building a network of contradictions. Furthermore, some practical hints are presented about how to guide a working team when building a network of problems within a forecasting study.

In September 2013 it was decided to adapt and test an approach of Network of Contradictions (NoC) for the FORMAT methodology of technological forecasting. At that moment, NoC has been tested since 2004 in the framework of the Researching Future methodology.

Reference model: Why to use contradictions?

In order to forecast future changes it is not enough having a lot of information; it is necessary to differentiate relevant-to-future data and information. Nevertheless, the knowledge that differentiates relevant data and information comes by definition from past experience – from learning. When considering the concept of time, it seems impossible to predict the future because knowledge will come only after. Probably, this is a profound reason why most of the people are sure about the impossibility of reliable forecast.

> **Contradiction** is a model for describing a problem situation which occurs when it is necessary to change or replace the old technology by new one. Contradiction as a model has a long and fruitful history of application when resolving inventive problems. Since 2001 it was suggested to combine contradictions into networks for systematic study.

Actually, whenever a forecasting method is used, analysts attempt to use information and knowledge from past-present for predicting the future. To predict future changes the question "What kind of available knowledge and information can be useful?" has to be answered explicitly.

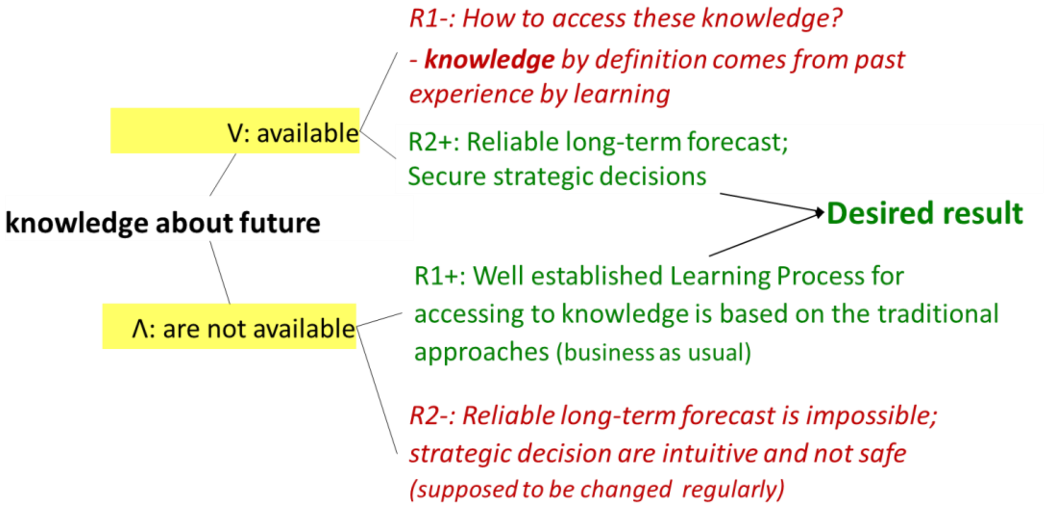

Fig. 1. Cognitive contradiction about prescient knowledge

In the framework of the Researching Future methodology it was suggested to exploit knowledge and information about problems and limiting resources as for predicting future reliably.

What does contradiction mean?

Contradictions occur when there are opposite requirements for an element (or its features) of the analysed system within a specific time, in a particular region of space, due to specific limitations. A contradiction describes the opposite requirements which arise from specific requirements and available resources on the one hand, and from laws of nature on the other hand. For instance, turbulent airflow has to be silent to decrease noise of vacuum cleaner, but a turbulent airflow cannot be silent according to the nature of airflow. At different stages of the problem solving process, three types of contradictions emerge: (1) Administrative[7] (problem description); (2) Technical (contradiction); (3) Physical[8] (parametric contradiction[9]).

In the context of NoC approach, a model of parametric contradiction is used.

a)

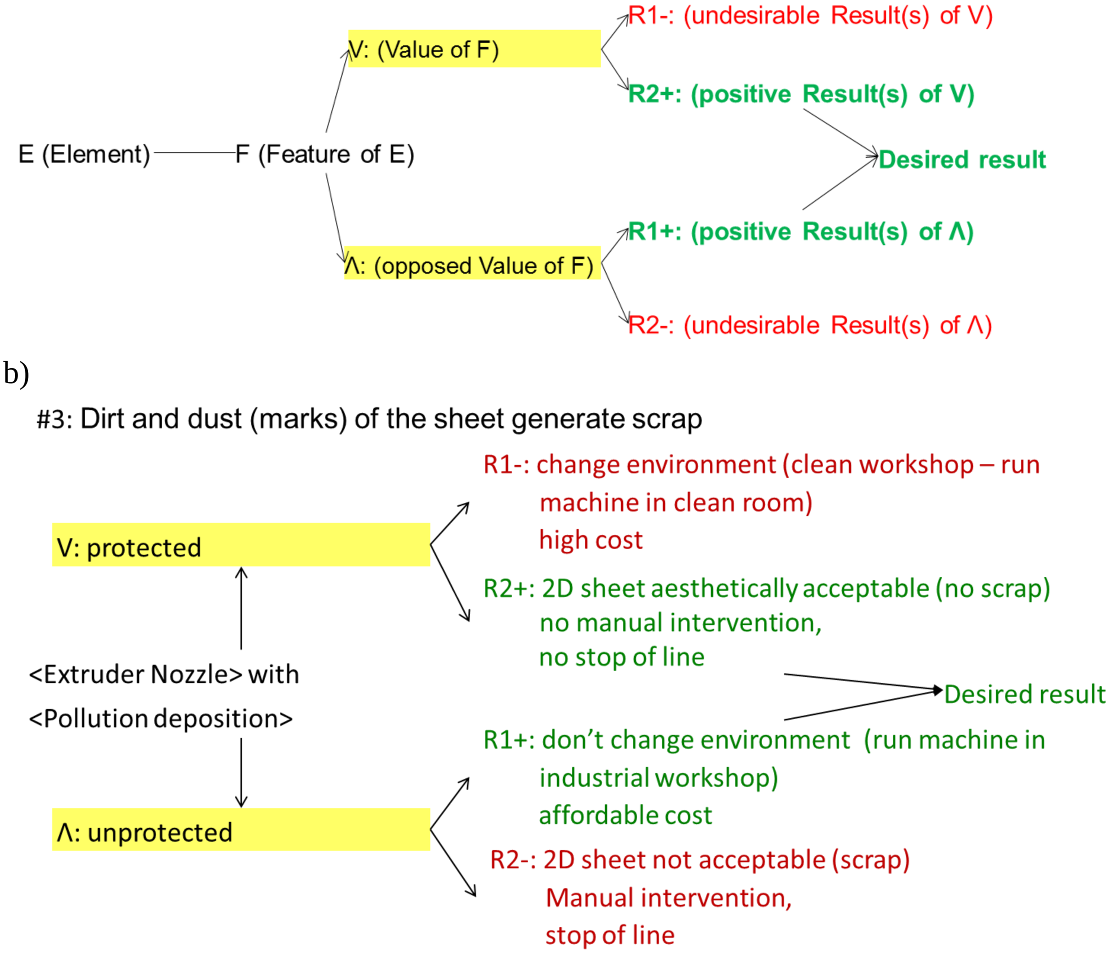

Fig. 2. Element-Name_of_feature-Value_of_feature (ENV) model of contradiction for describing parametric contradiction a) template of to describe problem; b) an example of problem description using the parametric contradiction model

Fig. 3 presents a brief description of the process for building a NoC model starting from the functional model of a technical system and ending with the list of limiting resources.
The flowchart is a simplified description without interactive loops and required reviews of developed documents. In practice, the process of development of the NoC is similar to the learning process. For instance, three to five versions of List of problems can be developed before a final version. In order to clarify a list of problems, a study of Drivers and Barriers for STF can be performed. When performing study of Drivers and Barriers at least four contexts have to be taken into account: *Technological, Economics, Environmental, and Social*.

Development of the List (set) of Contradictions is a laborious and knowledge-demanding task. Each contradiction is formulated in accordance with the formal rules and has to be peer-reviewed during study. Therefore, the set of contradiction can be also modified several times before the final version.

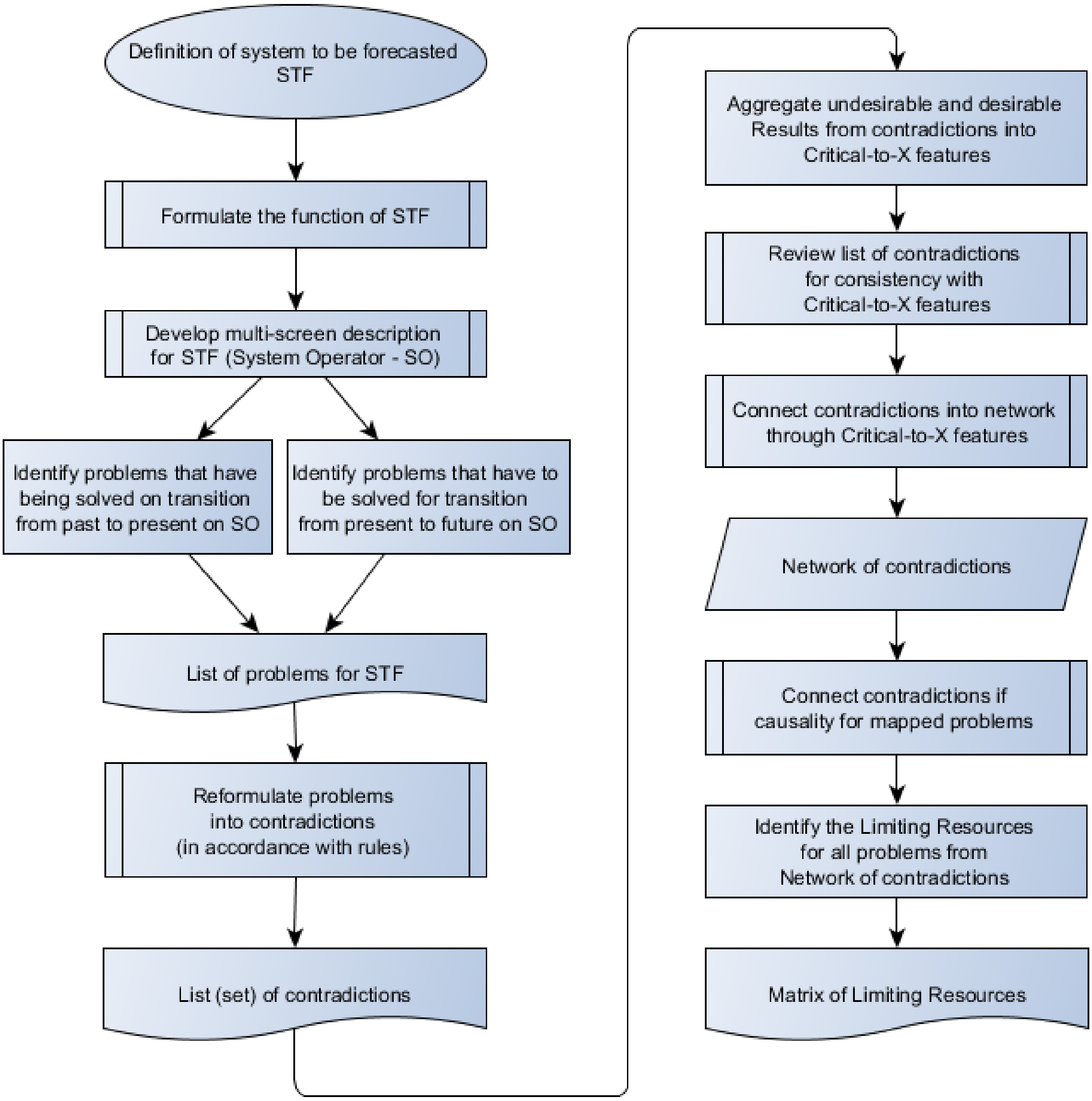

Fig. 3. A brief description of process for developing NoC model.

Usually, a Network of Contradictions model requires at least three revisions before the final version. In practice the model can be modified even more. Modifications of NoC model lead to modifications of Critical-to-X features, and clarifications of the List (set) of contradictions.

Finally, the Matrix of Limiting resources in combination with NoC model allows developing roadmaps for STF[10].

Development of NoC model boosts intensive learning about STF during forecasting study using problem-oriented and solution-oriented thinking approaches. On the same time, knowledge about problems that drive evolution of STF is organized in a systemic way with minimum expert-preconceptions.

Case study

In the FORMAT project, the NoC model was applied to forecast the evolution of Main Parameters of vacuum forming technologies in 20 years (2013-2033), for the production of refrigerators in

Western countries factories. We are presenting below a fragment of the study to illustrate the process of NoC model development.

Formulate the function of STF

The function of STF was formulated and stabilized after several reviews as:
<to make> <open polymer 3D-form (box-form)> from granules

Develop multi-screen description for STF (System Operator - SO)

For development of Multi-screen description slightly modified definition of function was applied:
To make an open 3D polymer form (for door and inner liner) from polystyrene granules

Description of System, Sub-systems and Super-systems were performed referring to year 2013. The Past of the System, Sub-systems and Super-systems was analyzed for the state of technology in 1993. This activity allowed to recognize the first part of problems that have been solved during these years about vacuum forming.

Set of screens for Future state of STF was elaborated for 2023. This preliminary description helped keeping the direction of study in accordance with trends in nearest Super-systems.

We do not include the full description of results for System Operator in this paper in order to keep the focus on NoC model.

Identify problems

After a first assessment of problems by means of the functional model of the process, the results of the System Operator and a study about Drivers and Barriers, a list of 26 problems was constructed (see Fig.4).

#4.1. List of problems

<to make> <open polymer 3D-form (box-form)> from granules

1. **When melting granules & scrap not all the granules and scrap are melted (homogeneity) – melt (process very sensitive to external condition)**
2. **Thickness of sheet can be out of tolerance – form (process very sensitive to external condition)**
3. **Dirt and dust (marks) of the sheet generate scrap (sometimes) – form (LR)**
4. **Long time and large space to stabilize temperature in sheet – stabilize (LR) (Needed big area) + (process very sensitive to external condition)**
5. **Viscosity (temperature after heating) of sheet is not distributed properly – softening (LR) (process very sensitive to external condition)**
6. **Overheating of sheet can produce emergency situation (fire) – softening (process very sensitive to external condition)**
7. **Thickness (very thin) of 3D form is not distributed properly – shaping (LR) (process very sensitive to external condition) + (Not possible to differentiate too much the thickness)**
8. **Time to change tool (mold) is long – shaping**
9. Dimensions of 3D form is not in tolerance – shaping (process very sensitive to external condition)
10. Excessive amount of materials – transportation inside VF (Not possible to differentiate too much the thickness)
11. Too many stations for decreasing cycle time (high investments in equipment VF) (IK)
12. Plasticity of forming material is limited (not possible to differentiate too much the thickness) + (process very sensitive to external condition)
13. Forming temperature is too high – shaping (IK, LR) (High energy consumption)
14. A lot of inventory between the stages in Super-system – (no lean manufacturing) (SK, MS) (LR??)
15. Inspection is needed – size and quality check (SK, MS)
16. Inspection is manual (is subjective) – size and quality check (SK, MS)
17. Constant extrusion thickness for entire sheet of HIPS when it is necessary to have a variable thickness (SK, MS)
18. Making of 3D form after an Extrusion of a 2D sheet (IK) (MS is going to check)
19. ~~Distance between heater and sheet – shaping (High energy consumption) (IK) –~~ in fact it is the same problem as #6

~~20. MP equipment occupies a large area~~
~~21. VF is very sensitive to a sheet's quality, (1) ambient temperature (humidity),~~
~~22. VF is very sensitive to a sheet's quality, (2) temperature of sheet~~
~~23. VF is very sensitive to a sheet's quality, (3) temperature of a mold;~~
~~24. VF is a process with Limited types of polymers~~
~~25. VF is a process with Limited types of shape: complex shape with big undercuts and draw ratio~~
~~26. MP is a process with High energy consumption~~

Fig. 4. A working version of List of Problems.

During a further study, eight problems were removed from the list as they were not relevant to the subject of study.

Reformulate problems into contradictions

For 18 problems,19 contradiction models were elaborated. An example of a contradiction from this set can be seen on Fig. 2b. The results of the study about Drivers and Barriers were clarified during the reformulation of the set of problems into a set of contradictions.

Network of contradictions

In this paper we don't focus on the process of development Critical-to-X features from a set of contradictions. Therefore, the following stages are omitted:

- Aggregate undesirable and desirable Results from contradictions into Critical-to-X features;
- Review the list of contradictions for consistency with Critical-to-X features;
- Connect contradictions into a network through Critical-to-X features.

After three rounds of peer review, the final version of NoC model was developed using Cmap Tools software[11].

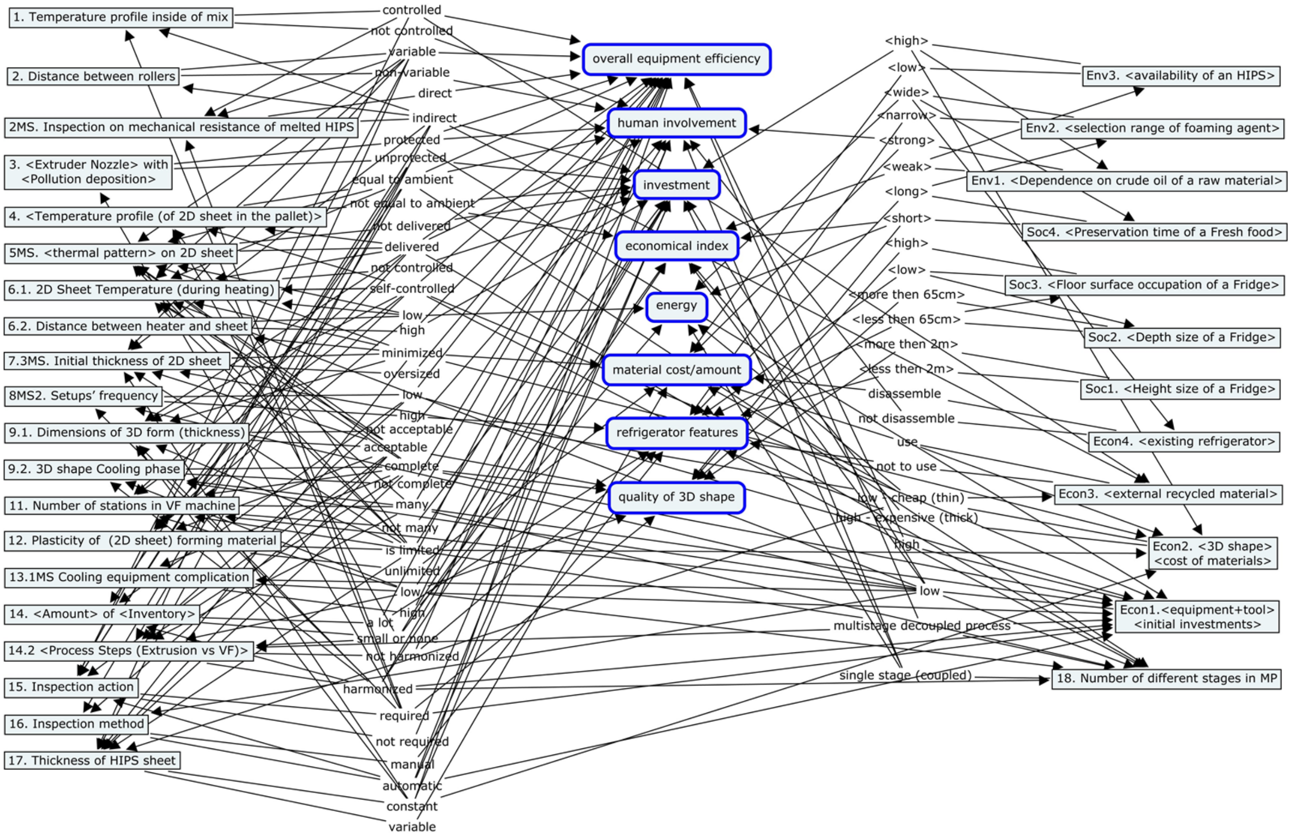

Fig. 5. NoC model to forecast the evolution of Main Parameters of vacuum forming technologies in 20 years, (2013-2033) for Refrigerators

After additional analysis, NoC model allows identifying top 7 problems for the evolution of vacuum forming technologies. This is reinforcing the conclusions about 8 critical-to-Manufacturing Process features.

Preliminary results

From methodological viewpoint, some preliminary results about application of NoC model in FORMAT project are summarized in the Table 1. These lessons were collected from two case studies and training course "Technology Forecasting and Researching Future" performed at Politecnico di Milano from March to June, 2014.

Table. 1. Strengths and Weaknesses of NoC approach

Strengths	Weaknesses
It allows learning about **traits for future technologies** (socio-technological changes) without being limited by a particular technology view; thus next technologies are identified precisely for long-term perspective.	It requires **firm skills** *to formulate contradictions* out of identified problems; model of contradiction is not common for engineers, analysts, and specialists.
It allows for **capturing long-term directions** for evolution of a technology.	It requires **contribution** of *high level specialists* and it takes considerable time to describe a system of problems consistently.
Level of expertise of working team members **grows up faster** when developing network of contradictions.	Process of network development is interactive and recursive, thus it leads to additional **time for correction** of initially formulated problem-contradictions and several reviews for critical-to-X features.
Cross-checking of identified problems using assessment of critical-to-X features improves **reliability** of results.	**Speed** of building network of contradictions and formulating critical-to-X features depends on *learning abilities of analysts*, and it cannot be improved by number of specialists involved in study.
Integration of non-technical problems into forecasting model allows **multidisciplinary study** and improves final forecast.	Identified critical-to-X features are *conditionally measurable*, thus there is some **room for biases.**
It allows to learn about limiting resources for system to be forecasted from **different perspectives** (mid-term, long-term, visionary)	It requires certain **skills to extract information** about limiting resources from developed network of contradictions (*interpretation issue*).
It allows to identify **critical problems** (R&D priority) for evolution of a particular technology	

In the FORMAT project, the presented NoC approach was tested at first time in October-December 2013. As a consequence of the lack of skills for formulating contradictions out of identified problems the process of elaborating NoC took significant time and efforts of workgroup. Regardless of some useful results provided by NoC models, due to the time/efforts requirements of the industrial partners it has been decided not to apply the presented algorithm in full scale.

Currently, in the framework of the FORMAT methodology, limiting resources are extracted from problem descriptions through a discussion about the conflicts emerging between drivers and barriers. Meanwhile, problem descriptions are formulated in free form question "How to …?". The current version of FORMAT methodology uses a more effortless and more time efficient approach without NoC models.

[1] H. A. Linstone and M. Turoff, “Delphi: A brief look backward and forward,” Technol. Forecast. Soc. Change, vol. 78, no. 9, pp. 1712–1719, Nov. 2011.
[2] R. N. Kostoff and R. R. Schaller, “Science and Technology Roadmaps,” IEEE Trans. Eng. Manag., vol. 48, no. 2, pp. 132–143, 2001.
[3] K.Vanherck, Requirements of the FORMAT methodology in terms of user friendliness and output, Whitepaper FORMAT, Sep. 2013. http://www.format-project.eu/deliverables
[4] M.Slupinski, Technology Forecasting – State of the art update, Deliverable 2.3 / FORMAT project, Jan. 2013. http://www.format-project.eu/deliverables

[5] D. Kucharavy, E. Schenk, and R. De Guio, “Long-Run Forecasting of Emerging Technologies with Logistic Models and Growth of Knowledge,” in Competitive Design, 19th CIRP Design Conference, 2009, pp. 277–284.
[6] S. R. Fye, S. M. Charbonneau, J. W. Hay, and C. a. Mullins, “An examination of factors affecting accuracy in technology forecasts,” Technol. Forecast. Soc. Change, vol. 80, no. 6, pp. 1222–1231, Jul. 2013.
[7] G. S. Altshuller, “Process of solving an inventive problem: fundamental stages and mechanisms.” Manuscript, p. 7, 1975.
[8] G. S. Altshuller, “Algorithm of Inventive Problem Solving (ARIZ 85C),” in Rules of a Game Without Rules, Petrozavodsk: Karelia, 1985, pp. 11–50.
[9] N. Khomenko, R. De Guio, L. Lelait, and I. Kaikov, “A Framework for OTSM-TRIZ Based Computer Support to be used in Complex Problem Management,” Int. J. Comput. Appl. Technol., vol. 30, no. 1/2, pp. 88–104, 2007.
[10] D. Kucharavy, R. De Guio, L. Gautier, and M. Marrony, “Problem Mapping for the Assessment of Technological Barriers in the Framework of Innovative Design,” in 16th International Conference on Engineering Design, ICED’07, 2007.
[11] http://cmap.ihmc.us/