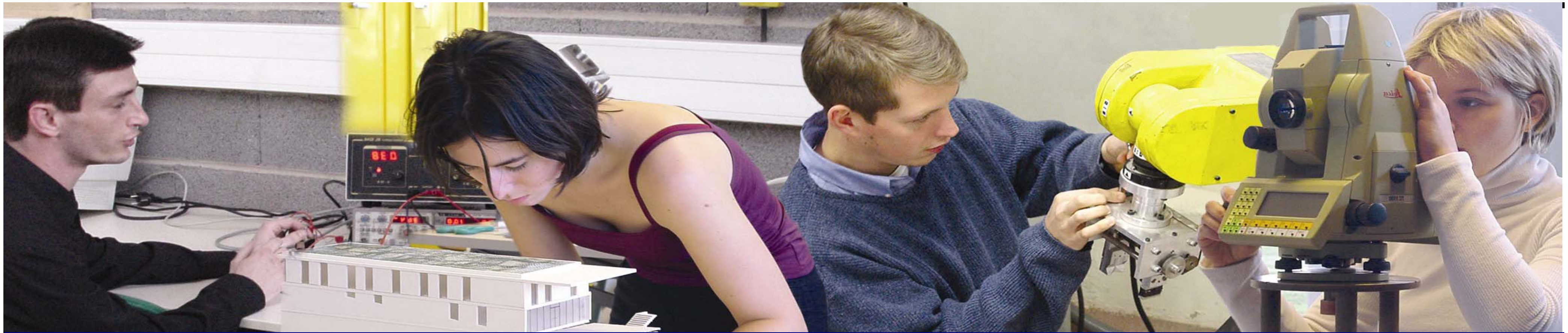

INSA STRASBOURG GRADUATE SCHOOL OF SCIENCE AND TECHNOLOGY

ARCHITECTS + ENGINEERS

LGECO INSA STRASBOURG

TECHNOLOGICAL FORECASTING
(prediction of technology change)

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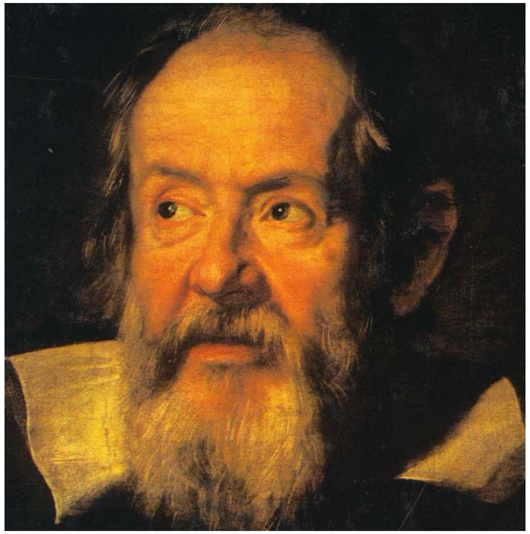
June-July, 2008

...You cannot teach a man anything; you can only help him discover it in himself...

Galileo Galilei



objectives of the course

- **To inform** about existing techniques for technological forecasting in body of knowledge of contemporary TRIZ.
- **To inform** about the interim results of research in scope of forecasting methodology based on contradiction mapping and limiting resources assessment.
- **Learn** about logistic curve application for study long-run of technology change.
- **Practice** how to fit a logistic curve to the data.
- **Realize** the scope of usage of the logistic growth models for technology study.

...Those who have knowledge, don't predict.

Those who predict, don't have knowledge...

Lao Tzu (6th century BC)

course outline

1. INTRODUCTION
2. TRIZ-instruments for forecasting: past and present
3. Technological forecasting process
4. Logistic substitution model
5. Waves and Cycles
6. PROBLEMS OF FORECASTING

- Definitions and scope
- Why it is difficult to forecast?
- How do ones forecast technology change?
- Short-term, medium-term, and long-term forecasts
- The key problem of technological forecast

The rapid pace of technology has not been matched by the pace of human change.

Linstone, H.A., Technological Slowdown or Societal Speedup - The Price of System Complexity?

1. Introduction

[] Definitions and scope

[working definitions]

- **Technological forecast** is a comprehensible description of emergence, performance, features, and impacts of a technology in a particular place of a particular point of time in the future. (What? When? Where? Why?)

- **Main Function of Technological forecasting** process: <to develop> <the explicit description> the future state of technology and its environment (super-systems) for target time-series at particular place.

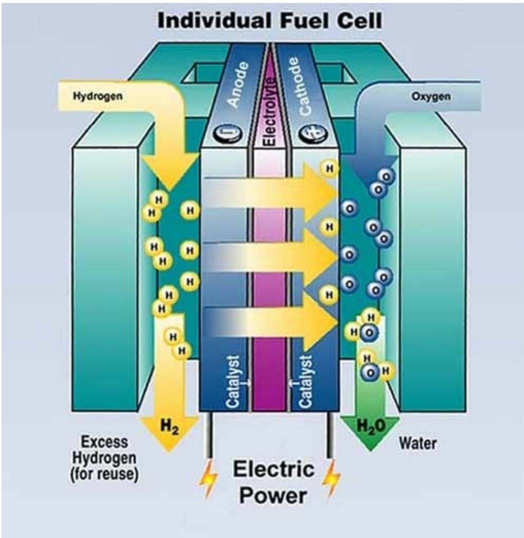
- **Prediction** is a statement made about the future, anticipatory vision or perception. This statement is mostly qualitative (What? Why?).

*Kucharavy, D. and R. De Guio, Problems of Forecast, in ETRIA TRIZ Future 2005. 2005: Graz, Austria. p. 219-235.

What is the future of fuel cell technologies?

[What is a technological forecast?]

Source: www.greenjobs.com/Public/images/fuel-cell.jpg



- What is the future of fuel cell technology within the coming 15 years?
- When will fuel cell really reach the market?
- What could make fuel cell reach the market?

Three different power ranges were defined for several applications:

- 0,5kW to 36 kW for residential and small building (individual and collective);
- 50kW to 300kW for small commercial application;
- 300kW to 1MW for industrial application.

Type 212 submarine with fuel cell propulsion of the German Navy in dock
Source:
http://en.wikipedia.org/wiki/Type_212_submarine

[] Why is it difficult to forecast?

Please, discuss and arrange a list of causes.

Place the most important causes high on the list:

1. ____
2. ____
3. ____
4. ____

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

[] Why do we need forecast?

- We delay to recognize and to be agree about problems and threats.
- We delay to solve problems and to be agree about solutions.
- We delay to implement a potential solution and recognize its limitations.

Why do we need forecast? (2)

Reliable technological forecast supposes to facilitate covering the delays for securing potentially threats:

- …Consumption exponential growth;
- Waste exponential growth;
- Pollution exponential growth;
- Environmental destruction exponential growth…

Alternatives to a forecast

[in the scope of a technological forecast]

- No forecast;
- Anything can happen;
  - There is no attempts to anticipate future
  - There are attempts to build as multiple **scenarios**
- Seduced by success (ignore the future);
- Future will be like the past (higher, faster, and father);
- Emergency service (waiting until the problem arrives)…

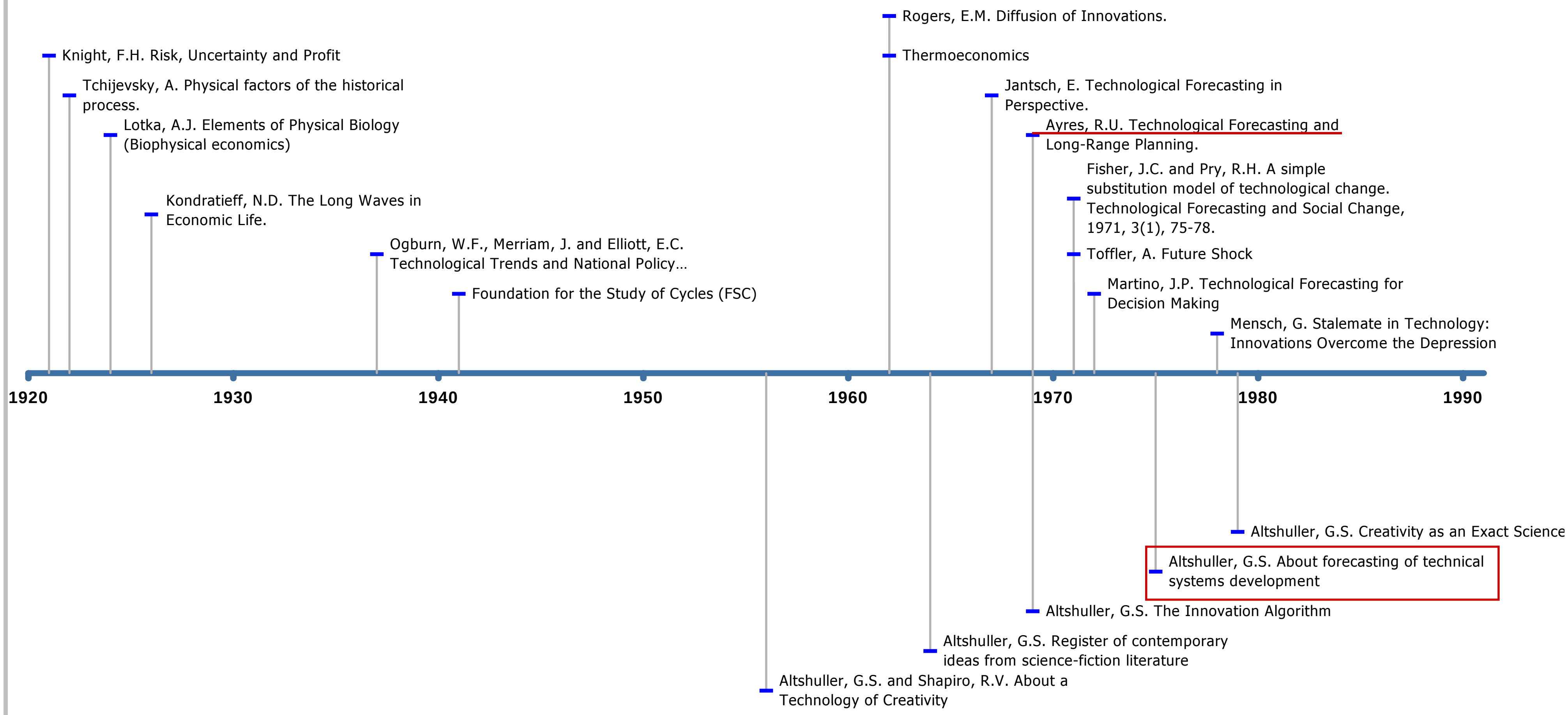
…Progress is made by answering questions.

Discoveries are made by questioning answers…

Bernard Haisch

[] How does one forecast a technology change?

[timeline fragment #1]



Technological forecasting

Technological forecasting and long-range planning

Types of Forecasts

- Exploratory projection (possible future)
- Target projection

Families of methods

- Morphological analysis
- Extrapolation of trends (quantitative)
- Heuristic forecasts
- Intuitive methods of forecasting (qualitative)
- Policy and Strategic planning

* Ayres R.U. (1969)

How does one forecast a technology change?
Technological forecasting for decision making

Types of Forecasts

- Normative Methods
- Exploratory Methods
- Combining Forecasts

Major methods

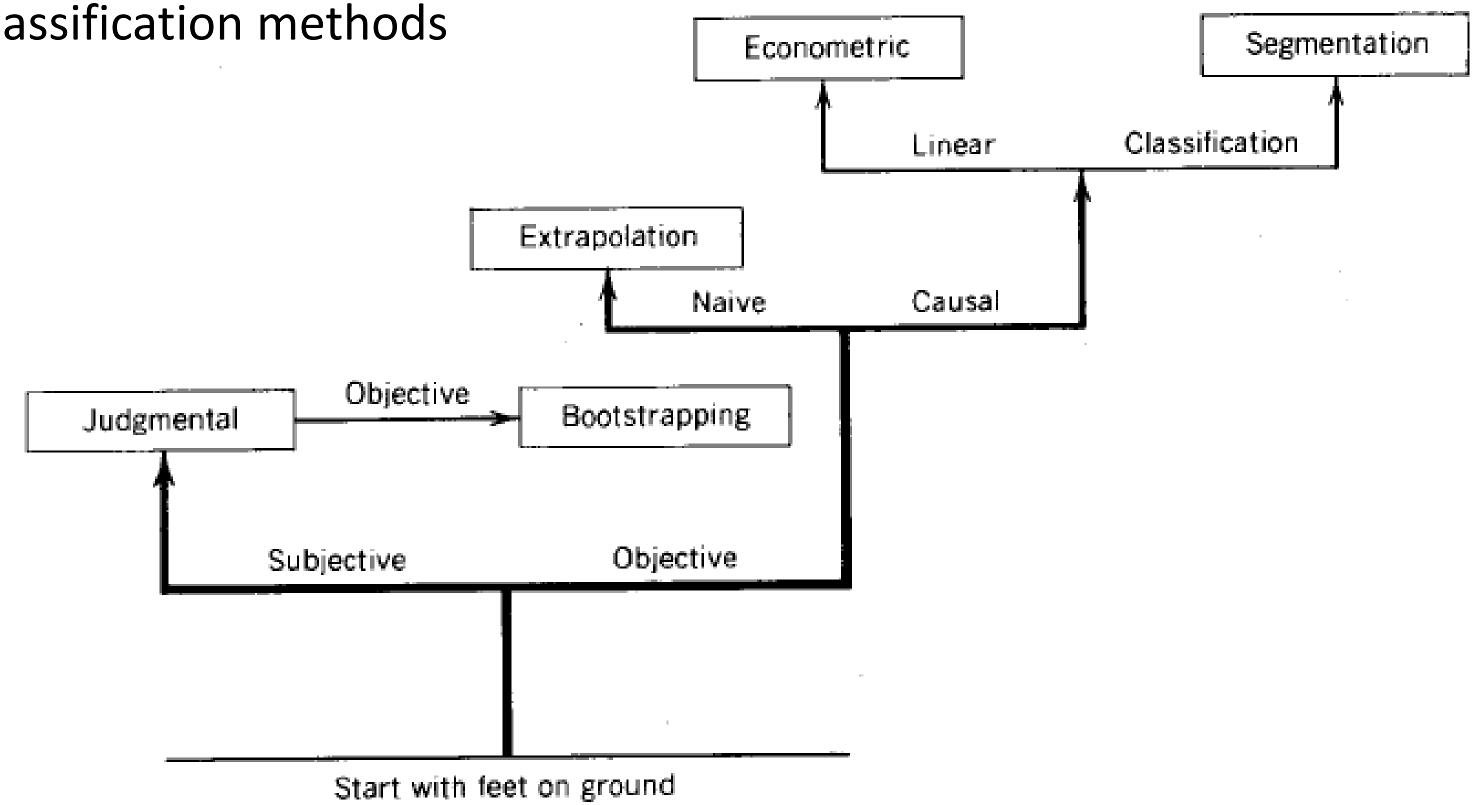
- Delphi surveys
- Forecasting by Analogy
- Growth curves
- Trend Extrapolation
- Analytical Models
- Monitoring for Breakthroughs

* Martino J.P (1972)

How does one forecast a technology change?
Long Range Forecasting. From Crystal Ball to Computer.

Three continuums:

- Subjective vs. Objective methods
- Naïve vs. Causal methods
- Linear vs. Classification methods



Technological forecasting

* Armstrong, Jon Scott (1985)

How does one forecast a technology change?
Forecasting: methods and applications

advanced forecasting methods

- dynamic regression; - neural networks; - state space modeling; - new ideas for combining statistical and judgmental forecasting

traditional time series methods

-decomposition; - exponential smoothing; - simple and multiple linear regression; - Box-Jenkins' ARIMA models

judgmental forecasting

- Bayesian approach

major statistical combination methods

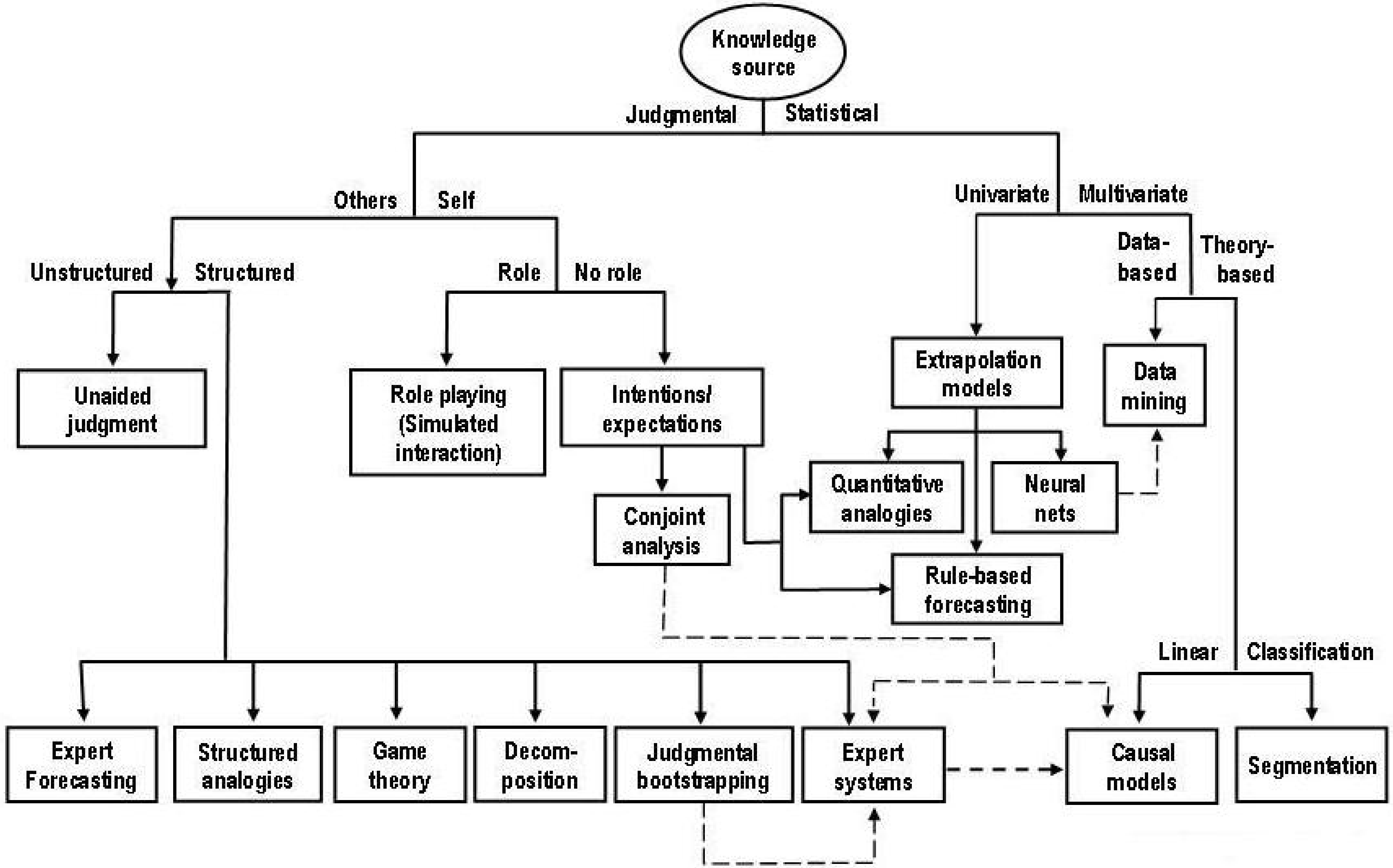
- `optimal' combination; - outperformance; - quasi-Bayes

approach to long-term forecasting

- based on mega trends; - based on analogies; - based on scenarios

* S.Makridakis (1998)

How does one forecast a technology change?
Methodology tree



http://www.forecastingprinciples.com/methodologytree.html J. Scott Armstrong (2002)

How does one forecast a technology change?
Technology Future Inc. (consulting company)

Extrapolations (*quantitative*)
- Technology Trend Analysis
- Fisher-Pry Analysis
- Gompertz Analysis
- Growth Limit Analysis
- Learning Curve

Pattern Analysts / Causal models
- Analogy analysis
- Precursor Trend Analysis
- Morphological Matrices
- Feedback Models

Goal Analysis / Scenarios
- Impact Analysis
- Content Analysis
- Stakeholder Analysis
- Patent Analysis
- Roadmaps
- Value Models

Counter Punchers / Monitoring
- Scanning, Monitoring, Tracking
- Scenarios
- Terrain Mapping
- Decision Tree
- Strategic Games

Intuitions (*qualitative*)
- Delphi Surveys
- Nominal Group Conferencing
- Structured and Unstructured Interviews
- Competitor Analysis

Vanston, J.H. (2003)

Technological forecasting

How does one forecast a technology change?
Futures Research Methodology (AC/UNU Millennium Project)

Method	Quantitative	Qualitative	Normative	Exploratory
Agent Modeling		x		x
Causal Layered Analysis		x		x
Cross-Impact Analysis	x			x
Decision Modeling	x			x
Delphi Techniques		x	x	x
Econometrics and Statistical Modeling	x			x
Environmental Scanning		x		x
Field Anomaly Relaxation		x		x
Futures Wheel		x	x	x
Genius Forecasting, Vision, and Intuition		x	x	x
Interactive Scenarios		x	x	x
Multiple Perspective		x	x	x
Participatory Methods		x	x	
Relevance Trees and Morphological Analysis		x	x	
Road Mapping		x	x	x
Scenarios	x	x	x	x
Simulation-Gaming		x		x
State of the Future Index	x	x	x	x
Structural Analysis	x	x		x
Systems Modeling	x			x
Technological Sequence Analysis		x	x	
Text Mining		x	x	x
Trend Impact Analysis	x			x

Quantitative

Qualitative

Normative

Exploratory

Jerome C. Glenn (2003)

How does one forecast a technology change?
Technology Future Analysis

Two groups:

Exploratory - beginning the process with extrapolation of current technological capabilities;

Normative - beginning the process with a perceived future need.

Two classes:

Hard - quantitative: empirical, numerical;

Soft - qualitative: judgmentally based, reflecting tacit knowledge;

Nine families:

Creativity; **Des**criptive and matrices; **Stat**istical; **E**xpert **O**pinion; **M**onitoring and Intelligence; **M**odeling & **S**imulation; **Scen**arios; **T**rend **A**nalyses; **V**aluing/Decision/Economic.

Porter, A.L. (2004)

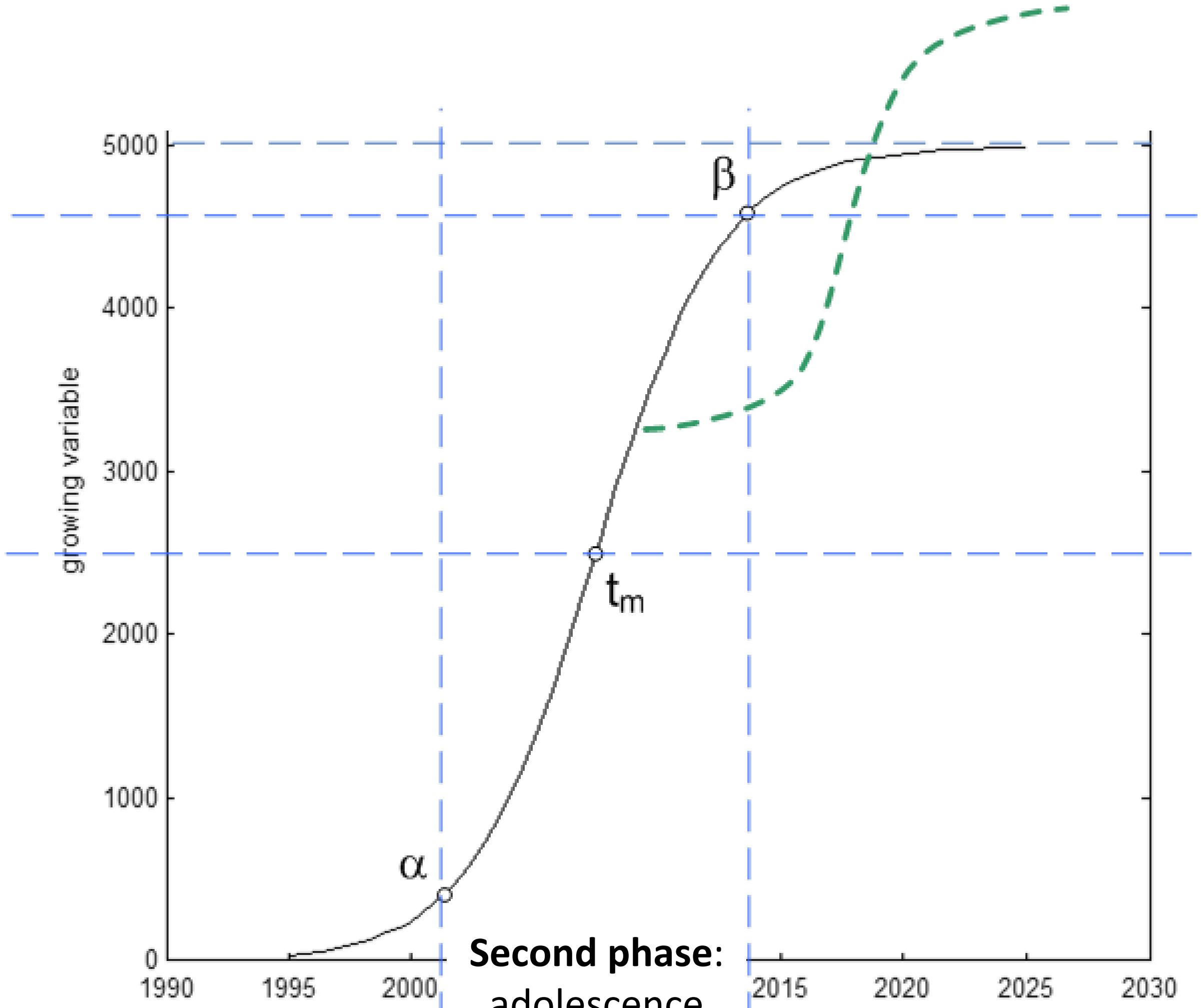
How does one forecast a technology change?

The best way to predict the future is to create it!
Peter Drucker

Method of forecasting *facilitates integration of knowledge about regularities in technology change (transformations) and invariants (patterns) of evolution with* available facts, data, and knowledge for answering some particular questions.

- **Normative vs. Exploratory (Planning vs. Prediction)**
- **Qualitative or/and Quantitative**
- **Scenarios vs. Determinism (Multi-variant / Univariant)**

[] Short-term, medium-term, and long-run technology change



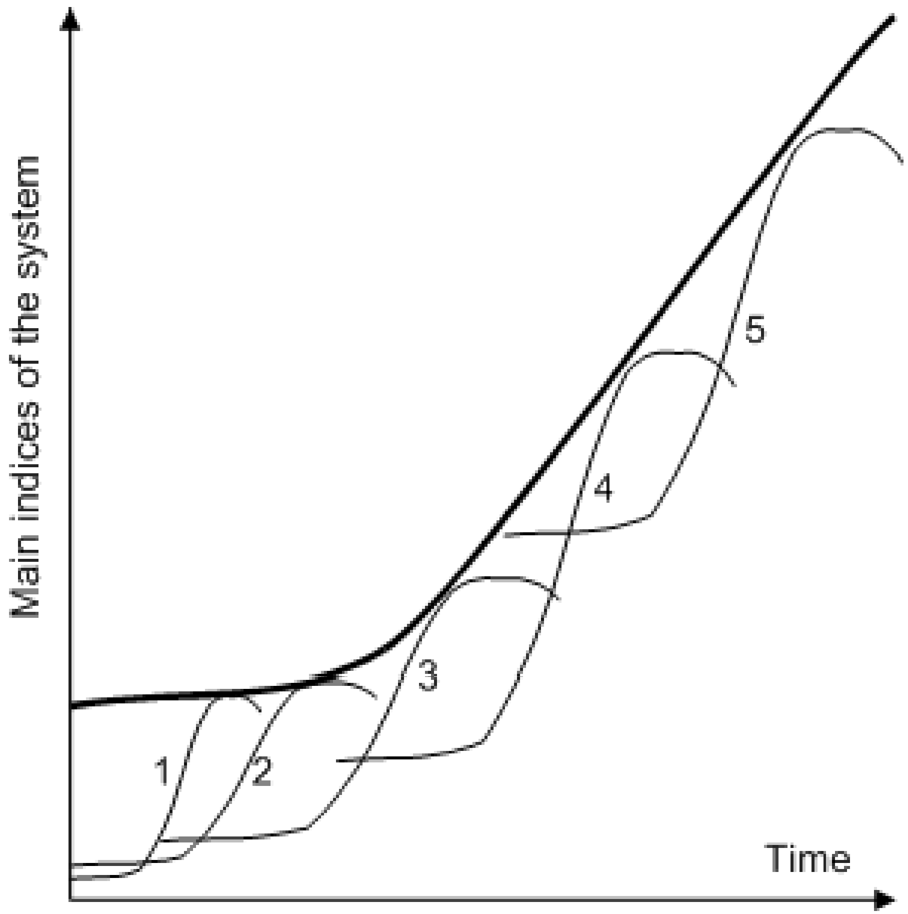
First phase: Childhood (invention & adaptation)

Second phase: adolescence (innovation & growth)

Third phase: maturity (decline & substitution)

- **Short-term** technology forecast - is about of one phase of S-curve of technology evolution.
- **Medium-term** technology forecast - is about of two phases of S-curve. It may lead for forecasting of technology substitution.

Short-term, medium-term, and long-run technology change



Envelop curve for successive technological substitutions for long-run technology change

- **Long-term** technology forecast - is about of three phases of S-curve (usually it is out of scope of one technology evolution).

  In other words, it is done for period, when large changes in the environment take place and technology substitution should be predicted.

Emerging, growing, mature technologies and the substitution of technology

- **Emerging** technology - is a technology before infant-mortality (α) threshold. It is necessary to foresee parameters of the process of transition *from invention to innovation* (adoption, diffusion, infrastructure, commercialization).

- **Growing** technology – is a technology which growth *exponentially* (from α to β). It is necessary to foresee parameters (speed and limits) of exponential growth.

- **Mature** technology – is a technology after saturation threshold (β). It is necessary to foresee parameters of *the process of substitution* of one technology by another (binary and multi- competition).

[] The key problem of a technological forecast

The systems approach uses two basic ideas*:

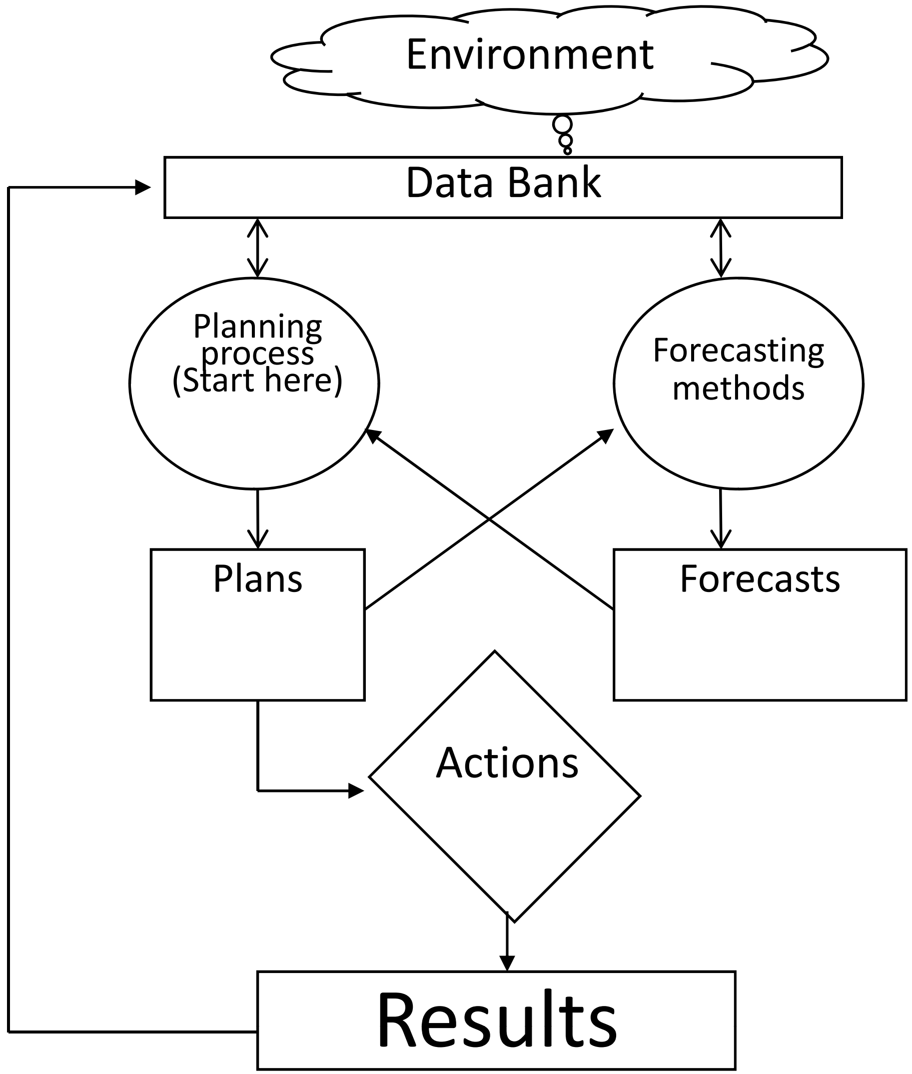
- *First, one should examine objectives before considering ways of solving a problem;*
- *Second, one should begin by describing a system in general terms before proceeding to the specific.*

- What are the *objectives* of technological forecast?
- What is a *system*** of technological forecast?

* Armstrong, J. S. (1985)

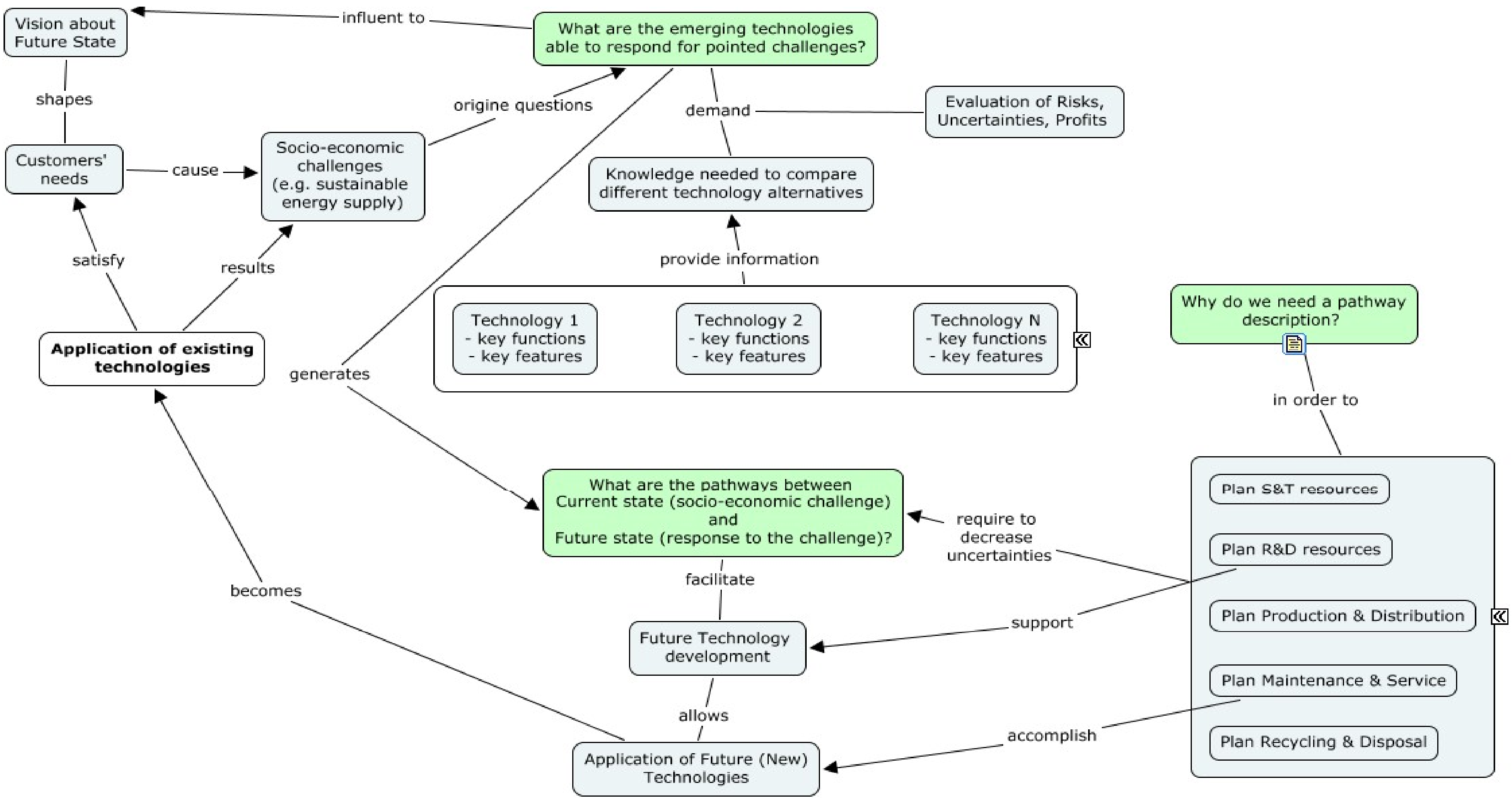
** What are super-system and sub-systems?

The key problem of a technological forecast
[What are the objectives of a technological forecast?]

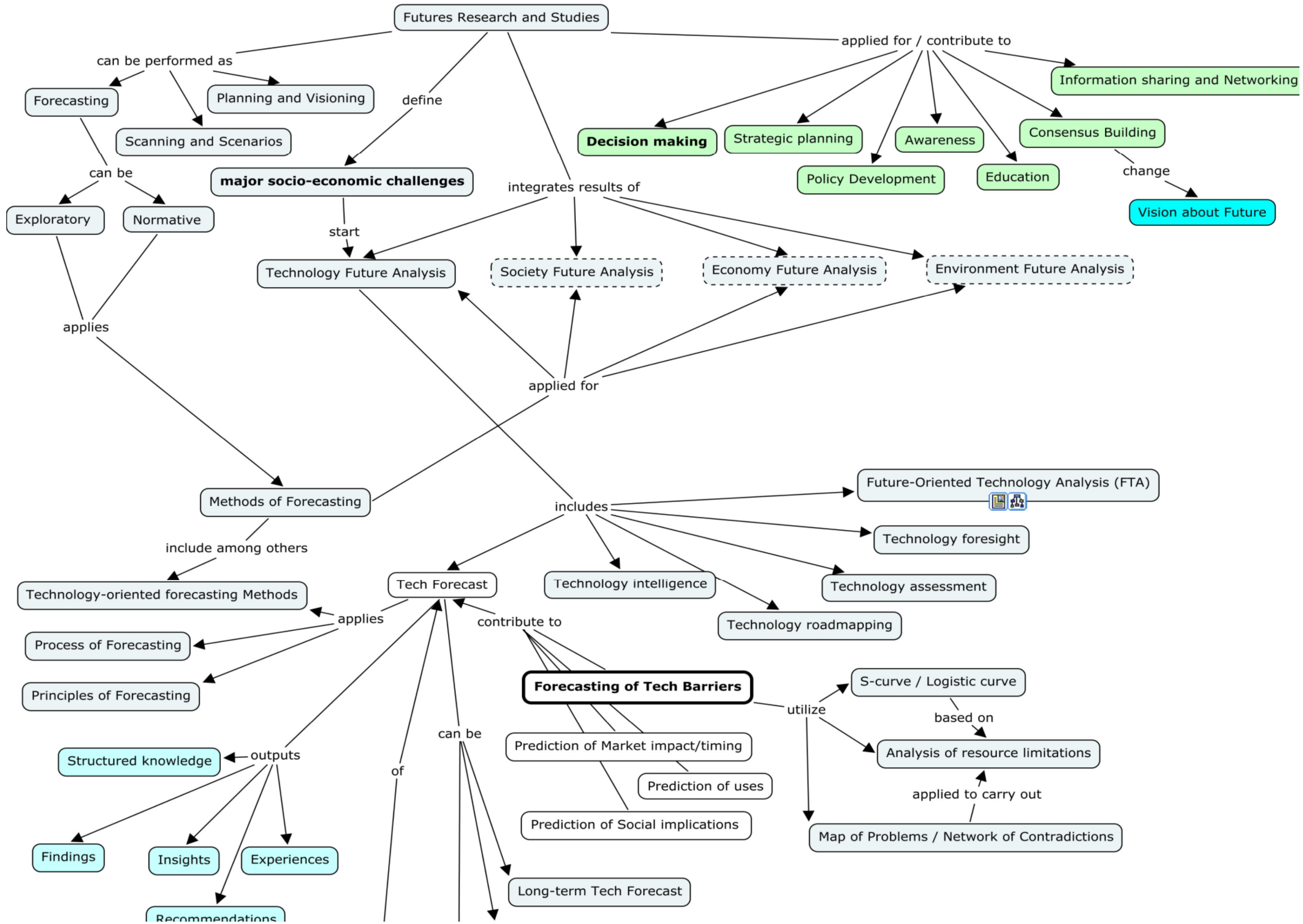


* Source: Armstrong, J.S. Strategic Planning And Forecasting Fundamentals. 1983

The key problem of a technological forecast
[What are the objectives of a technological forecast?]



The key problem of a technological forecast
[What is the system for a technological forecast?]



Technological forecasting

The key problem of a technological forecast

[exploratory long-term forecast]

Forecasting process

V: applies **qualitative** method

- *R1-: difficult to achieve repeatable results from experts; it costs a lot; it takes a lot of time (low frequency to update results); the results contains a lot of biases*
- R2+: *it can be applied for long-term forecast due to conformity with law (of dialectic**) of transformation quantity to quality* → Desired result

Λ: applies **quantitative** method

- R1+: *the results can be obtained a reproducible way; the process is cost effective; it is possible to update result frequently; the results consist less biases* → Desired result
- *R2-: it is not compatible with law of transformation 'quantity to quality', consequently it is mostly applied for short-term forecast.*

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

summary

1. ____

2. ____

3. ____

- Introduction
- Forecasting in the scope of TRIZ (past)
- TRIZ forecasting (present)

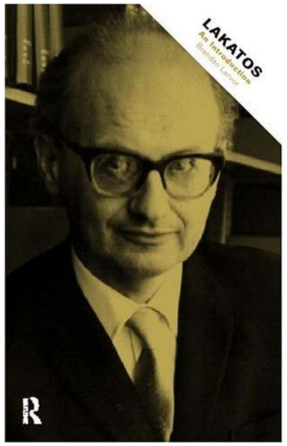
…We have crossed the Rubicon into in era in which the capacity to innovate increasingly complex technologies has created a set of problems no individual leader can solve…
(1995)

2. TRIZ-INSTRUMENTS FOR FORECASTING

Blind commitment to a theory is not an intellectual virtue:
it is an intellectual crime.

Imre Lakatos

philosopher of mathematics and science
(1922-1974)



What is TRIZ?

[Approach? Techniques? Method? Theory?]

TRIZ specialists

it is a theory, science, philosophy...

Consultants

it is a method, toolbox…

Scientists

it is applied science … it is not a science at all…

Engineers

it is a method and technique…

Inventors

"I don't use it. I just formulate some contradictions towards IFR and when physical contradiction is clear, I have got a solution…"

where does classical TRIZ come from?

1940

I stage:

From unsystematic and non-system approaches to "scientific approach to creating inventions".

- First version of method (program): "Scheme of creative process" (prototype of future ARIZ).
- Altshuller, G.S. and R.V. Shapiro, ABOUT A TECHNOLOGY OF CREATIVITY. Questions of Psychology, 1956(6): p. 37-49.

1950

II stage:

From approaches to a method: "..it is necessary to build a *program that performs step by step systematic analysis of the problem*, disclose, study and overcome technical contradiction."

1960

- Six consecutive versions of **the method for inventive problems** solving.
  1965: method was named *Algorithm of Inventive Problem Solving* (ARIZ).
- Books: Altshuller, G.S., HOW TO LEARN TO INVENT. 1961, p.128;
  Altshuller, G.S., THE FOUNDATION OF INVENTION. 1964. p.240;
  Altshuller, G.S., THE INNOVATION ALGORITHM. 1st ed. 1969; 2nd ed. 1973. p. 296

1970

where does classical TRIZ come from?

III stage:

From the efficient method to a Theory: ”..it is necessary to get a Theory of inventive problem solving. The theory has to be based on the knowledge of objective Laws of Technical Systems Evolution.”

1970

- Four new versions of ARIZ. Several versions of System of Inventive Standards. New versions of Pointer of scientific effects.
- First regular Public University of TRIZ – Baku, 1971. Regular training courses in various cities in the USSR.
- Books: Altshuller, G.S., THE INNOVATION ALGORITHM. 2nd ed. 1973. Altshuller, G.S., CREATIVITY AS AN EXACT SCIENCE. 1979.

1975

IV stage:

Research target formulated “from TRIZ to the *Theory of Technical Systems Evolution*”. TRIZ methods and techniques start to be applied for non-technical systems improvements.

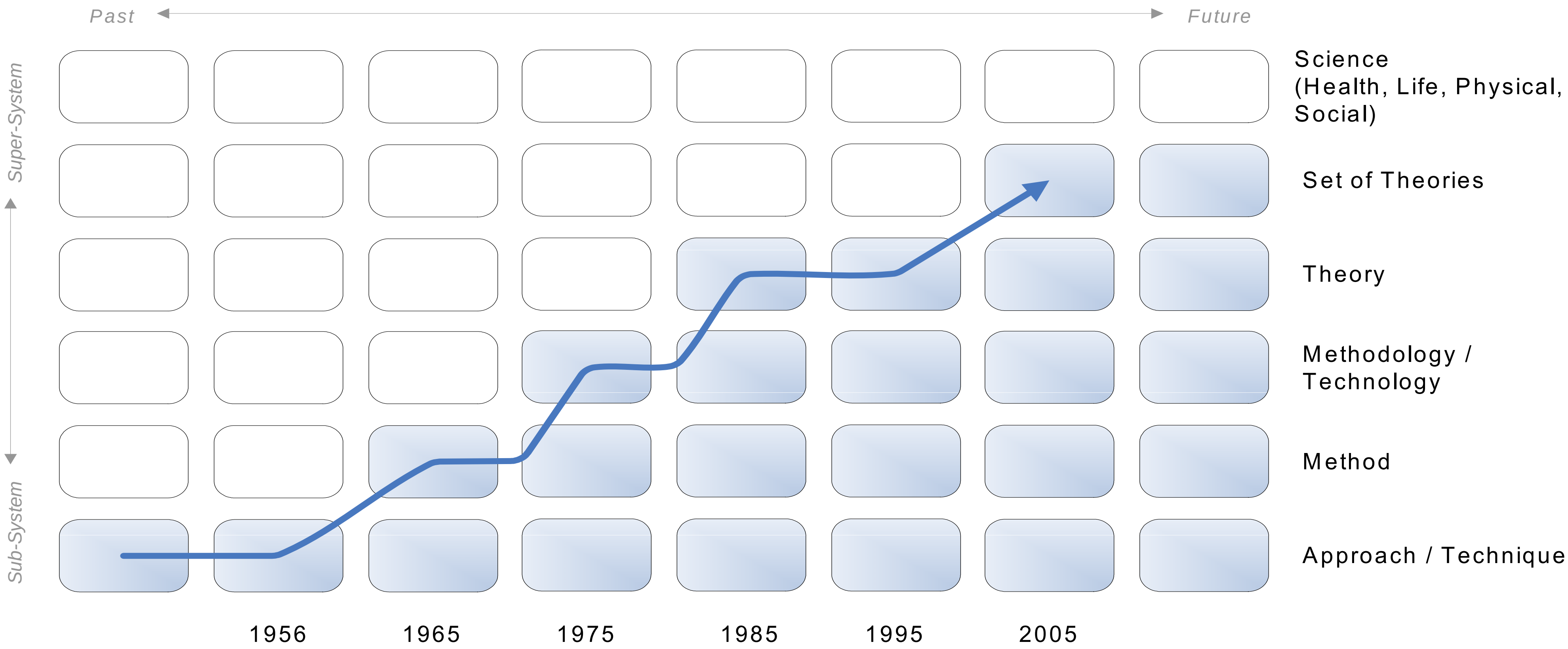
1980

- Three new versions of ARIZ. Several updates of System of Inventive Standards. Considerable updates of Pointer of scientific effects. Advanced Functional analysis + TRIZ methods.
- Books: Altshuller, G.S. and A.B. Selutskii, WINGS FOR ICARUS. 1980
  Altshuller, G.S., CREATIVITY AS AN EXACT SCIENCE. 1984 in English
  Altshuller, G.S. et al., PROFESSION: TO SEARCH FOR NEW. 1985,
  Altov, G., AND SUDDENLY THE INVENTOR APPEARED. 1984.
  several books of other authors

1985

Is TRIZ a method?

[transition from approach, to techniques, to method, towards theory]



Technological forecasting

where does classical TRIZ come from?

"…Behind the specific theories of evolution, it will be revealed clearly step by step the general theory, which we temporary named the General Theory of Advanced Thinking…"
[G.Altshuller, G.Filkovsky. Actual state of TRIZ. Baku, 1976]

1985

V stage:

Research target formulated towards Theory of Systems Evolution. First publications about Theory of Creative Personality Evolution (TRTL). Worldwide spread of TRIZ (mostly as some techniques out of TRIZ).

1990

- A lot of published books:
  - More than dozen books about engineering TRIZ,
  - two books about teaching elements of TRIZ-thinking to children,
  - two books about creative problem solving in advertisement,
  - a book about creative personality evolution:
    Altshuller, G.S. and I.M. Vertkin, How to Become a Genius. 1994.
- 1989 – International TRIZ Association is created in former Soviet Union.
- 1990 – first issue of Journal TRIZ in Russian.
  1990-1994 – 7 issues of of Journal TRIZ in Russian were published.
- 1989 – first TRIZ-software was commercialized.

1995

Is TRIZ a method?

[transition from approach, to techniques, to method, towards theory]

1995

Actual stage:
Massive application of methods and techniques from TRIZ for engineering system development worldwide. Growing application of TRIZ concepts and paradigms for improvements of non-engineering systems.

2000

- Books about TRIZ were translated, written, and published in English (>37), in German (>25), in Polish (>4), in French (3), in Spanish (3), in Italian , in Japanese (>15), in Korean (23), in Chinese (>11), in Portuguese, in Vietnamese, in Farsi (>8) and other languages…
- Nov. 1996 –The TRIZ Journal (in English) in Internet: monthly issues.
- 1998 – Altshuller Institute for TRIZ Studies (USA): annual conferences; nine proceedings - about 300 articles.
- 2001 – European TRIZ Association: annual conferences; seven proceedings - about 300 articles.
- Several national TRIZ associations and conferences were organized worldwide (Germany, Korea, France, United Kingdom, Italy, Japan, China, Mexico…)

2005

Application of TRIZ as a theory

- **…WOIS** - Contradiction Oriented Innovation Strategy (The School of Mechanical Engineering of the University of Applied Sciences in Coburg: H.J. Linde)
  - **ASIT** - Advanced Systematic Inventive Thinking (Roni Horowitz)
- **I-TRIZ** problem-solving methodologies (Ideation International Inc.):
  - **USIT** - Unified Structured Inventive Thinking: problem-solving methodology (Ford Motor Company Research Laboratory: Ed. Sickafus)
- **xTRIZ** - eXtended TRIZ (V.Suchkov)
- **Simplified TRIZ** (K.Rantanen, E.Domb)

OTSM-TRIZ - General Theory of Powerful Thinking (G.Altshuller, N.Khomenko)

GTI - General Theory of Innovation (G.Yezersky) …

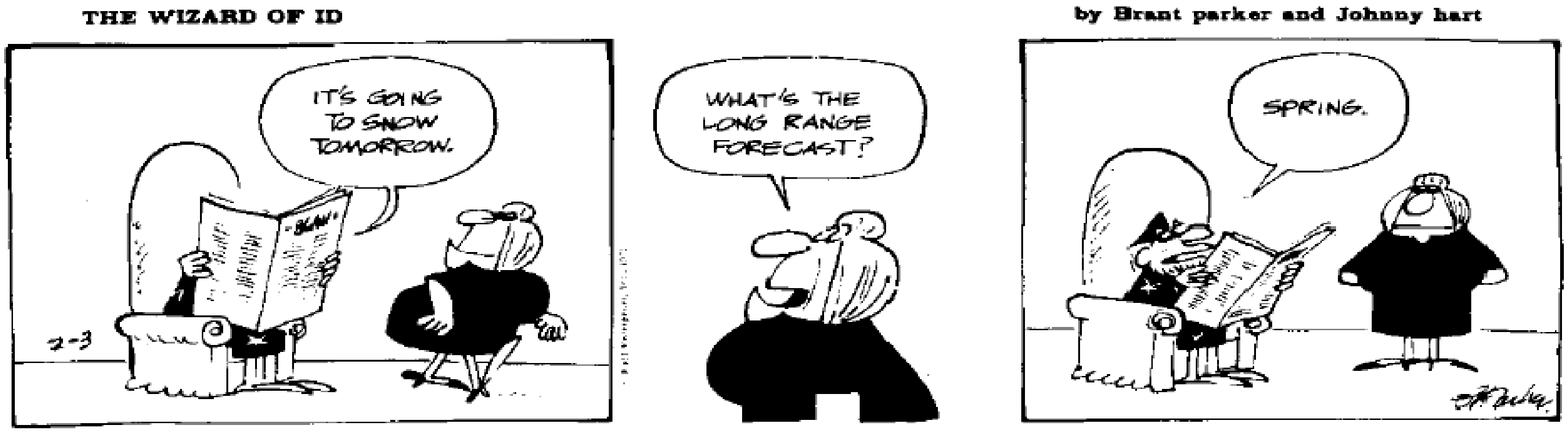
My interest is in the future because I am going to spend the rest of my life there.

C.F. Kettering

INTRODUCTION

Prediction and forecast…

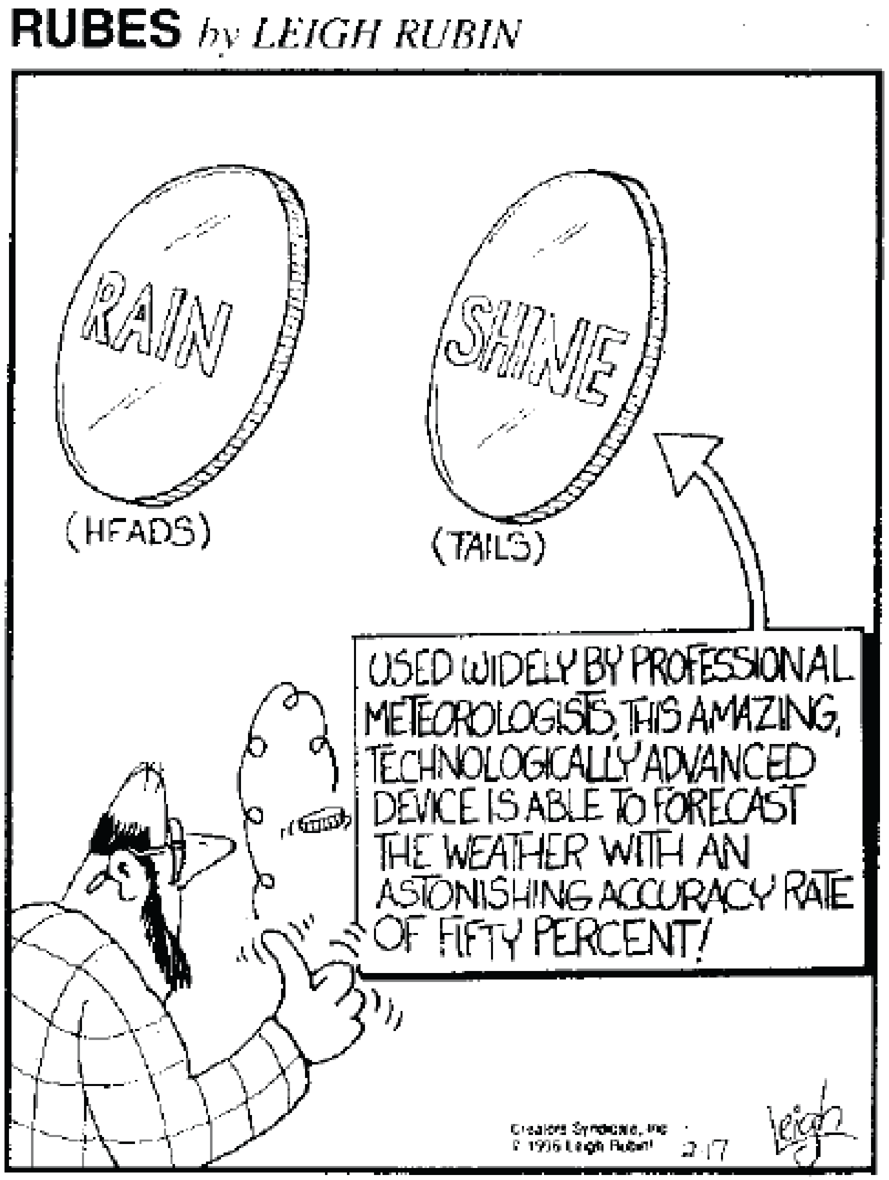
[…foresight, provision, prophecy, foretelling, prognosis, anticipation…]



* Source: Armstrong, J.S. Long Range Forecasting. From Crystal Ball to Computer. (John Wiley & Sons, Inc., 1985), 689. ISBN 0-471-82360-0.

Prediction and forecast…

[…foresight, provision, prophecy, foretelling, prognosis, anticipation…]



Prediction or forecast…

[…foresight, provision, prophecy, foretelling, prognosis, anticipation…]

	Weather forecast	**Technological Forecast**
What?	Cloud / Precipitation / Sunshine; Temperature (max/min) (°C); Air pressure (mm); Humidity (%); Wind / Storm (m/s); Duration of Sunshine (h); Geomagnetic Activity / Magnetic Storms; Air quality ???	
Where?	Latitude | Longitude Krutenau / Strasbourg / France / Europe	
When? (resolution)	by the hour / (am / pm / overnight) / Tomorrow / 4 days / 10 days /	
Update Frequency	by the hour / 4 times a day / daily	
Why?		
Probability		

What do we foresee with Technological Forecast?

a prediction with TRIZ-instruments

[Case Study: Yarn Spinning Technology]

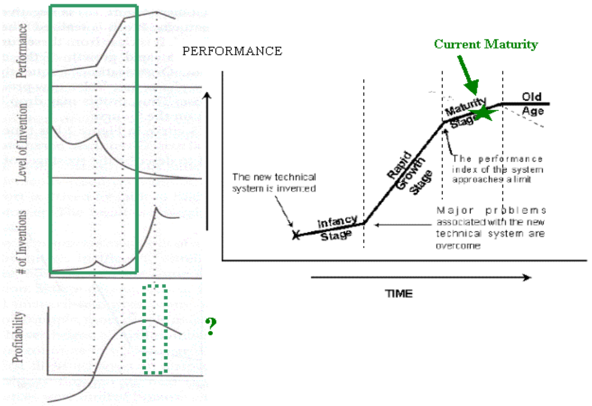


Figure shows that rotor spinning technology is in the mature stage. …The system has reached a threshold and recommendations are to *use the patterns of evolution* with a focus on a change of the core technology. …Actions should be taken now to insure a profitable future. Yarn rotor spinning has reached a maturity. A dramatic change (to the core itself) is strongly recommended.

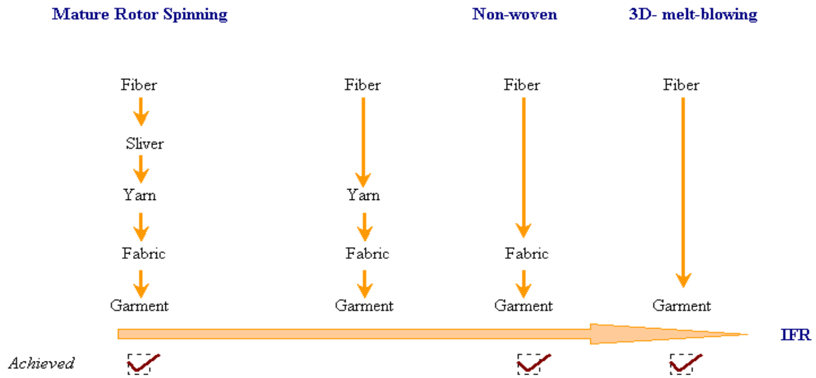


Figure represents the trend of ideality for Rotor spinning.
Summary: Since 1) rotor spinning is mature, 2) the trend of dynamization recommends the use of field as the ultimate devolvement and 3) early vortex machines were not successful when the new vortex machines are, it is relevant to analyze the maturity of fasciated yarns to forecast innovation in spinning…

The other patterns of evolution can be applied to generate additional solution directions to provide a complete picture of possible technological developments in yarn formation.
… even though the focus was on rotor spinning, the patterns clearly showed new core technologies, such as nonwovens and fasciated assembly technologies to replace the existing core technology.

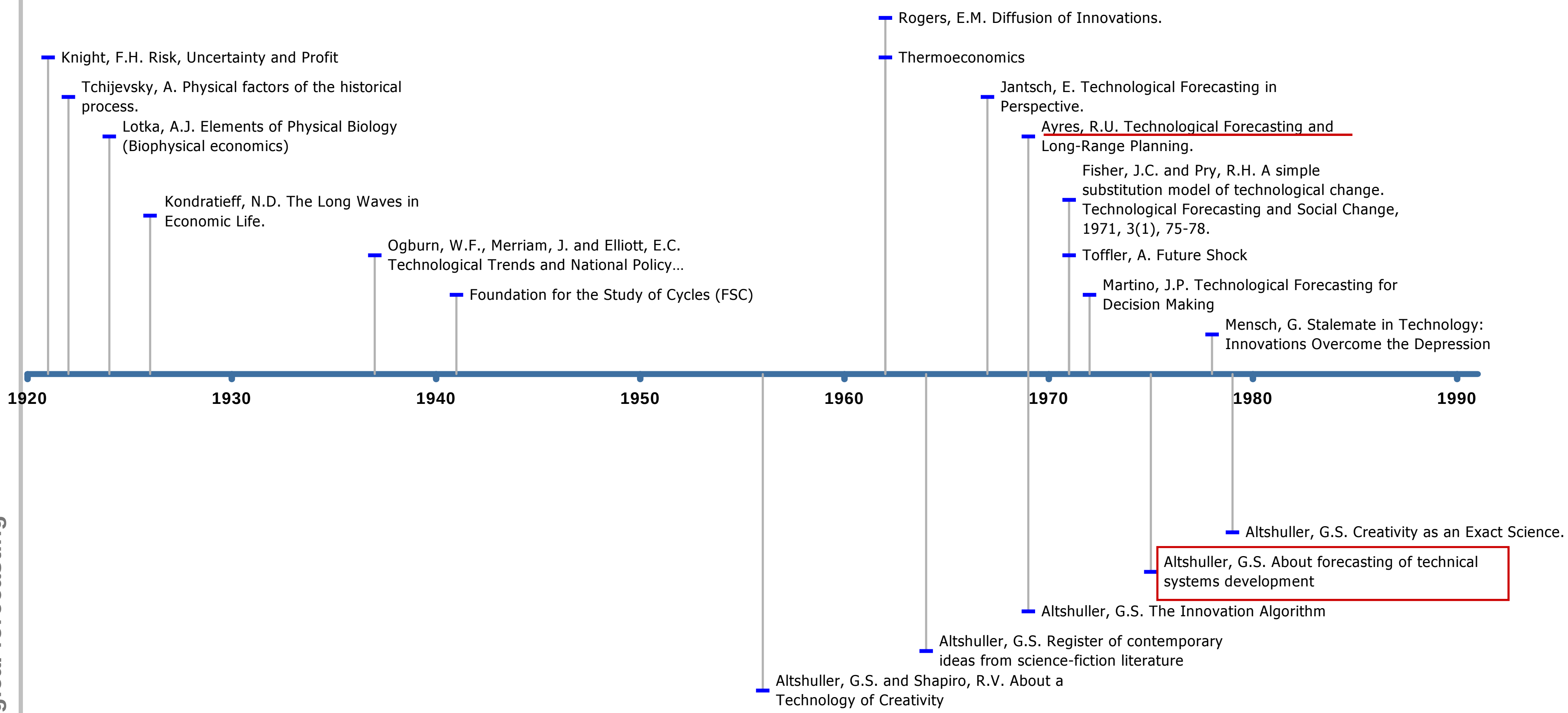
* Source: Severine Gahide, . (2000) Application of TRIZ to Technology Forecasting. Case Study: Yarn Spinning Technology. www.triz-journal.com

FORECASTING
IN THE SCOPE OF TRIZ

Forecasting & inventive problem solving

Forecasting and TRIZ (past)

[timeline fragment #1]



Technological forecasting

Inventive problem solving and technology change

[when the method for inventive problems became mature…]

G. Altshuller's problem statement (April 18, 1975)*:

- There are more than 100 methods of forecasting: scientific-and-technological, economic, and social. Four books was proposed as references.
- "Inventor is looking answers for **qualitative** questions*:
  - What is growth potential of given engineering system?
  - What is system that substitute the existing one in future?
  - What are the fundamental and principal problems should be solved in future?"
- Starting assumption: inherent drawback for most of the known forecasting methods: they are essentially subjective (full of biases).

* Source: Altshuller, G.S. *About forecasting of technical systems development*. Seminars materials p. 8 (Baku, 1975). Manuscript in Russian

Inventive problem solving and forecast

[how to foresee a technology change?]

What was proposed by G. Altshuller (April 18, 1975)*:

- To apply existing 'Extrapolation of trends and curve fitting' methods. As a main reference was proposed: Ayres, R.U. *Extrapolation of Trends.* in Technological Forecasting and Long-range Planning. (McGraw-Hill book Company, 1969), 237.
- "…Curve fitting… gives opportunity to recognize *unbiased regularities of engineering systems evolution*…"
- Further application of curve fitting method for Theory of Inventive Problem Solving (TRIZ) was proposed:
  - Four sections on the evolution curve;
  - Peculiarities of theoretical and some real curves of substitutions;
  - Natural reasons of ceiling for curves;
  - Three cases of data analysis for curves;

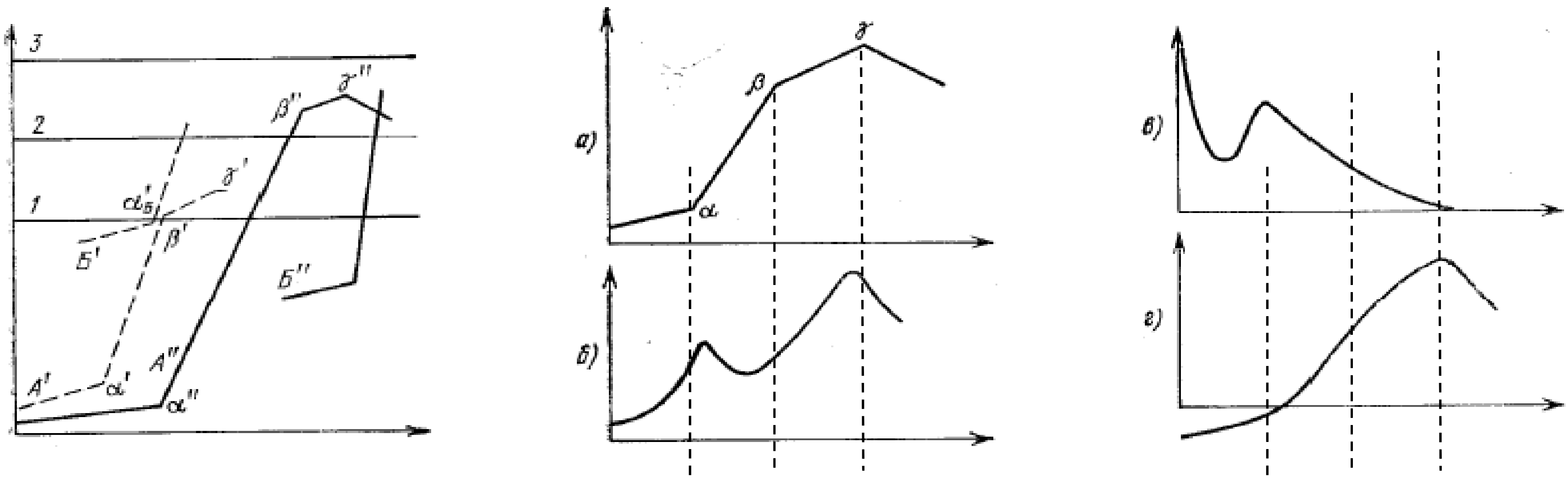
* Sources: Altshuller, G.S. *About forecasting of technical systems development*. Seminars materials p. 8 (Baku, 1975). Manuscript in Russian
Altshuller, G.S. *Creativity as an Exact Science: The Theory of the Solution of Inventive Problems*. (Gordon and Breach Science Publishers, 1984), 320. (in Russian - 1979)

Inventive problem solving and technology forecast

[how to foresee a technology change?]

G. Altshuller (April 18, 1975): (continuation)

- Regularity: next generation system includes the foregoing one as subsystem. In other words: “evolution by becoming a subsystem”.
- It was suggested some correlations between engineering system evolution curve and inventive curves (number of inventions, level of inventions, and profitability).



* Source: Altshuller, G.S. *About forecasting of technical systems development*. Seminars materials p. 8 (Baku, 1975). Manuscript in Russian

Altshuller, G.S. *Creativity as an Exact Science: The Theory of the Solution of Inventive Problems*. (Gordon and Breach Science Publishers, 1984), 320. (in Russian - 1979)

Inventive problem solving or forecast

[how to foresee a technology change?]

G. Altshuller (1976):

- Altshuller, G.S. and Filkovsky, G. *Current State of Theory of Inventive Problem Solving*. Seminar materials. (Baku, 1976). There is no even a paragraph about forecasting and prediction techniques. (!?)

G. Altshuller (1988):

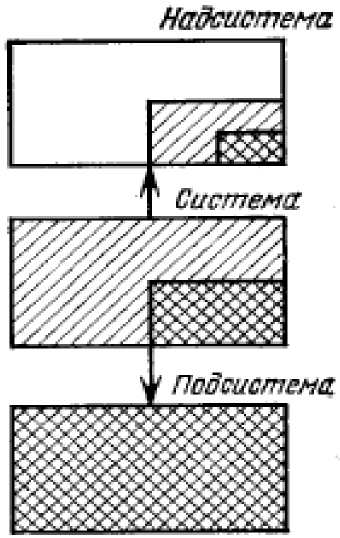
- Altshuller, G.S. *Information about TRIZ-88*. Seminar materials. (Baku, 1988). There is nothing about forecasting and prediction techniques in body of TRIZ. (!?)

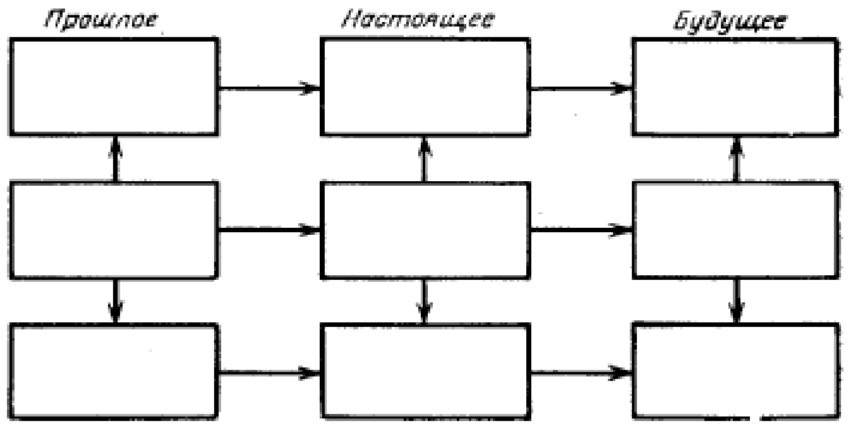
Inventive problem solving and system thinking

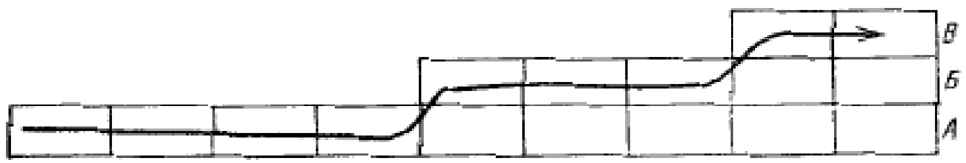
[how to foresee the future]

G. Altshuller (1979):

System operator or Multi-screen scheme of advanced thinking.







* Source: Altshuller, G.S. *Creativity as an Exact Science: The Theory of the Solution of Inventive Problems*. (Gordon and Breach Science Publishers, 1984), 320. (in Russian - 1979)

Inventive problem solving and technology change

[how to foresee a technology change?]

G. Altshuller (1977-1979)*:

System of laws of technical systems evolution.

- law of System Completeness
- law of Energy Conductivity in systems
- law of Harmonization

- Law of Increasing Ideality
- law of Irregularity of the Evolution of a System's Parts
- law of Transition to the Super-system

- law of Transition from Macro- to Micro-level
- law of Increasing Substance-Field Interactions
- law of Dynamics Growth (added in 1985)

* Source: Altshuller, G.S. *Creativity as an Exact Science: The Theory of the Solution of Inventive Problems*. (Gordon and Breach Science Publishers, 1984), 320. (in Russian - 1979)
Altshuller, G.S. *About Laws of technical systems evolution*. Manuscript (20.01.1977).

Engineering systems development

[how to foresee a technology change in the scope of problem solving?]

Altshuller G.S., Zlotin B.L., and Philatov V.I. (1985)*:

Principal ways for increasing rate of Ideality.

1. Towards differentiation: special-purpose engineering systems with better efficiency for particular purpose (customization).
2. Towards versatility: many-purpose system perform many functions.
3. New deployment of existing properties and parts of system.
4. Transition to self-adjusting systems: many-purpose specially adjusted system. Towards adaptability for effective operation.
5. Towards increasing harmonization of system and external changes without changing working principle.
6. Transition to super-system when no other ways.
7. Transition from macro- to micro-level when no other ways.
8. Increasing system completeness towards pushing out human as a part of system.

* Source: Altshuller, G.S., Zlotin, B.L. and Philatov, V.I. PROFESSION: TO SEARCH FOR NEW. (Kartya Moldovenyaske Publishing House, Kishinev, 1985), 196. in Russian

TRIZ-forecast

[example]

G. Altshuller, M. Rubin (1987):

What Will Happen After the Final Victory. Eight thoughts about Nature and Technology.
(condensed version in English: Izobretenia, 1999, 1, pp. 4-9)

- Several impressive and uncommon (at those time) trends are proposed. Concept of Natureless technological world (NTW) is proposed and developed.
- Method of forecasting is not described. Data sources are not presented. Basic assumptions and hypothesis presented inexplicit way.
- Social impact and proposals about strategy are discussed.
- Twenty years later, a lot of described aspects can be recognized in reality.
- It is impossible to judge about accuracy of this forecast, due to its qualitative nature and fuzziness of “Where” and “When” estimates.

…and a long-run forecast (a vision)

[how to foresee the future: bypassing way]

G. Altshuller as Science Fiction writer:

- "Register of contemporary ideas from science-fiction literature*" (1964-1997): 11 classes, more than 1000 typescript pages.
    - o Methods and techniques to design and develop science-fiction ideas (e.g. 'Four levels' scheme, 'Fantogramma' - 1971);
    - o "Scale Fantasy-2" scale (mid of 80's) is a technique to measure science-fiction ideas (metrics).
- Analysis of science-fiction ideas from literature as support for long-term technological forecasting.
    - o More than 85% of ideas from Jules Verne science-fiction novels today are real engineering systems (e.g. submarine, aviation, helicopter...)
    - o Stanisław Lem - Summa Technologiae ("Sum of Technologies" in English) 1964…

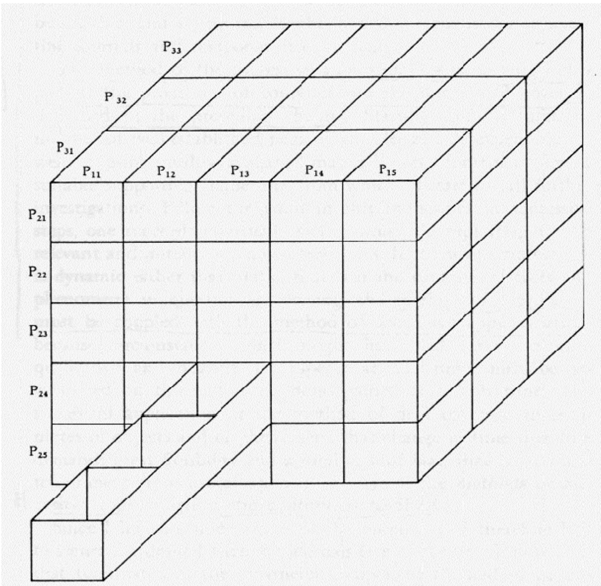
* Source: http://www.altshuller.ru/rtv/sf-register.asp in Russian

problem solving and prediction (vision)

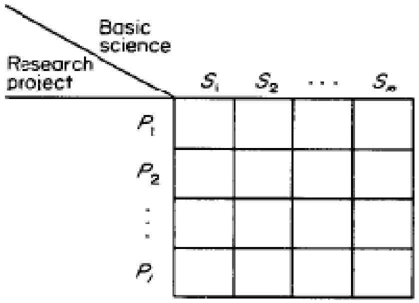
[how to foresee the future: how to see the non-obvious?]

Morphological analysis

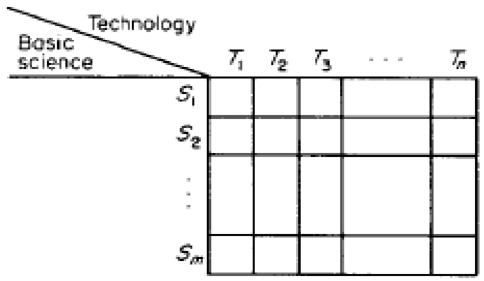
- Zwicky F. *Discovery, Invention, Research through the Morphological Approach.* (1966)
- Ayres, R.U. *Technological Forecasting and Long-range Planning*. (McGraw-Hill book Company, 1969), 237.



A 3-parameter Zwicky box containing 75 cells or "configurations" (Zwicky, 1969, p. 118.)



Project-science matrix



Science-technology matrix

problem solving and prediction (vision)

[how to foresee the future: how to see the non-obvious?]

Manuscripts:

- Gerasimov & Litvin. Manuscript and material of seminars. Prediction through analysis of *alternative systems combination*.
- Inventive Machine project: Recommendation based on patterns of evolution with example.

Engineering systems evolution

[how to foresee the future in the scope of problem solving?]

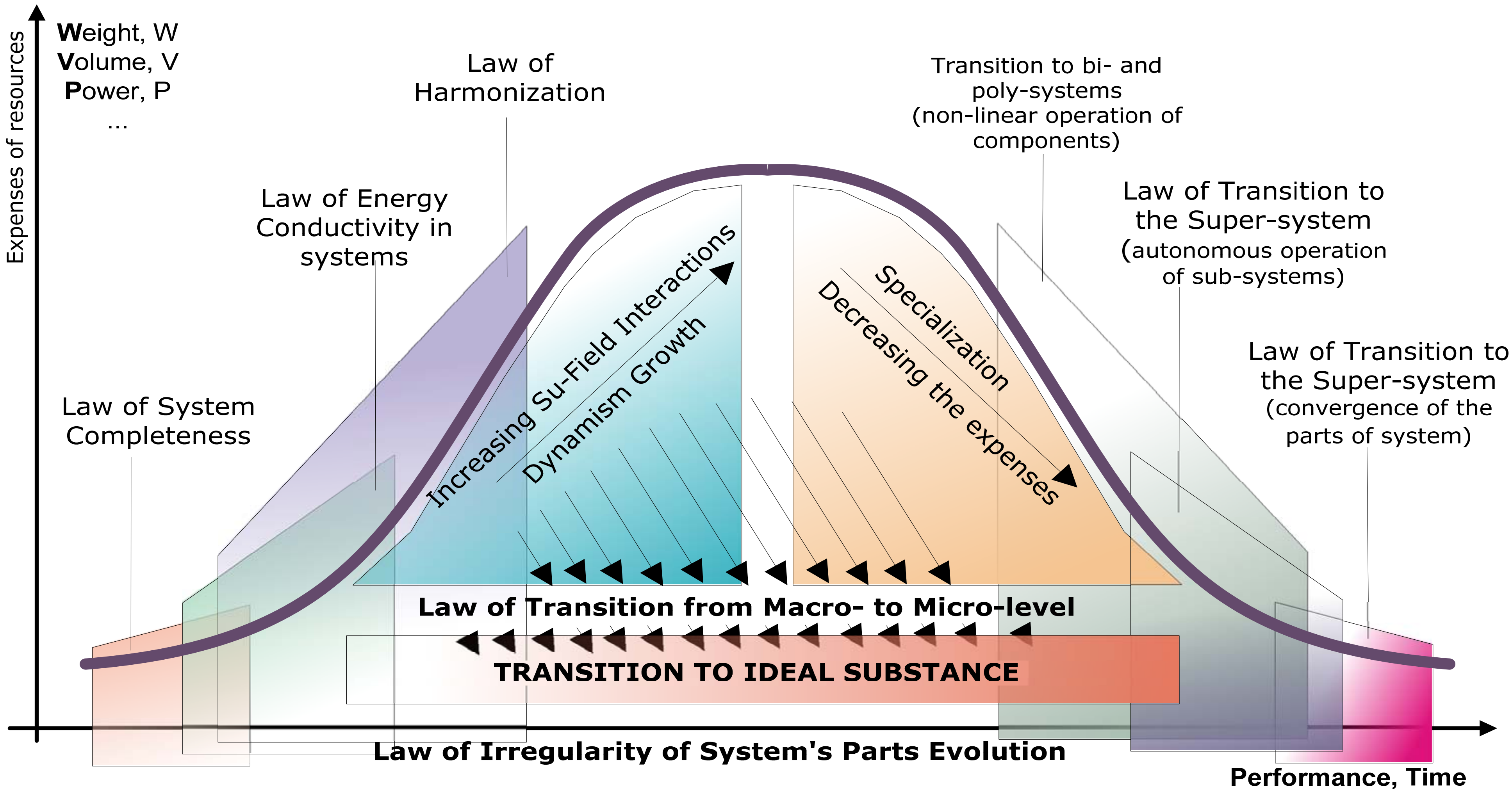
Altshuller G.S., Zlotin, B.L., Zusman, A.V. and Philatov, V.I. (1989)*:

- Basic principles of technological forecasting based on TRIZ.
- Forecasting procedure was proposed (4 stages; 26 steps; recommendations):
  1) express forecast;
  2) preparation to forecast;
  3) forecasting using laws of technical systems evolution;
  4) aggregate forecast.
- 22 lines of engineering systems evolutions were presented.
- Some peculiarities of practical forecasting were discussed.
- Example of interim results of TRIZ forecast were described.

* Source: Altshuller, G.S., Zlotin, B.L., Zusman, A.V. and Philatov, V.I. Search for New Ideas: From Insight to Technology. (Kartya Moldovenyaske Publishing House, Kishinev, 1989), 381. ISBN 5-362-00147-7. in Russian

Engineering systems evolution

Salamatov Y.P (1984-1991)*: wave model (bell-shaped running curve)



* Source: Salamatov, Y.P. *System of The Laws of Technical Systems Evolution*. CHANCE TO ADVENTURE, pp. 7-174 (Karelia Publishing House, Petrozavodsk, 1991). in Russian

Engineering systems evolution

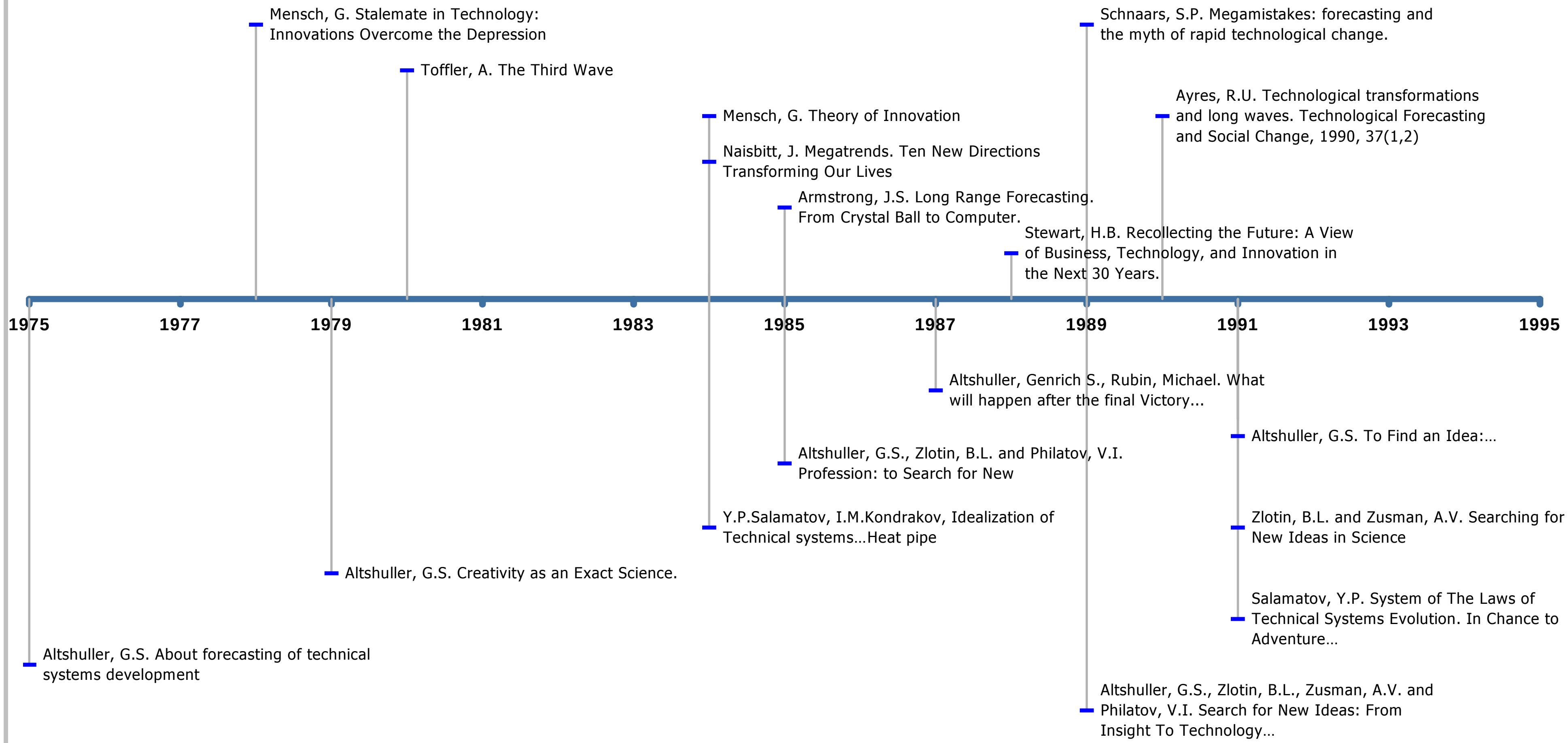
Salamatov Y.P (1991)*:

- Detail summary description for laws of technical systems evolution, proposed by Altshuller G.S. with examples.
- Analysis of technical system's origin and evolution.
  Line of evolution for instruments of production.
- Definition of technical system and its properties.
  Graphical language to describe structure of systems was proposed.
- Patterns (lines) of changes with examples to give in detail Altshuller's Laws of technical system.
- Generic scheme of technology evolution: bell-shaped curve (so called 'running curve').
- Brief information about Long wave cycles of Kondratieff N.D.

* Source: Salamatov, Y.P. *System of The Laws of Technical Systems Evolution*. CHANCE TO ADVENTURE, pp. 7-174 (Karelia Publishing House, Petrozavodsk, 1991). in Russian

Technological forecasting & TRIZ

[timeline fragment #2]



Past of techology forecasting and TRIZ

[interim conclusions]

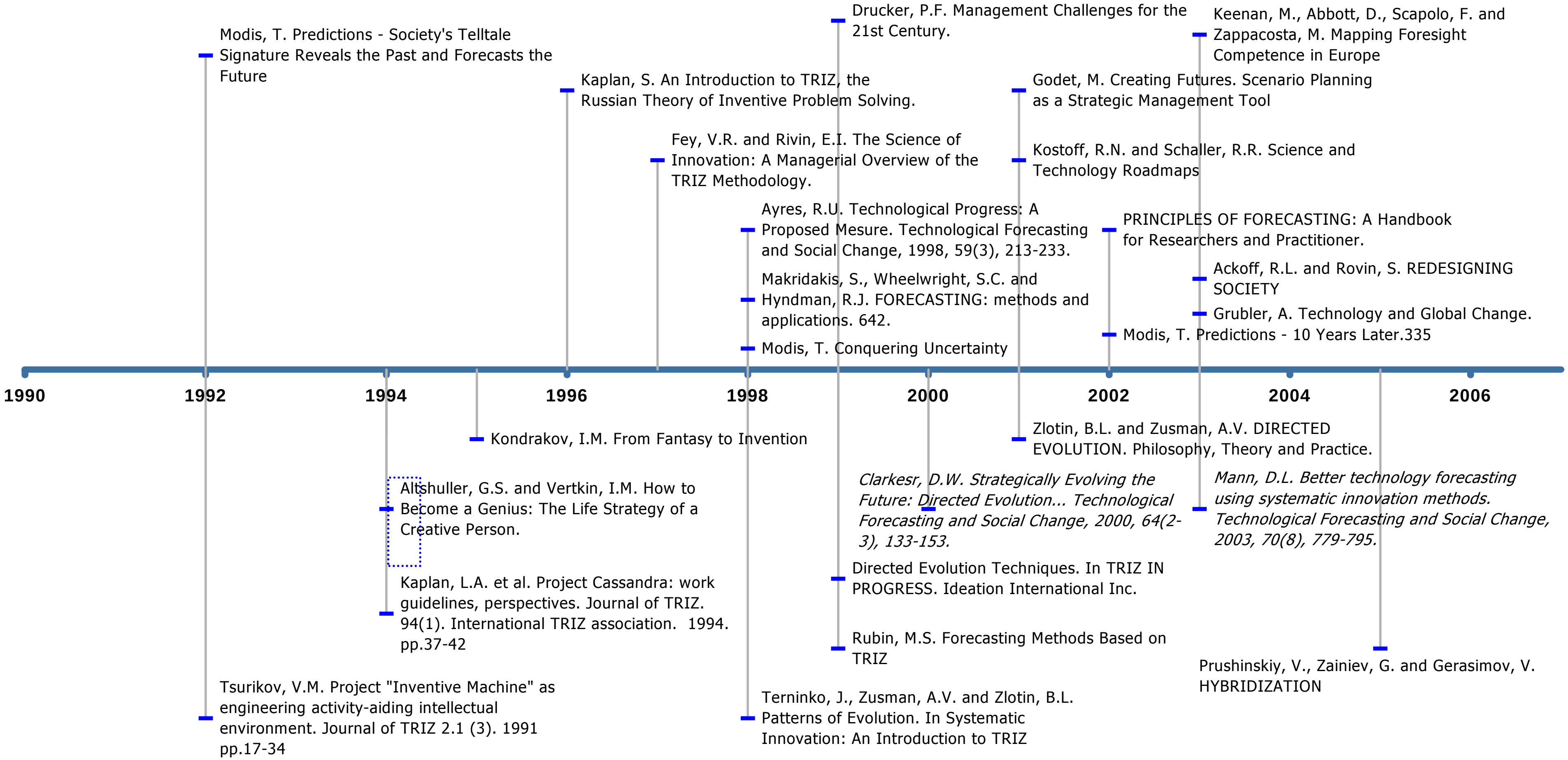
- **TRIZ instruments** for prediction: S-curve, system operator, laws of technical systems evolution, lines of evolution (trends) towards Ideality increase, morphological analysis, wave model of systems evolution, ARIZ.
- Prediction instruments produced **essentially qualitative** outcome.
- No two research teams, working independently, could get the repeatable predictions. **Reproducibility** and biases free issue.
- TRIZ instruments for prediction supported problem oriented, visionary and farseeing **engineering outcome**.

Science is nothing but perception.
Plato

TRIZ FORECASTING (PRESENT)

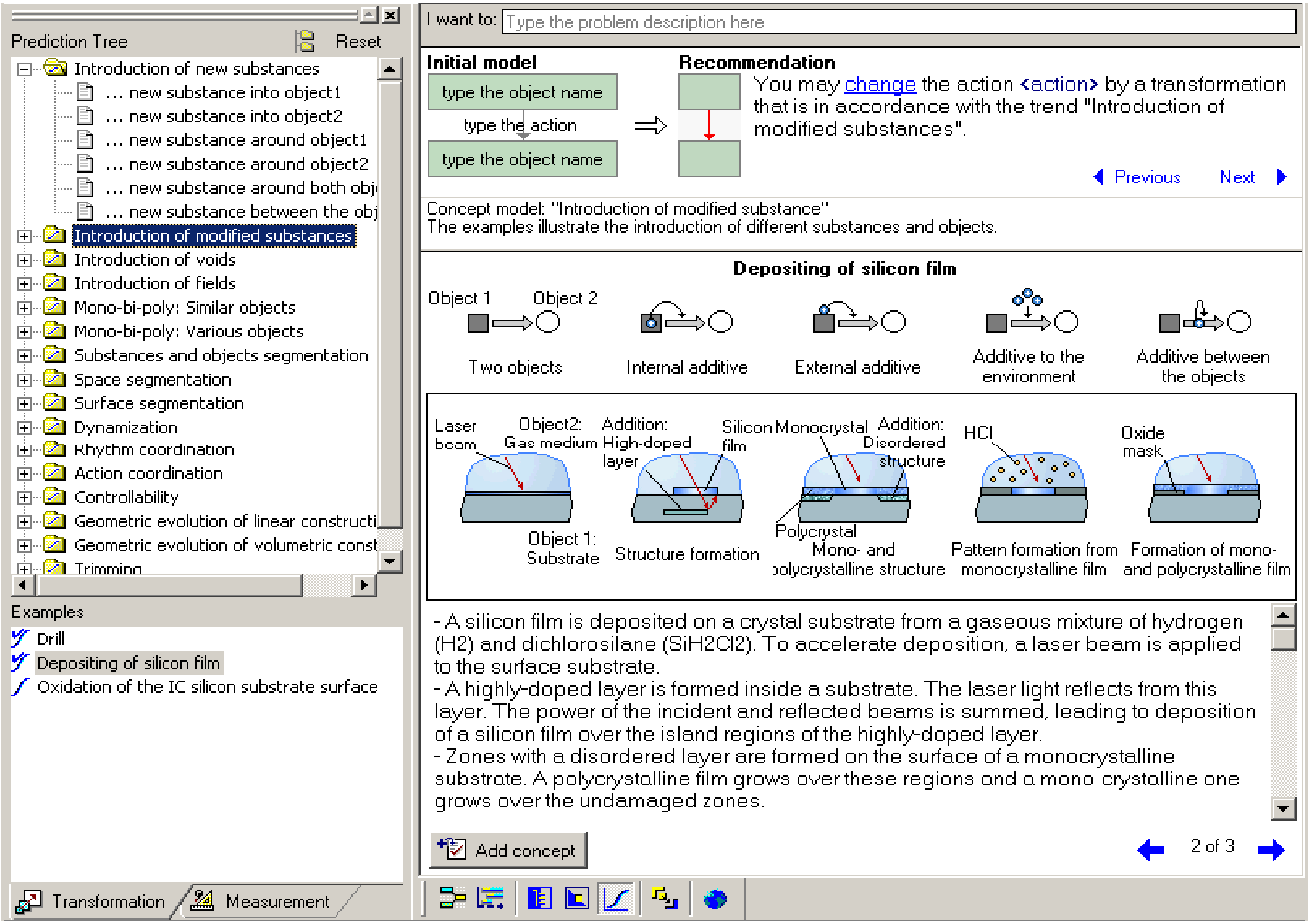
Technological forecasting & TRIZ

[timeline fragment #3]



TRIZ software for prediction

[IM-prediction 1991-1999]



…predict the next phases in the evolution…

Technological forecasting

* Source: TechOptimizer 3.01 (Invention Machine Corp. 1995-1999)

AFTER-96 (1997)

[Algorithm for Forecasting Technology-Evolution Roadmaps]

- **What is applied as instruments:** the four relationship curves operator (S-curve correlations analysis); *the circular evolutionary-patterns diagram*; the "four parts" operator; the "four stages" operator; the scale and scope operator; function, phenomena, form operator; the ideal final result operator; trends of evolution/prediction tree operator; alternative systems operator.
- **What is proposed:** To apply nine Technology Forecasting Operators (TFO) on the objects and actions (summary table is suggested).
- **Questions**: *What*? – can be answered; *When*? – n/a; *Where*? – n/a;
- **Repeatability**: n/a. **Qualitative forecast** – Yes. **Quantitative** – n/a.
- **Adaptability**: n/a.

* Source: *TECHNOLOGY FORECASTING WITH TRIZ - Predicting Next-Generation Products & Processes Using AFTER - 96* (Algorithm for Forecasting Technology-Evolution Roadmaps) - By: James F. Kowalick, PhD, PE. January 1997 www.triz-journal.com

Directed Evolution (1999)

[questions to be answered]

Traditional technological forecast

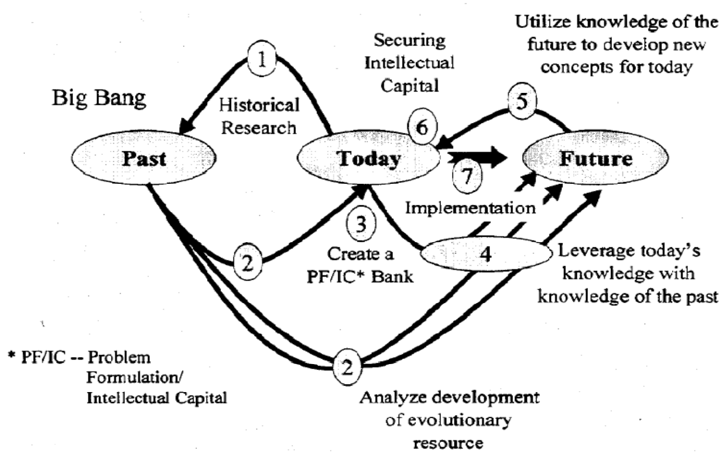
What is going to happened with my product of process parameters?

TRIZ (Technological) forecasting

What change(s) should be made to move my product or process to the next position on a specific pre-determinded Line of Evolution?

Directed Evolution

Which evolutionary scenario should be selected from an identified comprehensive set of scenarios to make it a winner?



* Source: *TRIZ IN PROGRESS*. (Ideation International Inc., 1999). ISBN 1928747043.

Technological forecasting

Directed Evolution (1999)

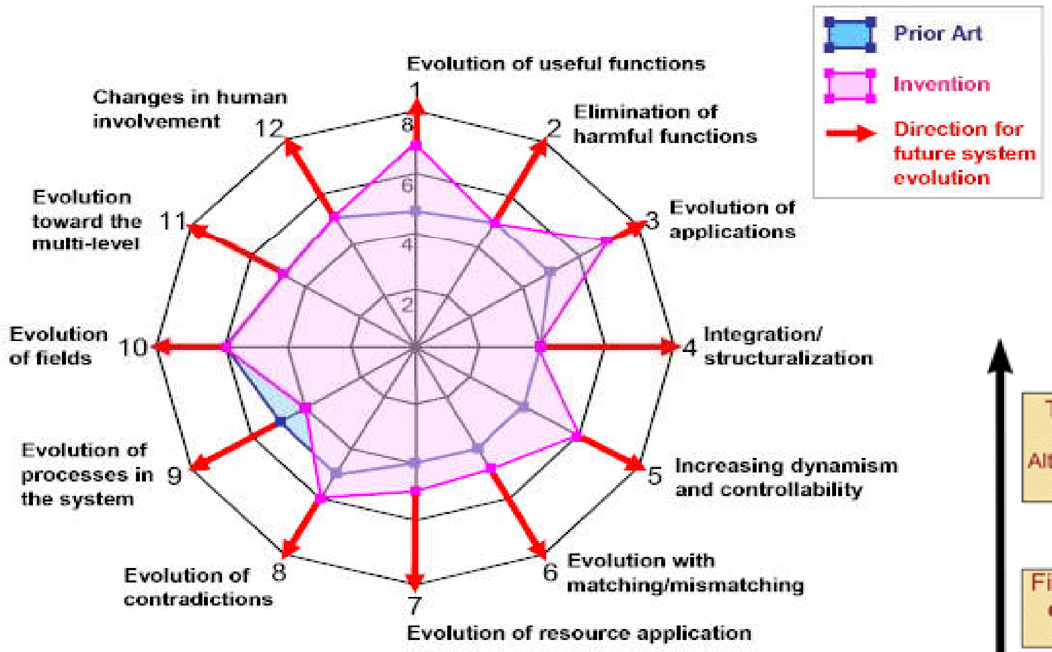
[continuation]

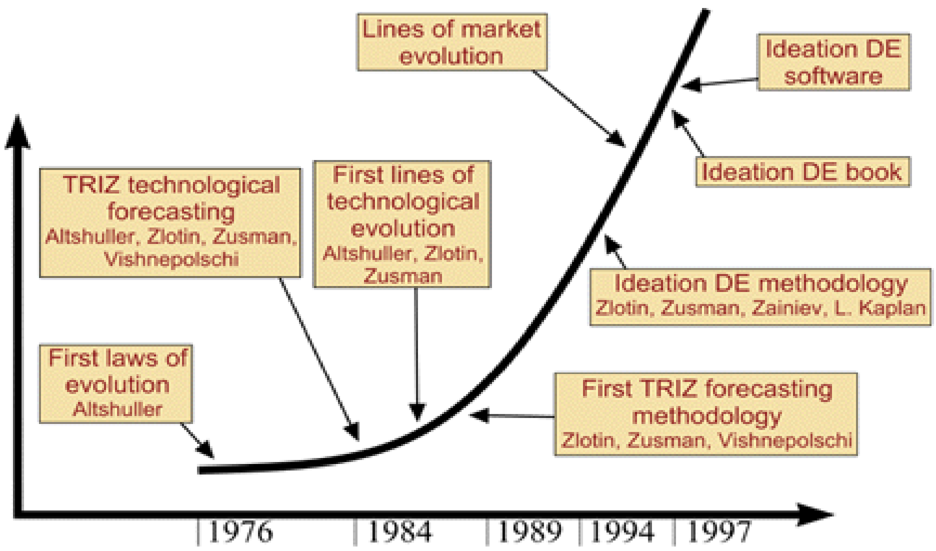
- **What is applied as instruments:** specific information search; S-curve analysis; developing general scenarios of evolution; new system synthesis technique; hybridization technique; integration technique; utilization of pseudo-primary function; Anticipatory Failure Determination (AFD) technique.
- **What is proposed:** Directed evolution process; set of techniques; updated trends, patterns and lines of evolution.
- **Questions**: *What*? – answered; *When*? – n/a; *Where*? – n/a;
- **Repeatability**: n/a. **Qualitative forecast** – Yes. **Quantitative** – n/a.
- **Adaptability**: postulated for product/service; technology; company/organization; industry; market; society.

* Source: *TRIZ IN PROGRESS*. (Ideation International Inc., 1999). ISBN 1928747043.

Directed Evolution (2007)

[directed evolution and the patterns of evolution]





- Directed Evolution™ is based on the 12 Patterns together with over 400 Lines of Evolution.
- The DE process has been applied not only to products but to markets, industries, organizations, technologies, processes, and services.

* Source: http://www.ideationtriz.com/DE.asp#STAGE_5

Guided technology Evolution (1999)

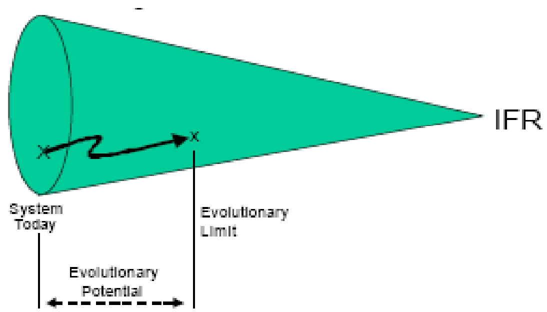
[Victor R. Fey, Eugene I. Rivin]

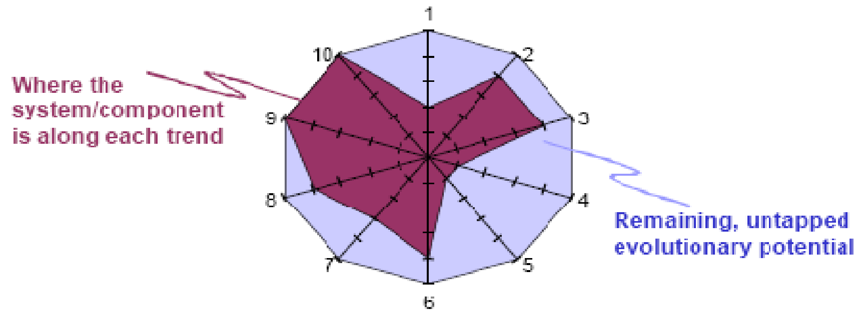
- **What is applied as instruments:** Laws and Lines of Technological Systems Evolution.
- **What is proposed:** Steps of the TRIZ technology forecasting; case examples; comparison between traditional and TRIZ technology forecasts; analysis of the system's evolution by an S-curve.
- **Questions:** *What*? – answered; *When*? – n/a; *Where*? – n/a;
- **Repeatability:** n/a. **Qualitative forecast** – Yes. **Quantitative** – n/a.
- **Adaptability**: limited by scope of laws of technical systems evolution.

* Source: Victor R. Fey, Eugene I. Rivin, *Guided Technology Evolution(TRIZ Technology Forecasting)*. January 1999. www.triz-journal.com

Evolutionary potential (2002)

[D.L. Mann]



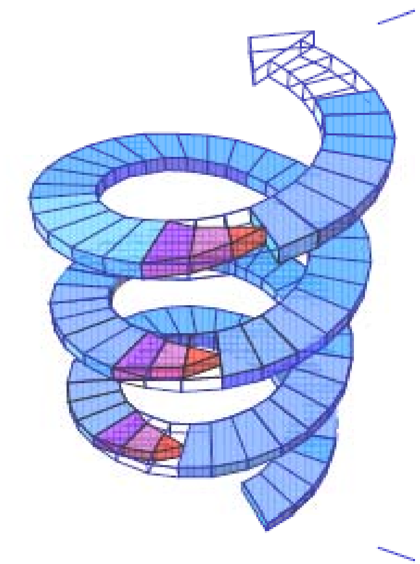


- **What is applied as instruments:** model of Ideal Final Result; patterns of technical systems evolution; technology evolution trends.
- **What is proposed:** updated version of technology evolution trends; procedure to “measure” evolutionary potential of system; business equivalent trends; example for hypothetical organization.
- **Questions:** *What*? – answered; *When*? – n/a; *Where*? – n/a;
- **Repeatability:** n/a. **Qualitative forecast** – Yes. **Quantitative** – quasi(?).
- **Adaptability**: to engineering systems, to business systems.

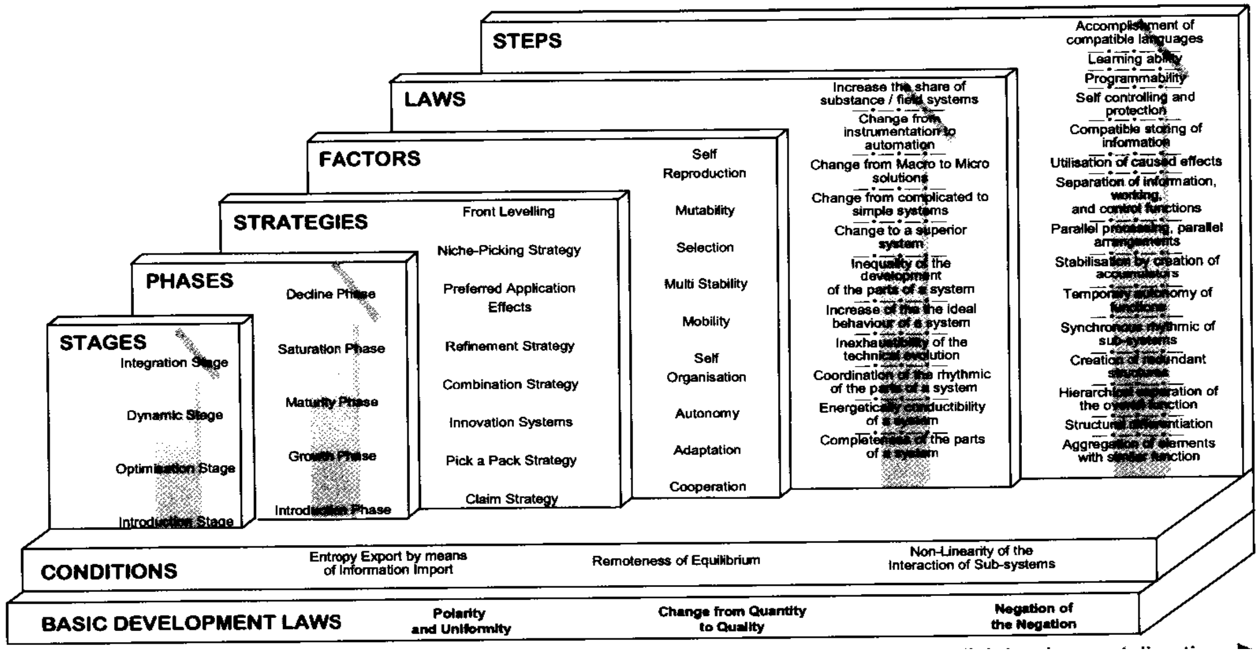
* Source: Mann, D.L. *Better technology forecasting using systematic innovation methods*. Technological Forecasting and Social Change, 2003, 70(8), 779-795.

Model of Evolution with Contradictions (2002)

[Hansjürgen Linde]



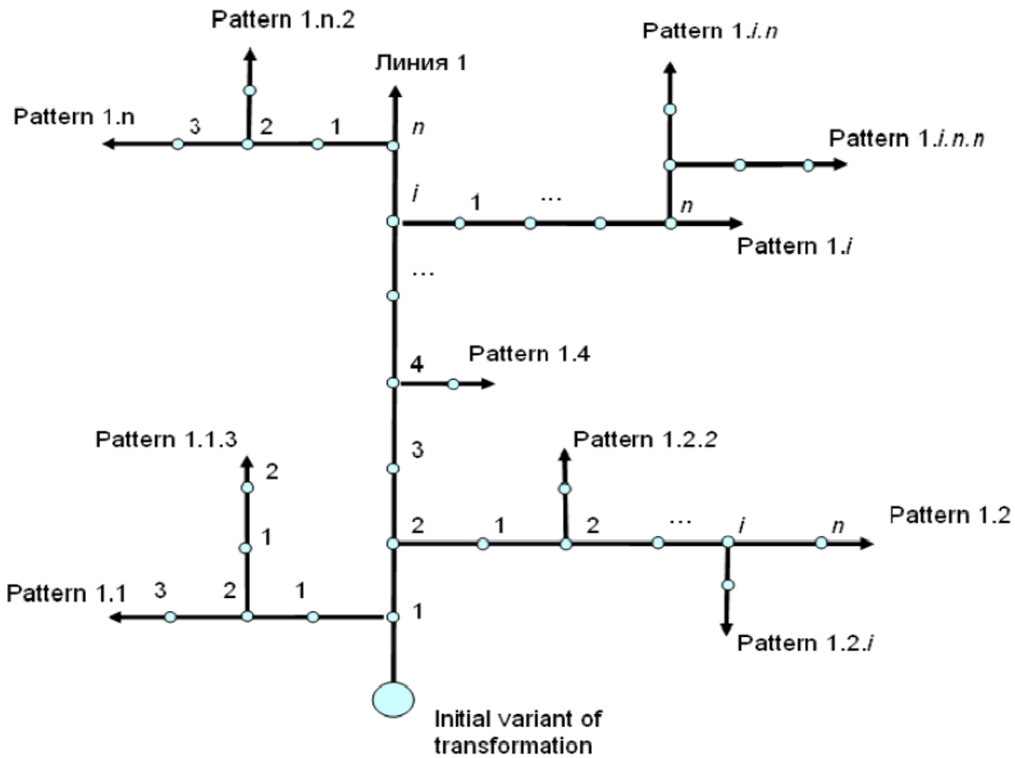
WOIS-Spiral as a model of evolution with contradictions

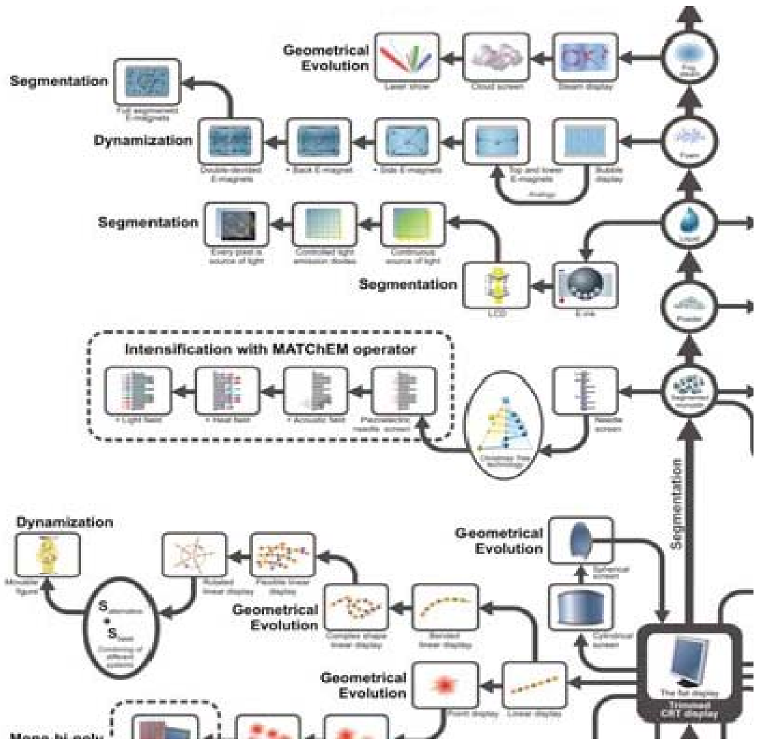


* Source: Hansjürgen Linde, Gunther H. Herr. Professional Strategic Innovation by Intrating TRIZ and WOIS. In TRIZ Future Conference 2004. In ETRIA World conference. Cascini, G., ed. p. 530, (Firenze: Firenze University press, Florence, Italy, 2004).

Evolution trees (2003)

[Nikolai. Shpakovsky]





* Sources: 1. *Tool for generating and selecting concepts on the basis of trends of engineering systems evolution*. In World Conference TRIZ Future 2002. In TRIZ Future 2002. p. 402, (ETRIA, European TRIZ Association, Strasbourg, France, 2002).
2. http://www.gnrtr.com/tools/en/a03.html
3. *Analysis and Representation of Information In Forecasting*. In TRIZ Future Conference 2005. In ETRIA World conference. Jantschgi, J., ed. (Leykam Buchverlag, Graz, Austria, 2005).

Evolution trees (2003) (2)

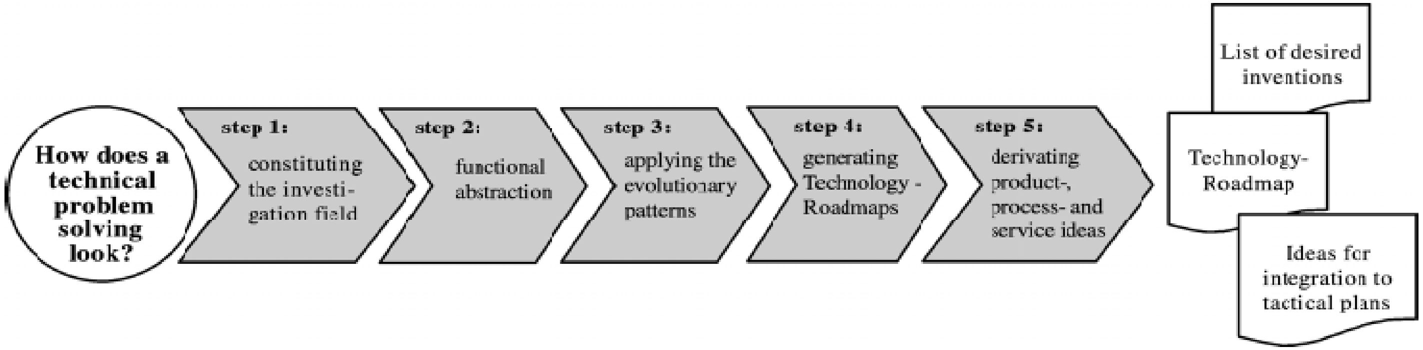
[N. Shpakovsky]

- **What is applied as instruments:** trends, evolution patterns and laws of technological systems evolution; rules to apply evolution patterns.
- **What is proposed:** procedure for constructing an evolution trees; procedure for information classification; the evolution tree structure; procedure for analysis of structured information.
- **Questions:** *What*? – answered exhaustively; *When*? – n/a; *Where*? – n/a;
- **Repeatability:** n/a. **Qualitative forecast** – Yes. **Quantitative** – n/a.
- **Adaptability**: n/a.

* Sources: 1. *Tool for generating and selecting concepts on the basis of trends of engineering systems evolution*. In World Conference TRIZ Future 2002. In TRIZ Future 2002. p. 402, (ETRIA, European TRIZ Association, Strasbourg, France, 2002).
2. http://www.gnrtr.com/tools/en/a03.html
3. *Analysis and Representation of Information In Forecasting*. In TRIZ Future Conference 2005. In ETRIA World conference. Jantschgi, J., ed. (Leykam Buchverlag, Graz, Austria, 2005).

TRIZ-based technology-roadmapping (2004)

[Martin G. Moehrle]

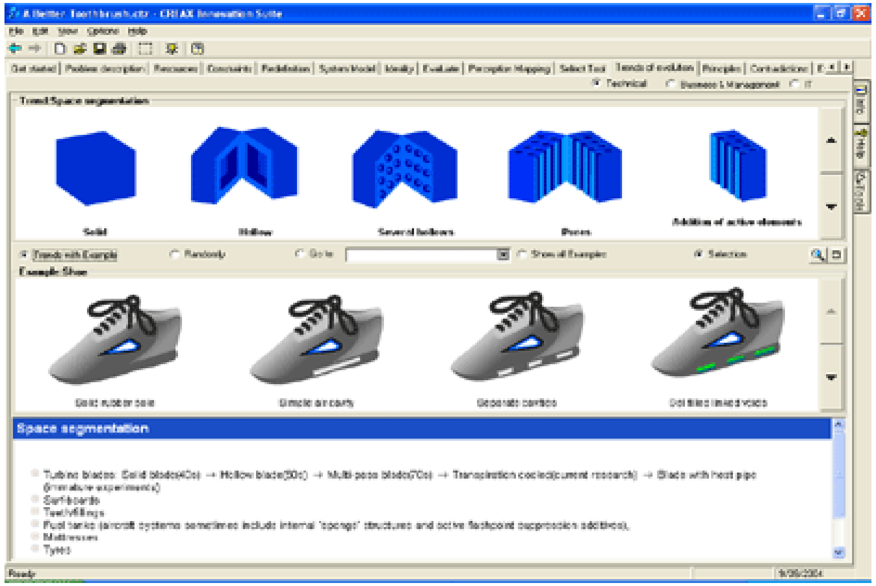


- **What is applied as instruments:** laws of technological systems evolution; invention principles; evolutionary patterns of technical systems.
- **What is proposed:** procedure for technological roadmapping using some of TRIZ techniques.
- **Questions:** *What*? – answered; *When*? – n/a; *Where*? – n/a;
- **Repeatability:** n/a. **Qualitative forecast** – Yes. **Quantitative** – n/a.
- **Adaptability**: to engineering systems with various complexity.

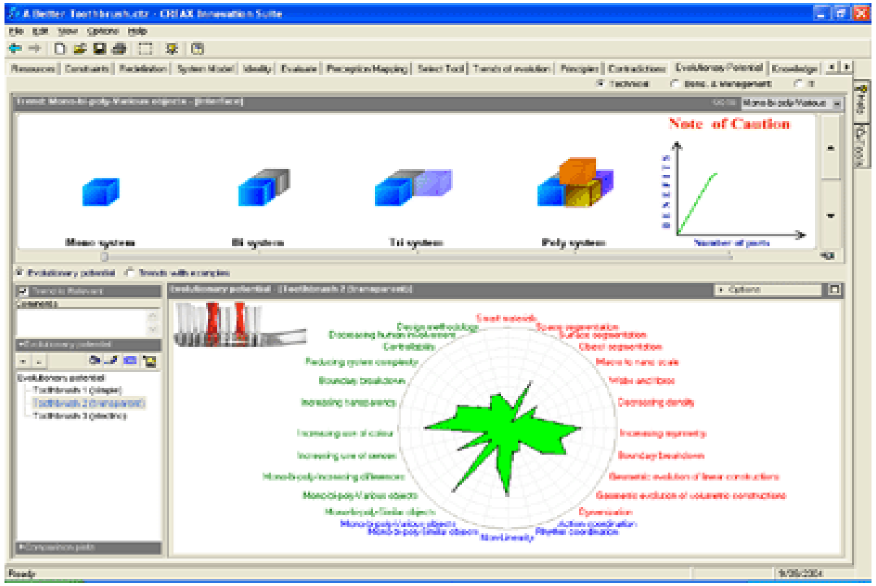
* Source: Moehrle, M.G. *TRIZ-based technology-roadmapping*. Int. J. Technology Intelligence and Planning, 2004, 1(1), 87-99.

Creax innovation suite 3.1

[trends of evolution & evolutionary potential]



Trends of Evolution will show you how products or processes evolve over time.



Evolutionary Potential can visualize where your product, process or service is in its innovation process.

* Source: http://www.creaxinnovationsuite.com/

TRIZ for forecasting

- 1994 *software project Cassandra*: Several Forecasting modules described. [Journal of TRIZ. 94(1). International TRIZ association. 1994. 130. In Russian. ISSN 0869-3943]: Technological forecasting of particular systems; Forecasting using Laws of technical systems evolution; Forecasting of emergency situations; Marketing forecast.
- Prushinskiy, V., Zainiev, G. and Gerasimov, V. *Hybridization: the new warfare in the battle for the market*. (Ideation International, Inc., 2005), 121. ISBN 1-59872-069-4.
- P. Chuksin. Selecting of Key Problems and Solution Search Area in Forecasting http://www.trizland.ru/trizba/pdf-articles/vibor_ptoblem.pdf
  N. Shpakovsky, P. Chuksin, E. Novitskaja. Forecasting Maps of Engineering System Evolution. http://www.gnrtr.com/tools/en/a03.html
- Rubin M. Forecasting of socio-technical systems,
  Rubin, M.S. Future Is Projecting on the basis of TRIZ. Petrozavodsk, Russia, 2002).
  In border of research about “Theory of Evolution of substance and models”

TRIZ forecasting - summary

[interim results of observation]

- **TRIZ instruments** for prediction:
  - updated, adopted and enhanced patterns and lines of evolution;
  - new ways to apply existing knowledge about laws of technical systems evolution;
  - problem solving techniques applied for predictions.
- Prediction instruments produce **qualitative** outcome with some quasi quantitative results.
- **Reproducibility** of TRIZ forecasting is questionable.
- TRIZ instruments for prediction become more **customized** and intend to be applied for non-engineering domains.

…TRIZ is definitely a valuable tool for innovation in engineering. There is a continuing need for advances in many engineering tasks and they merit a major share of attention in technological forecasting…

Harold A. Linstone (May 2000)
Editor-in-Chief of International Journal Technological Forecasting and Social Change

1. Linstone, H.A. Victor R. Fey and Eugene I. Rivin -- The Science of Innovation: A Managerial Overview of the TRIZ Methodology: Southfield, MI, The TRIZ Group, 1997, 82 pages. ISBN 0-9658359-0-1. Technological Forecasting and Social Change, 2000, 64(1), 115-117.
2. Clarke Sr., D.W. Strategically Evolving the Future: Directed Evolution and Technological Systems Development. Technological Forecasting and Social Change, 2000, 64(2-3), 133-153.
3. Mann, D.L. Better technology forecasting using systematic innovation methods. Technological Forecasting and Social Change, 2003, 70(8), 779-795.

summary

[trends in evolution of TRIZ instruments for forecasting]

- **Customization**: special techniques to predict technological future, company or organization evolution, market future, and social changes.
- Increasing **number** of applied lines and patterns (increasing complexity).
- **Integration** with methods and techniques outside TRIZ (towards super-system) and including some techniques as part of complex problems analysis (towards additional sub-system).
- Attempts to enrich qualitative predictions by **quantitative** analysis.
- Attempts to develop methods and techniques which will facilitate **reproducible** forecasts.

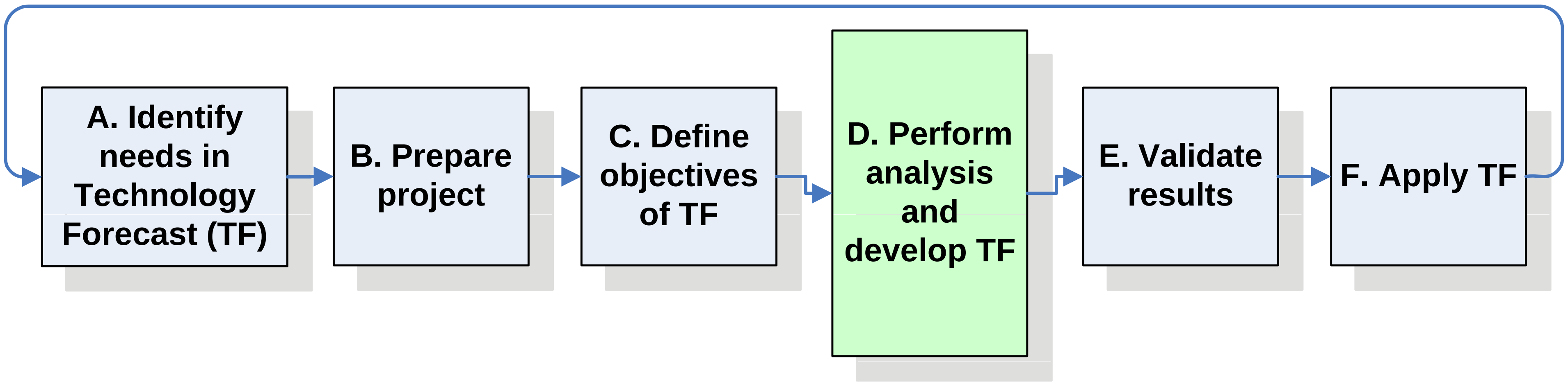
- Before studying the past for trends
- Perform a study and develop forecast
- Validate and apply forecast

".. Like any powerful tool, it can create marvels in the hands of the knowledgeable, but it may prove deceptive to the inexperienced .."

3. TECHNOLOGICAL FORECASTING PROCESS

Six phases project for Technology Forecast (TF)

"…providing a consensual vision of the future science and technology landscape to decision makers." [Kostoff and Schaller, 2001]



Before studying the past for trends

A. Identify needs

- What are main objectives and expected outputs?
- How it will be applied for decision making process?
- Can we satisfy formulated needs without TF?
  -> *Go / Not to Go*

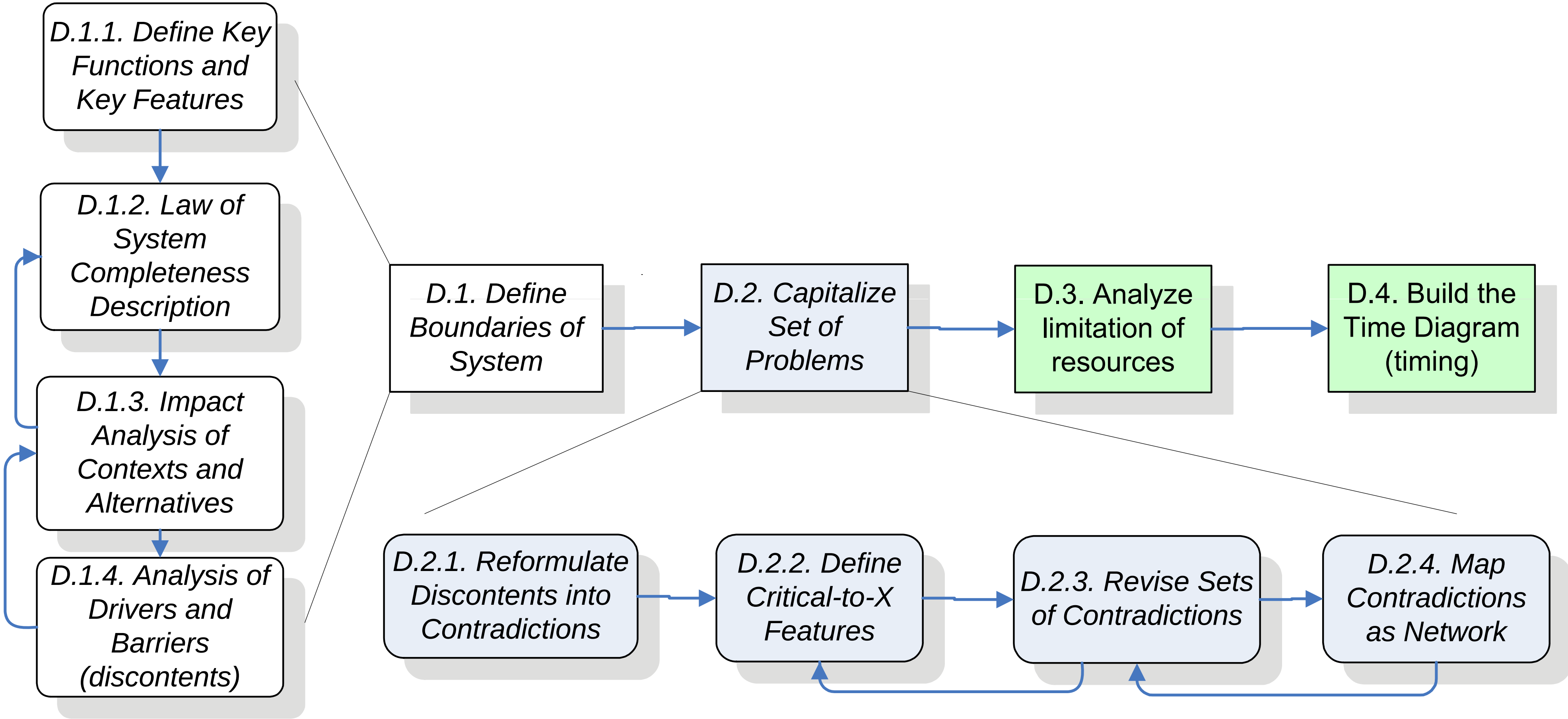
B. Prepare project

- What are available and necessary resources to perform study?
- What is an optimal time span to realize project?
- Who are clients, core team, and necessary external participants? -> *Detailed plan of project*.

C. Define objectives

- What kind of question should be answered?
- What would we need a technology forecast for?
- How would we like to use the forecast?
- What are the data sources…? -> *Validated project specification*

D. Perform a study and develop TF



Technological forecasting

D.1. define the boundaries of a system

D.1.1. Define key functions and key features

- What are main function (set of major functions) and what are significant traits?
  -> *First approximation to boundaries of system to be studied.*

D.1.2. Law of System Completeness

- What are four major components of system? What are product and tool? How energy passes through system?
  -> *Defined system with boundaries and major sub-systems*.

D.1.3. Impact analysis of Contexts and Alternatives

- How system is positioned according to Economic, Social, Environmental and Technological contexts?
  -> *Definition of system and major super-systems.*

D.1.4. Analysis of Drivers and Barriers

- What are driving forces and obstacles on evolution of system?
  -> *Preliminary lists of resources and dissatisfactions.*

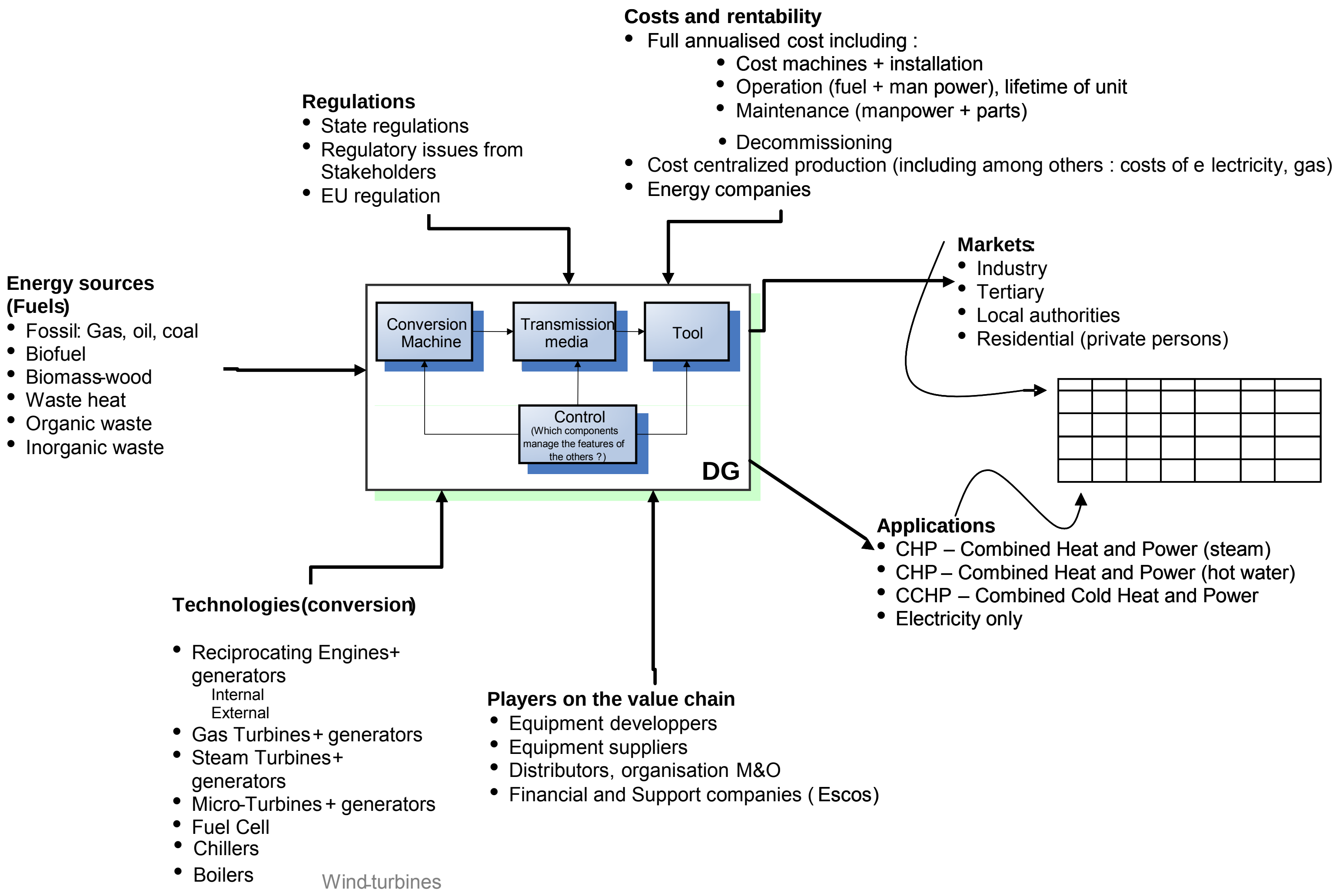
To manage a system effectively, you might focus on the interactions of the parts rather than their behavior taken separately.

Russell Ackoff

Professor Emeritus Wharton School,
University of Pennsylvania,
(Author of Redesigning Society)

D.1. define the boundaries of a system (example)

Law of System Completeness: Distributed Energy Generation system



* Information provided courtesy of EIFER, Karlsruhe [Henckes, L. et al., 2006]

D.1. define the boundaries of a system (example)

List of Drivers and Barriers: Stationary Fuel cell

Sociological context		Economic context	
Drivers	***Barriers***	***Drivers***	***Barriers***
Good image of fuel cell Local policy to reduce GHG effect (demand-side management) Security of energy supply Lower electricity dependence from other countries Manpower demand	Safety issue Public ignorance of CHP: conservative market Decrease of heat demand Need of education for manpower Unemployment in old technology field Uncertainty on distributed generation development (dependant of fiscal and regulatory policies)	New business creation (premium power, domestic CHP, energy services, back-up power, market for gas utilities) Possible synergies with mobile sector will help cost reduction	In recession period, hard to introduce new technologies Allowable cost evaluation influenced by several factors, i.e. future energy cost Profitability not demonstrated (standby attitude of investors)

Technological context		Environmental context	
Drivers	***Barriers***	***Drivers***	***Barriers***
Modularity Reduction of electricity transmission losses Heat available High power to heat ratio Lower maintenance cost High efficiency at low power High efficiency at part load	Technical difficulties to grid connection for large scale integration of FC Availability of components Reliability on field (lifetime, maintenance)	High electrical efficiency: reduction of GHG emission and natural resources consumption Large choice of primary energy sources to produce H2 (fossil, renewable, nuclear…) Very low pollutant emissions (NOx, SOx, particles..) CO2 sequestration potential	Occupied area use

* Information provided courtesy of EIFER, Karlsruhe [Gautier, L. et al., 2005]

D.2. Capitalize Set of Problems

D.2.1. Reformulate Discontents into Contradictions

- What are the problems behind of discontents and barriers?
  -> *List of contradictions (technical ones).*

D.2.2. Define Critical-to-X Features

- What are root causes of discontents and contradictions?
  -> *Set of metrics to measure evolution of system*.

D.2.3. Revise Sets of Contradictions

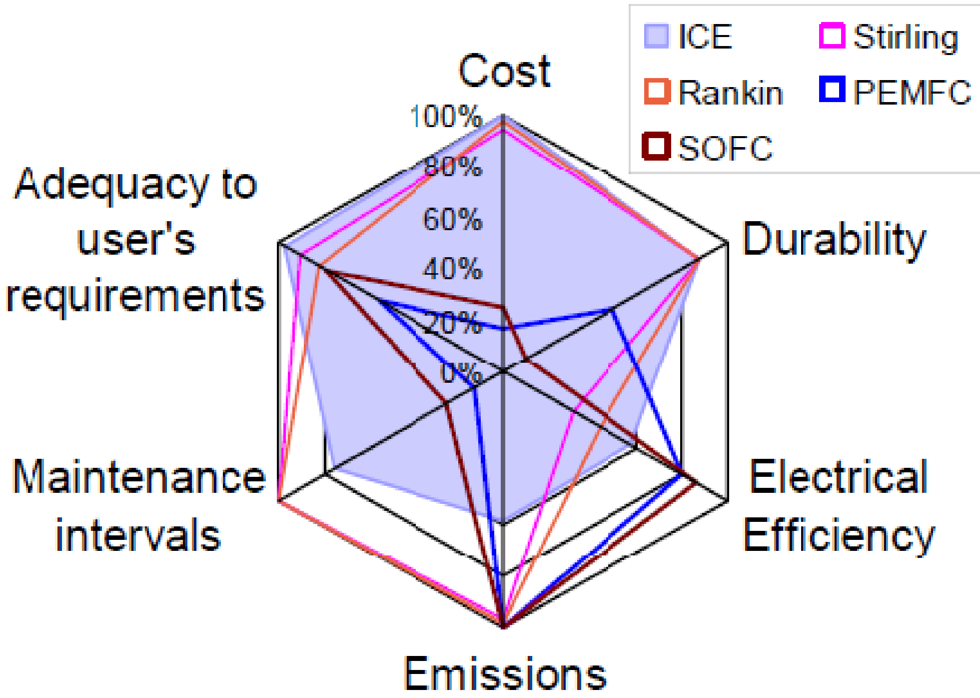
- How root causes are relevant to formulated contradictions?
  -> *Prototypes of physical contradictions (contradictions of parameters – OTSM-TRIZ).*

D.2.4. Map Contradictions as Network

- How formulated contradictions are linked? Is any network of contradictions?
  -> *'one page' presentation of interconnected contradictions.*

Capitalize Set of Problems (example)

Critical-to-Market features: Stationary Fuel Cell

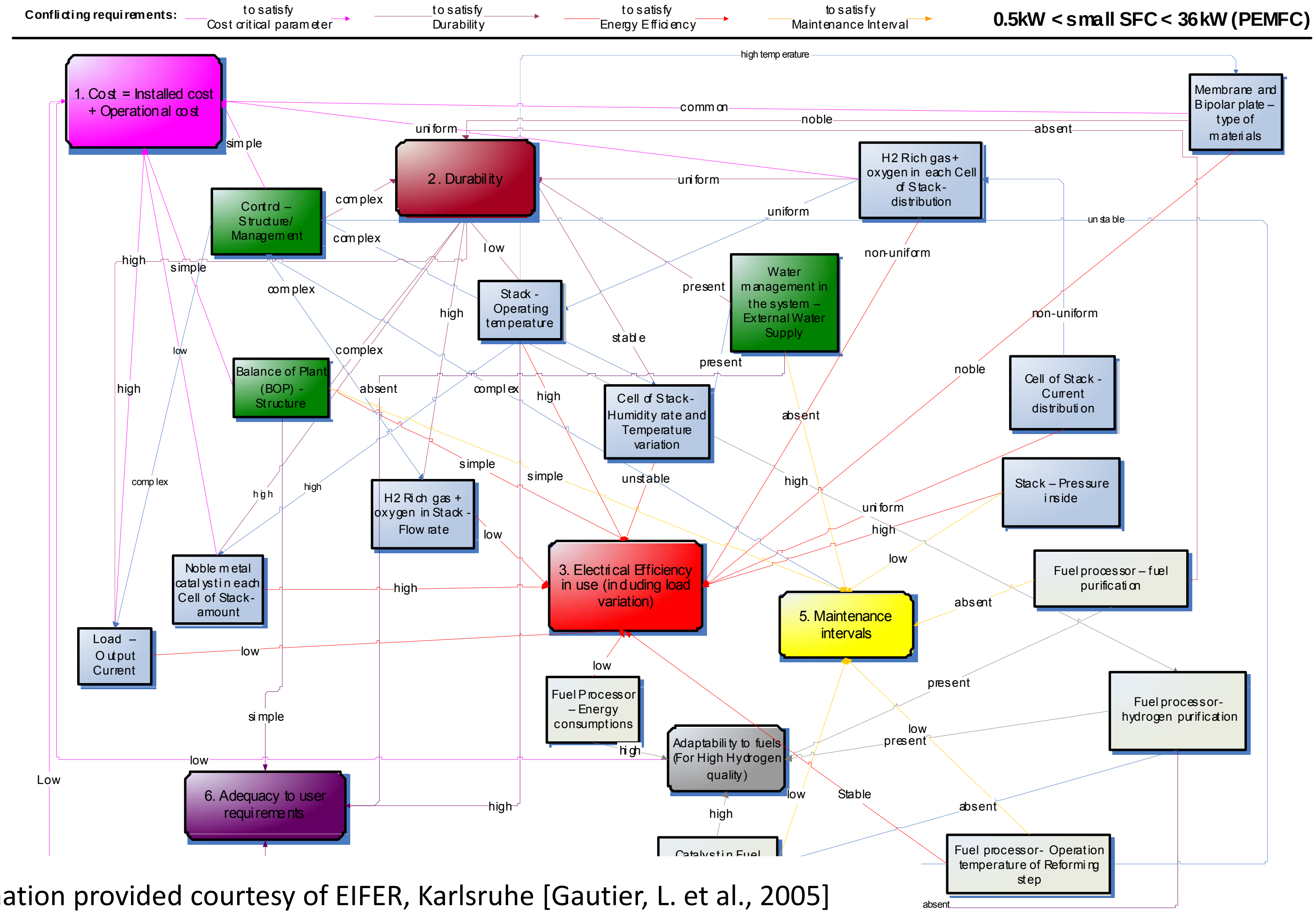


		PEMFC			SOFC		
		actual	market target	performed	actual	market target	performed
1.	Cost:	17%	100%		25%	100%	
1.1.	Installed Cost NG, EUR/kW Importance: High	15000	4000	27%	10000	4000	40%
1.2	Operational cost, EUR/kWh Importance: High	0.3	0.02	7%	0.2	0.02	10%
2.	Durability:	49%	100%		10%	100%	
2.1	Durability in operating conditions, years Importance: High	2	15	13%	2	15	13%
2.2	Cycling ability, number of stops per year Importance: High	125	125	100%	10	125	8%
2.3	Start up time, min Importance: Moderate	90	15	17%	240	15	6%
3.	Energy Efficiency, %	85%	100%		93%	100%	
3.1	Electrical efficiency, %	28%	35%	80%	30%	35%	86%
3.2	Thermal efficiency, %	59%	65%	91%	55%	59%	100%
3.3	Ratio Electrical power / Thermal Power	0.51	0.04		0.04	0.04	
4.	Emissions Importance: High	100%	100%		100%	100%	
4.1	Substances, ppm Importance: High	40	CO < 50ppm NOx<34 ppm	100%		CO < 50ppm NOx<34 ppm	100%
4.2	Noise, dB Importance: High	0		100%	0		100%
5.	Maintenance interval, h Importance: Moderate	1000	8000	13%	2000	8000	25%
6.	Adequacy to user requirements,	56%	100%		79%	100%	
6.1	min. temperature return, °C Importance: High	50	60	83%	500	70	100%
6.2	min. flow temperature, °C Importance: Moderate	70	80	88%	600	90	100%
6.3	size, m Importance: Moderate	1.5x0.85x1.7 2.17	0.5x0.5x1 0.25	12%	0.55 x 0.55 x 1.60 0.48	0.5x0.5x1 0.25	52%
6.4	weight, kg Importance: Moderate	500	70	14%	170	70	41%
	Average for technology:	38%	100%		40%	100%	

* Information provided courtesy of EIFER, Karlsruhe [Gautier, L. et al., 2005]

Capitalize Set of Problems (example)

Map of Contradictions: Low temperature Stationary Fuel Cell



* Information provided courtesy of EIFER, Karlsruhe [Gautier, L. et al., 2005]

Technological forecasting

D.3. Analyze the limitations of resources

Technological barriers assessment:

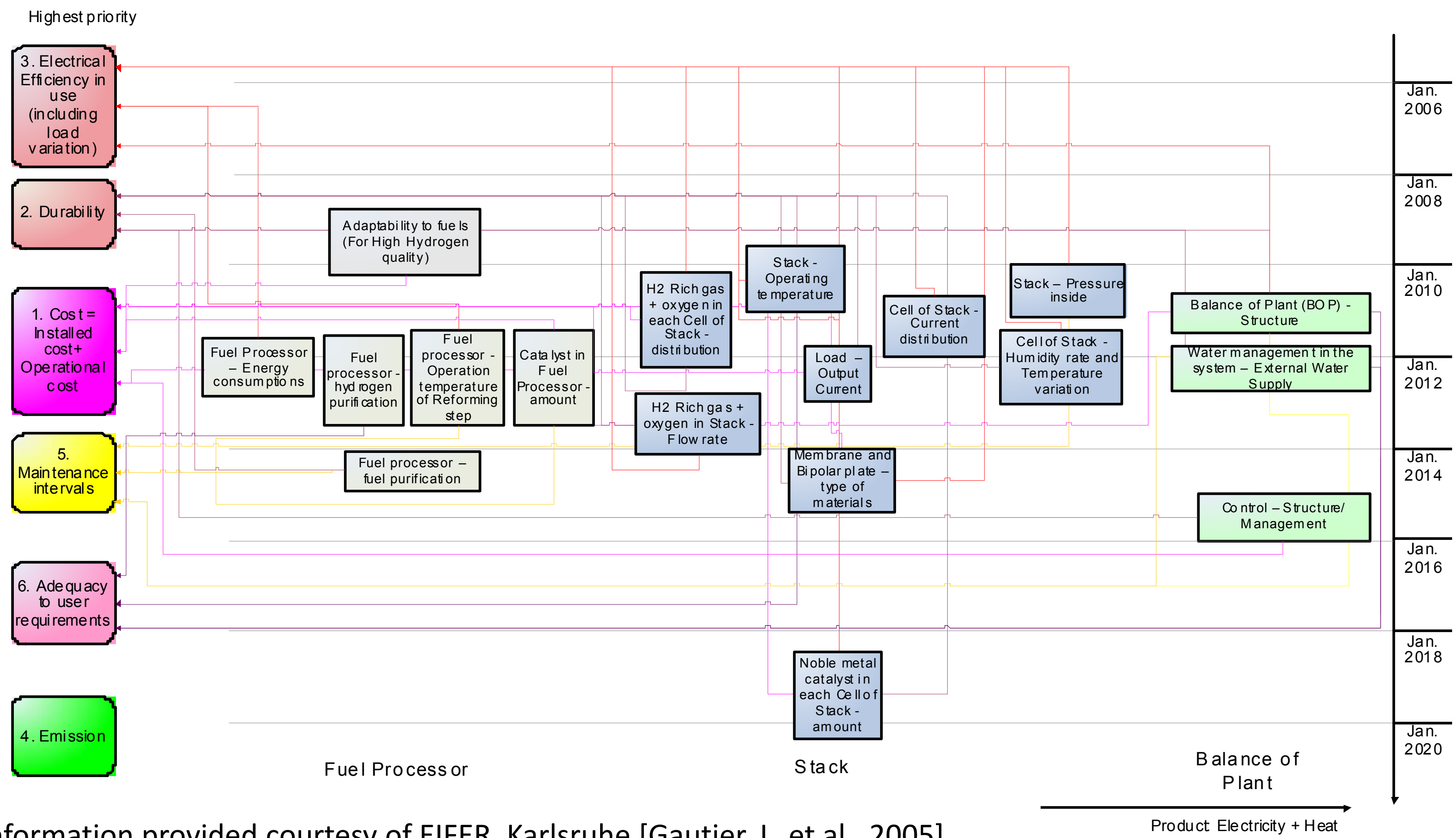
- What are Science and Technology + Research and Development activities addressed to identified problems?

Element-Feature	Value 1	Value 2 (opposed)	Limiting resources	S&T, R&D activities, Project names	Exploration, years	Experimentation & examination, years
Noble metal catalyst in each Cell of Stack - amount	Low	High	Platinum needed at low temperature (<400°C)	<Project 1 name>	<Project1 duration>	<Time for field tests>
<E2 – F2>	<V>	<Λ>	<Substance, Field, Time, Space etc.>	<Project 2 name>	<Project2 duration>	<Time for field tests>
<E3 – F3>	Present	Absent	<Time, Space etc.>	No specific project	<Project3 duration ??>	<Time for field tests ??>
<…>	<…>	<…>	<…>	<…>	<…>	<…>
Fuel processor - Quality of outlet gas	Low	High	complex fuel processing technology for NG and biofuels	<Project N name>	<Project N duration>	<Time for field tests>

D.3. Build the time diagram

Time delays assessment and technology roadmapping:

- Map of problems for low temperature SFC on a time scale: technological context



* Information provided courtesy of EIFER, Karlsruhe [Gautier, L. et al., 2005]

Technological forecasting

Validate and apply the forecast

E. Validate results (peer review)

For consistent validation of TF the major clients and partners should agree on:

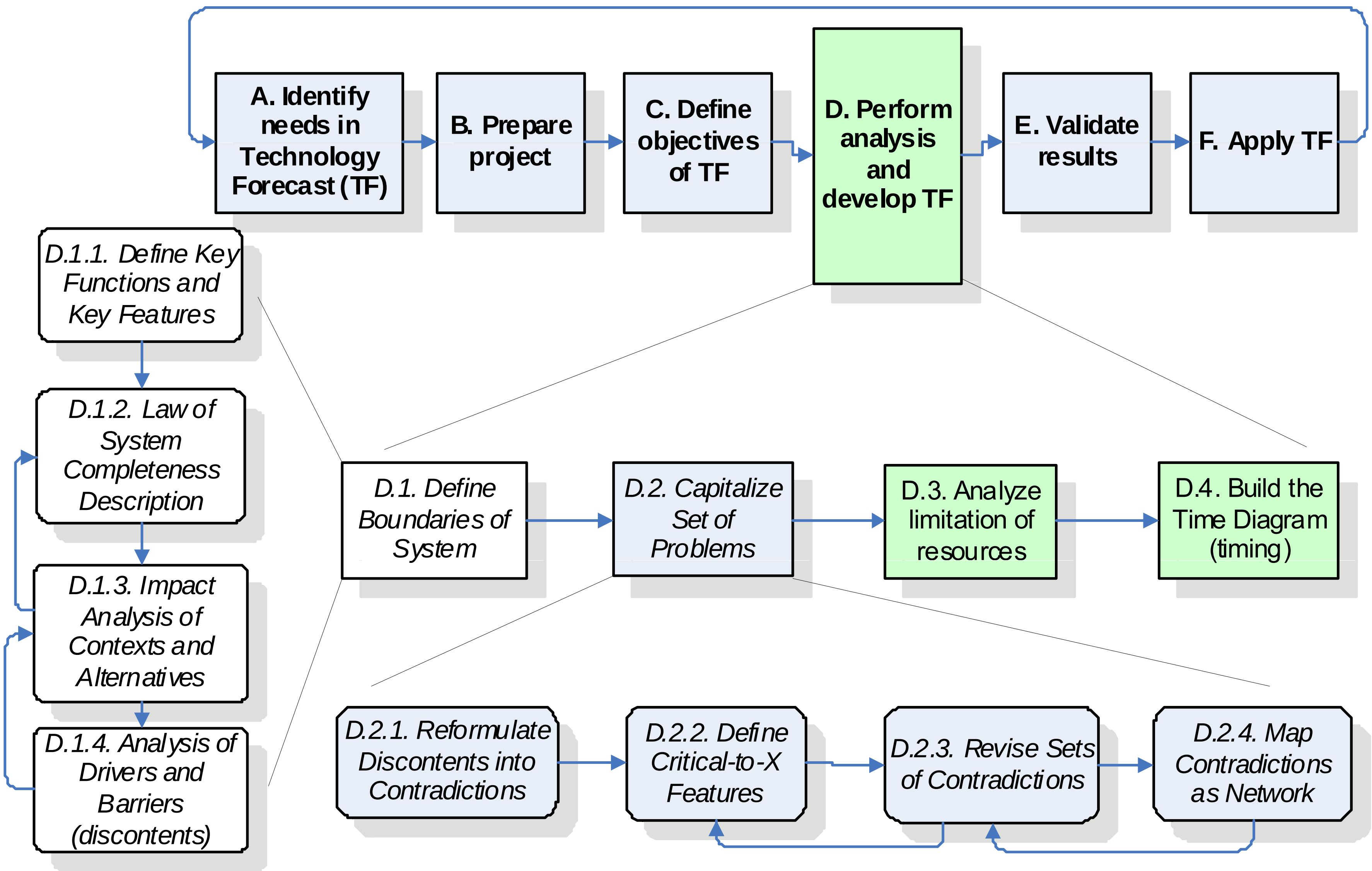
- *key functions of the analyzed system,*
- *key enabling technologies*
- *major trends in the evolution of the surrounding super-systems.*

F. Apply TF

Depends on:

- *needs and formulated objectives,*
- *transparency and intelligibility,*
- *credibility and consistency of the technology prediction.*

flow chart of technological forecasting project



- What does S-curve mean?
- Technology substitution model
- Component logistic model

4. LOGISTIC SUBSTITUTION MODEL

Brief history of logistic models

1825 - Benjamin Gompertz published work developing the Malthusian growth model for demographic study (law of mortality);

1838, 1845, 1847 - logistic curve introduced by Belgian mathematician Pierre-Francois Verhulst as a model of population growth;

1923 – Robertson, T.B. was the first to use the function for describing the growth process in a single organism or individual;

1924, 1925 – Raymond Pearl rediscovered the function and used it extensively to describe the growth of populations, including human population;

1925, 1926 - Alfred J. Lotka and Vito Volterra independently generalized growth equation to model competition among different species (the predator-prey equations);

1957 - Griliches, Z. showed that technological substitution can be described by an S-shaped curve;

1961 – Mansfield, E. developed a model to explain the rate at which firms follow an innovator;

1971 – Fisher, J.C. and Pry, R.H. formulated model of binary technological substitution; it uses the two-parameter logistic function to describe the substitution process;

1979 – Marchetti C. proposed logistic substitution model to describe several technologies in dynamics of competition.

1994 – Meyer P.S. proposed component logistic model (bi-logistics, multiple logistics)…

Limitation of resources and logistic S-curve

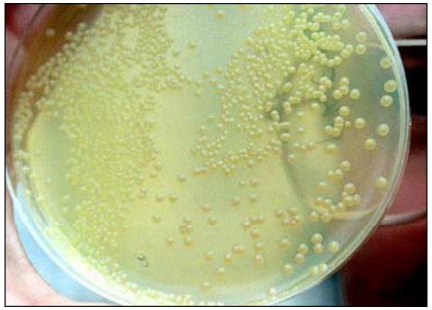
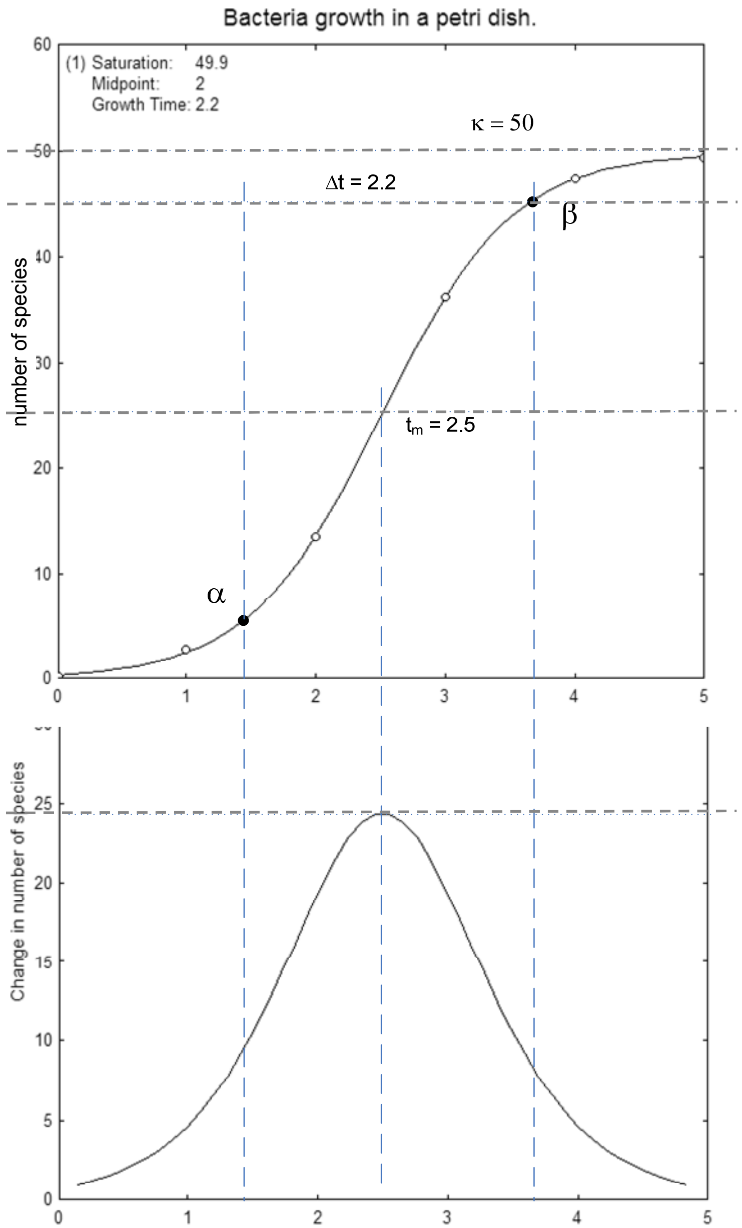


Image source: www.cbsnews.com

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

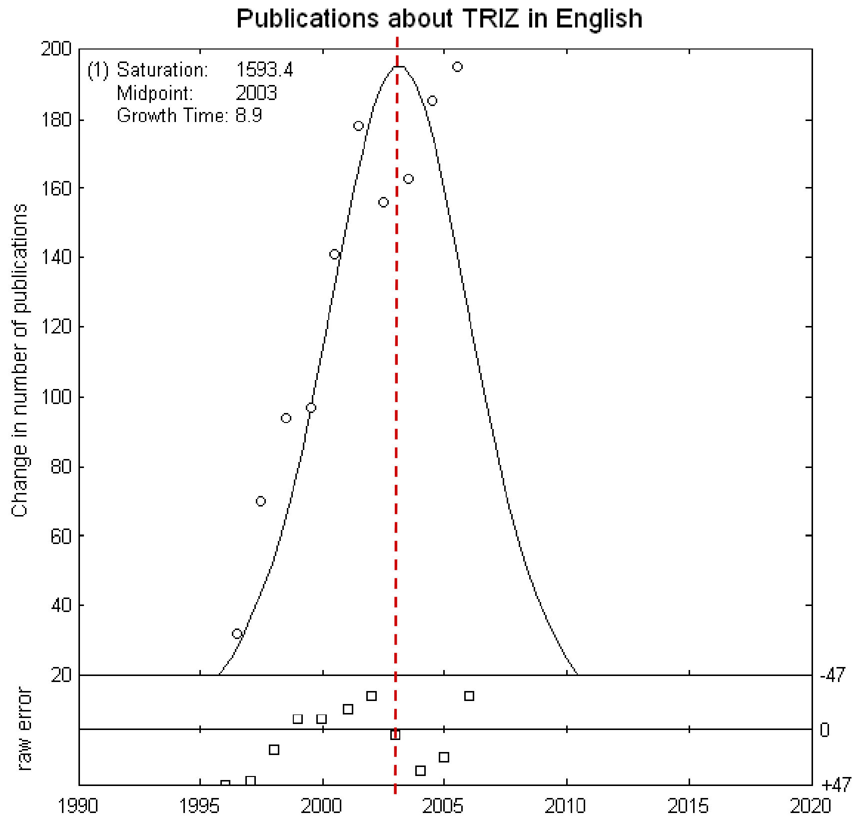
α – growth rate parameter, time required for "trajectory" to grow from 10% to 90% of limit *κ*
characteristic duration (Δt);
β – parameter specifies the time (t_m) when the curve reaches 0.5*κ*
midpoint of the growth trajectory;
κ – is the asymptotic **limit of growth**.



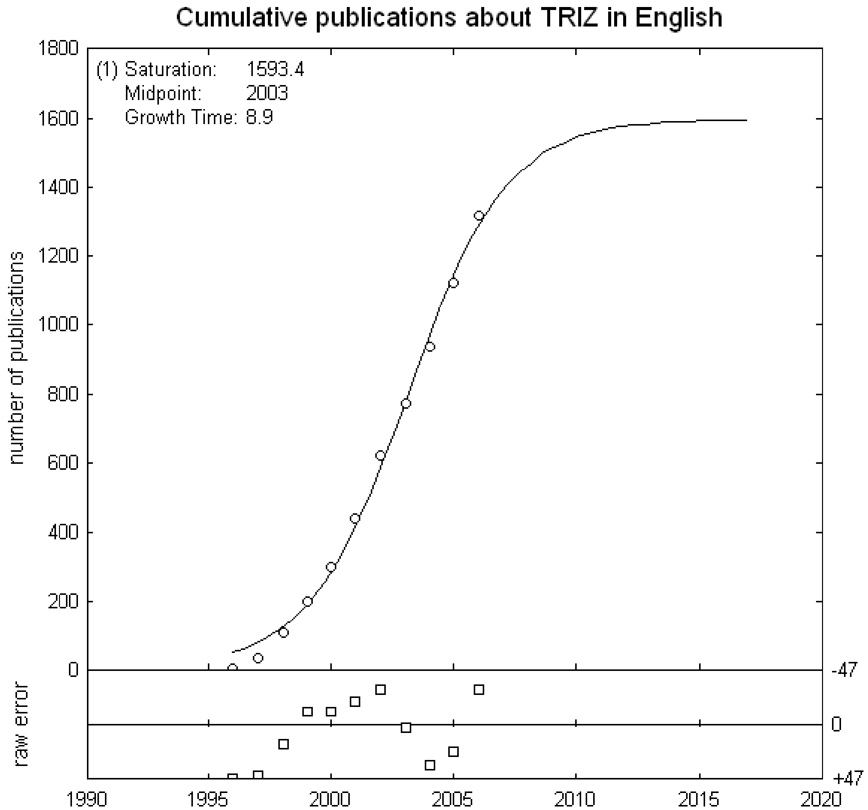
The model of growth under competition

- *Natural growth* of autonomous systems *in competition* might be described by logistic equation and logistic S-curve.
- Natural growth is defined as ability of a '*species*' to multiply inside finite *'niche capacity*' through *time period*.
- For socio-technical systems the three-parameter S-shaped growth model is applied for describing "trajectories" of growth or decline through time.

rate of growth, cumulative growth



Bell-shaped ("normal" distribution)



Simple logistic (symmetric) S-curve

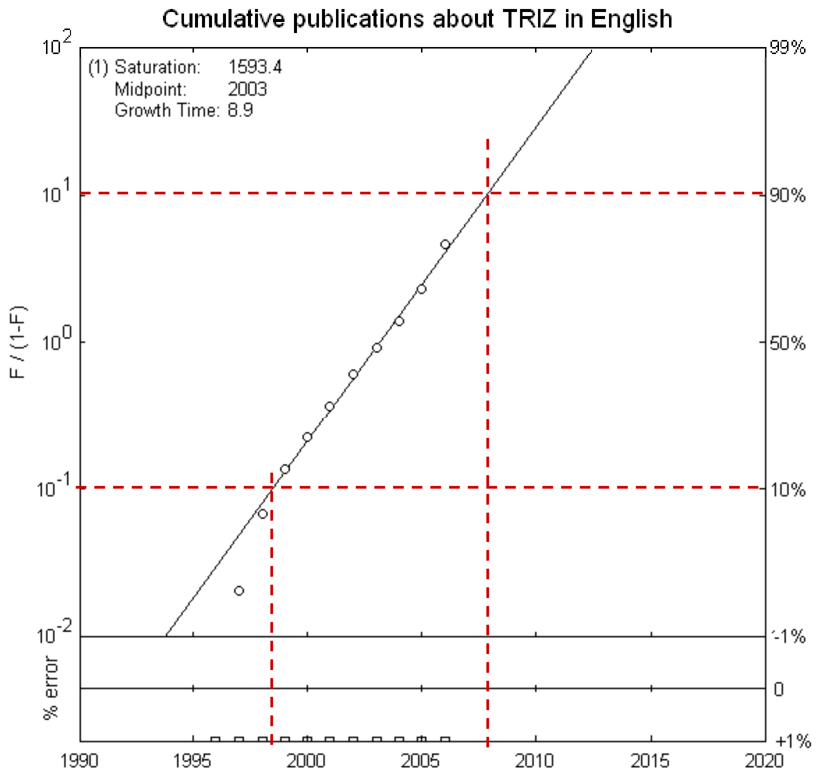
Data sources: The TRIZ Journal (1996-2006), proceedings of the TRIZCON (1999-2006), proceedings of the ETRIA TFC (2001-2006). The same articles from different sources where taken into account just once.

* S-curve fit on data by Loglet Lab Version 1.1.4

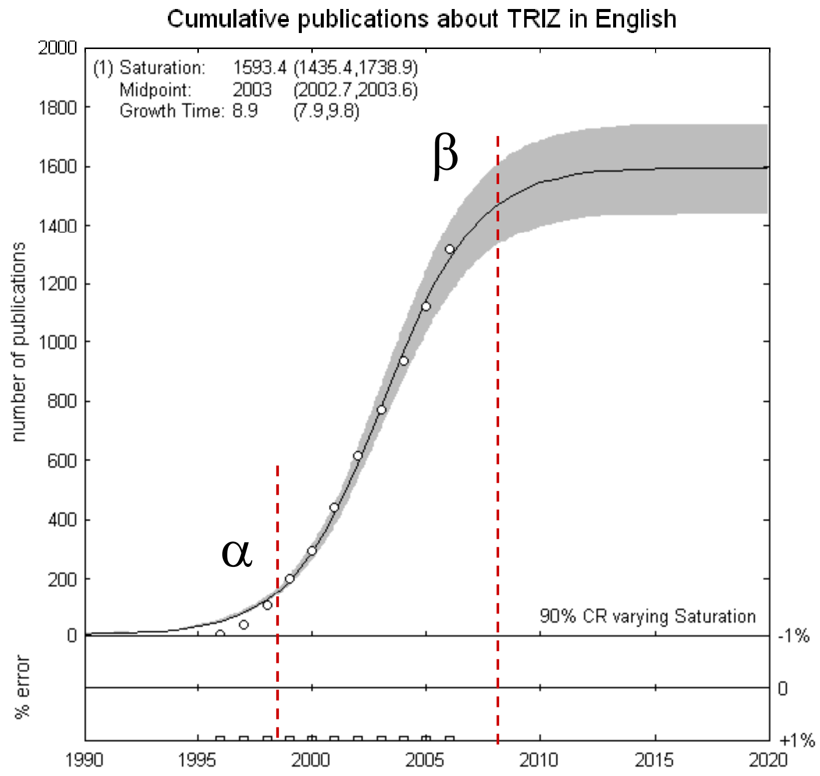
Fisher-Pry transform. Confidence intervals

Fisher-Pry transform

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



Forecast with confidence intervals



* S-curve fit on data by Loglet Lab Version 1.1.4

Technological forecasting

Why does it possess forecasting power?

Logistic S-curve describes evolution of system under limitation of resources through time

Strength:

- Properly established logistic growth reflects the action of a natural law.
- Relatively easy to apply. Clear concept and working mechanism.
- Can be applied for systems where the growth mechanisms are understood and where the mechanisms are hidden.

…and Weakness:

- *What is growing variable (species) and what is underlying competing mechanism in particular case? Lack of formal procedure to define.*
- *Bias towards low or high ceiling: 'no two people, working independently, will ever get EXACTLY the same answer for an S-curve fit'.*
- *Should we fit S-curve to the raw data or to cumulative number? Fitting technique errors and uncertainties.*

Technology substitution model

...the sciences can be seen as a systematic search for invariants...
Marchetti C.

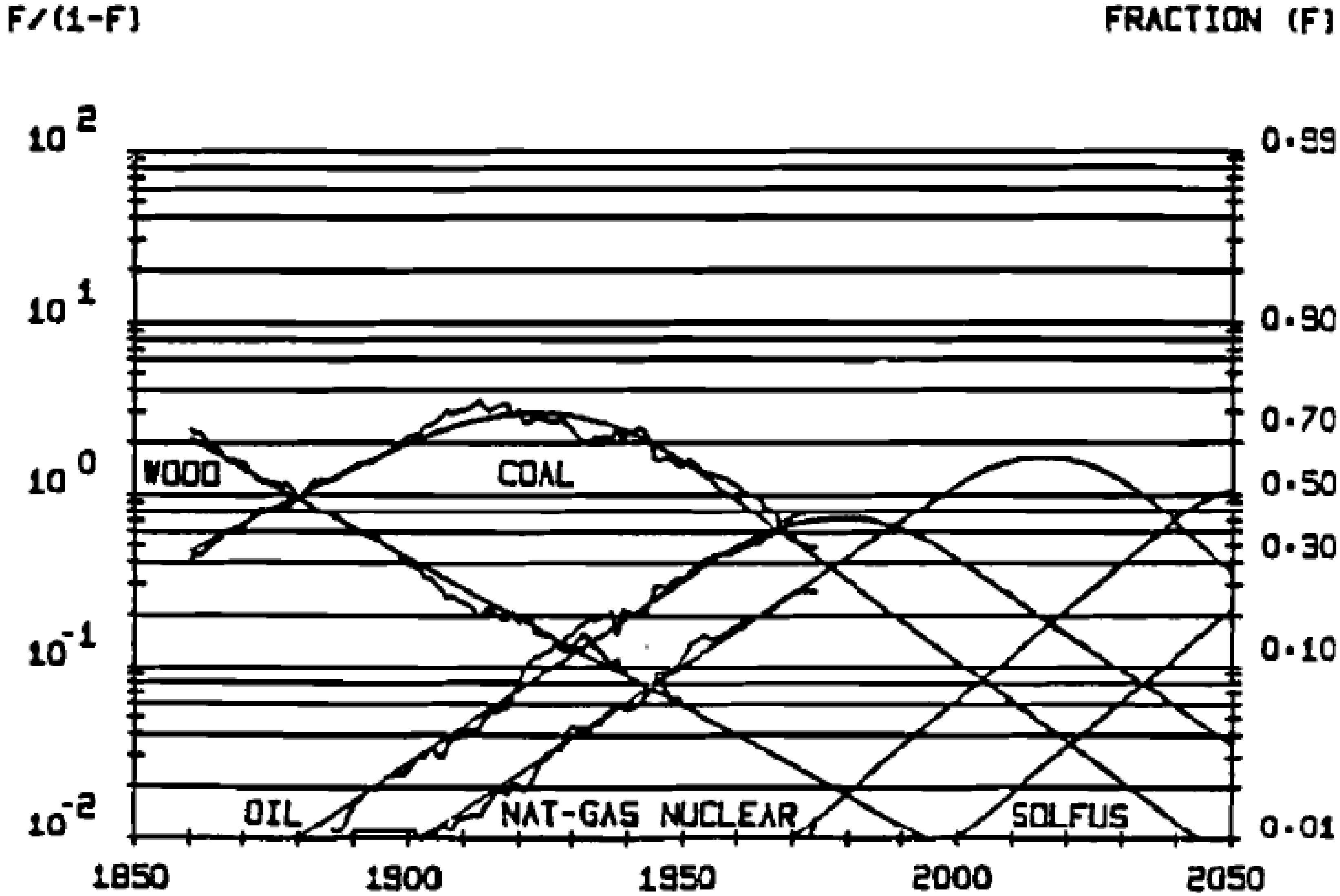
Initial Demand: *"to improve the methodology of medium- and long-range forecasting in the areas of the energy market and energy use."*

The basic hypothesis: *"primary energies, secondary energies, and energy distribution systems are just different technologies competing for a market and should behave accordingly."*

Empirical evidence: "..almost all binary substitution processes, expressed in fractional terms, follow characteristic S-shaped curves…"

Source: Marchetti, C. and Nakicenovic, N. The Dynamics of Energy Systems and the Logistic Substitution Model. p. 73 (IIASA, Laxenburg, Austria, 1979).

World – primary energy substitution (1979)



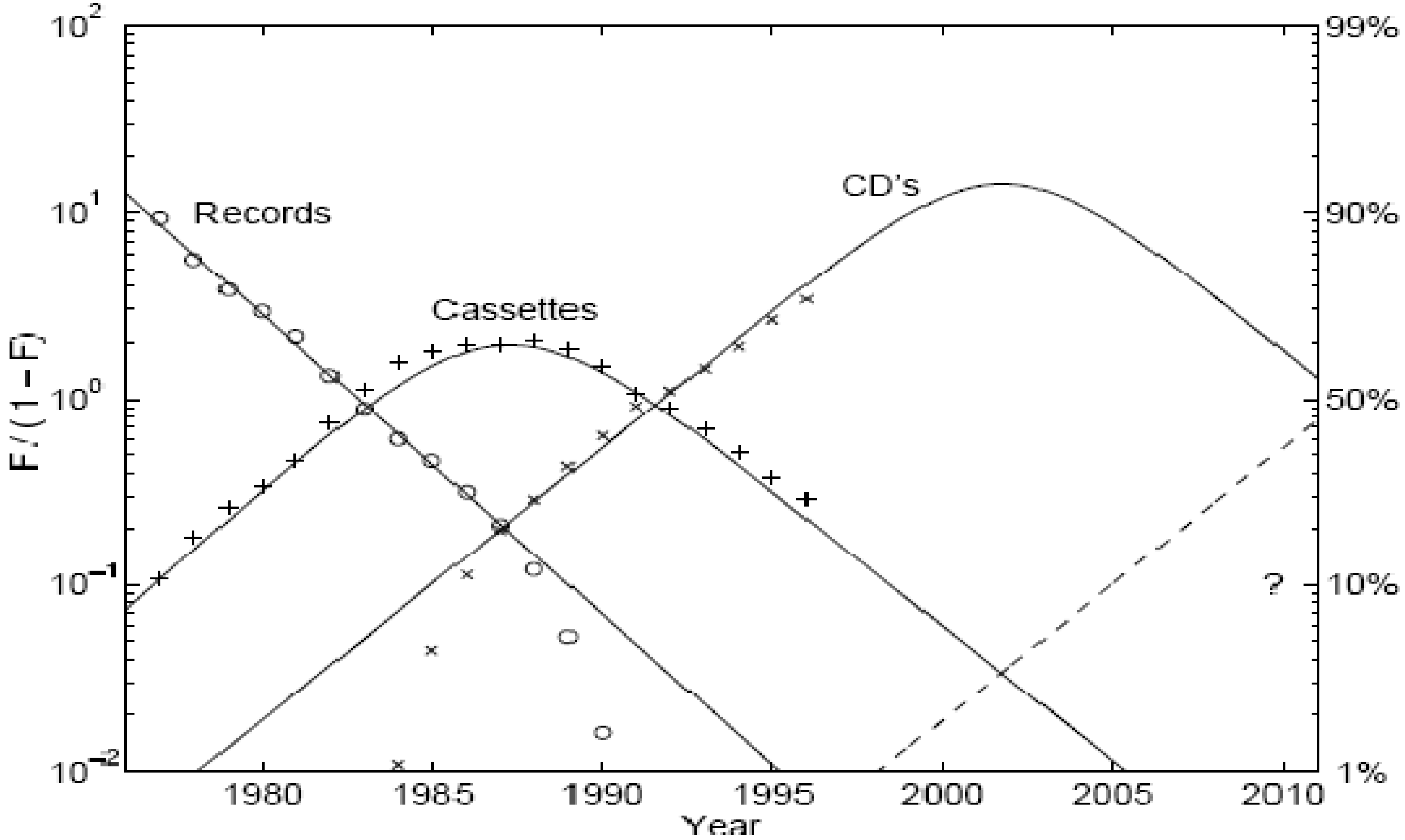
Source: Marchetti, C. and Nakicenovic, N. The Dynamics of Energy Systems and the Logistic Substitution Model. p. 73 (IIASA, Laxenburg, Austria, 1979).

Assumptions for logistic substitution models (LSM)

- only one technology is in the saturation phase at any given time;
- declining technologies fade away steadily at logistic rates uninfluenced by competition from new technologies;
- new technologies enter the market and grow at logistic rates;
- there are n competing technologies ordered chronologically in the sequence of their appearance in the market;

Source: Marchetti, C. and Nakicenovic, N. The Dynamics of Energy Systems and the Logistic Substitution Model. p. 73 (IIASA, Laxenburg, Austria, 1979).

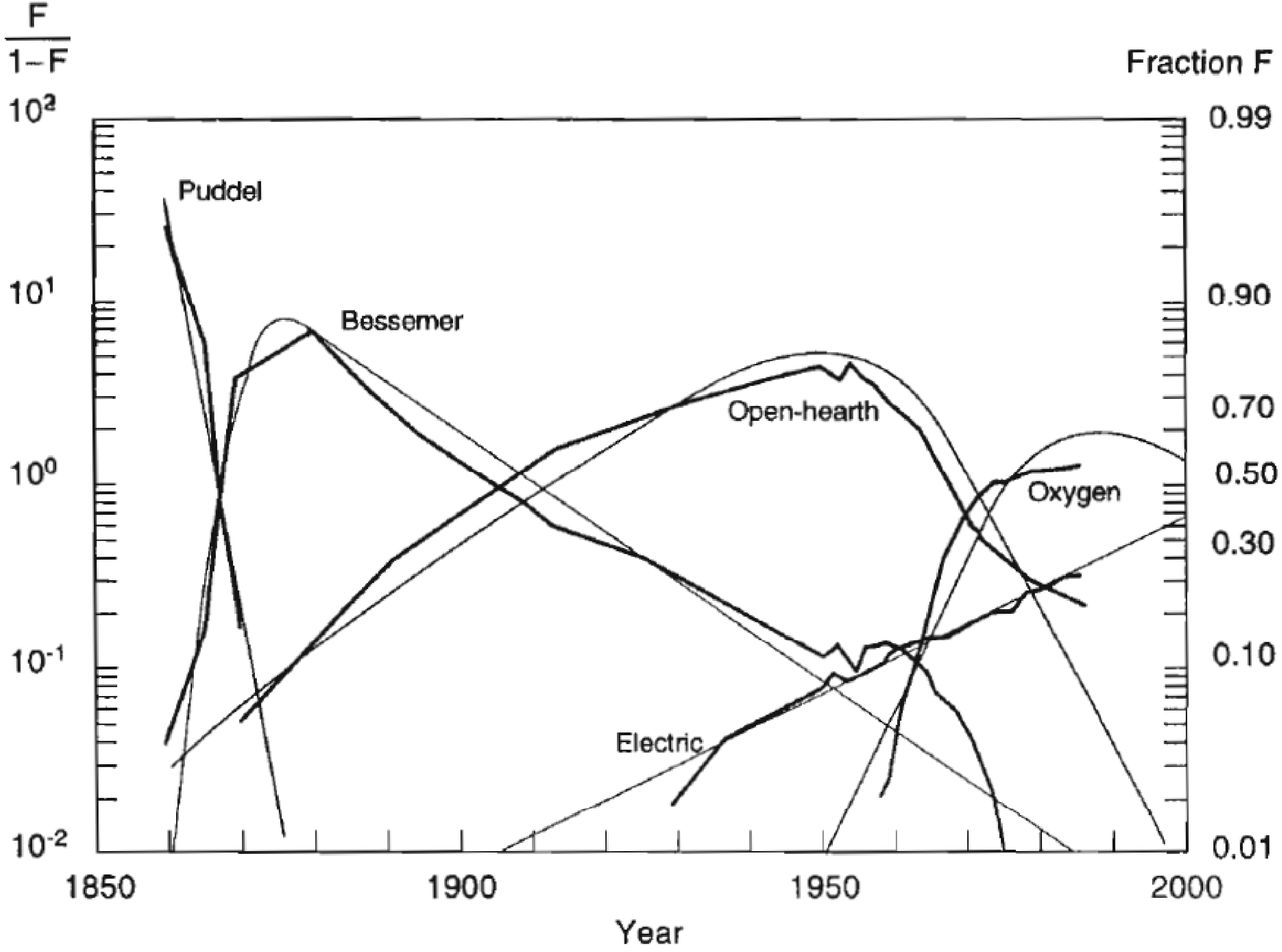
LSM example: US music recording media (1997)



* Source: Meyer, P.S., Yung, J.W. and Ausubel, J.H. A Primer on Logistic Growth and Substitution: The Mathematics of the Loglet Lab Software. Technological Forecasting and Social Change, 1999, 61(3), 247-271.

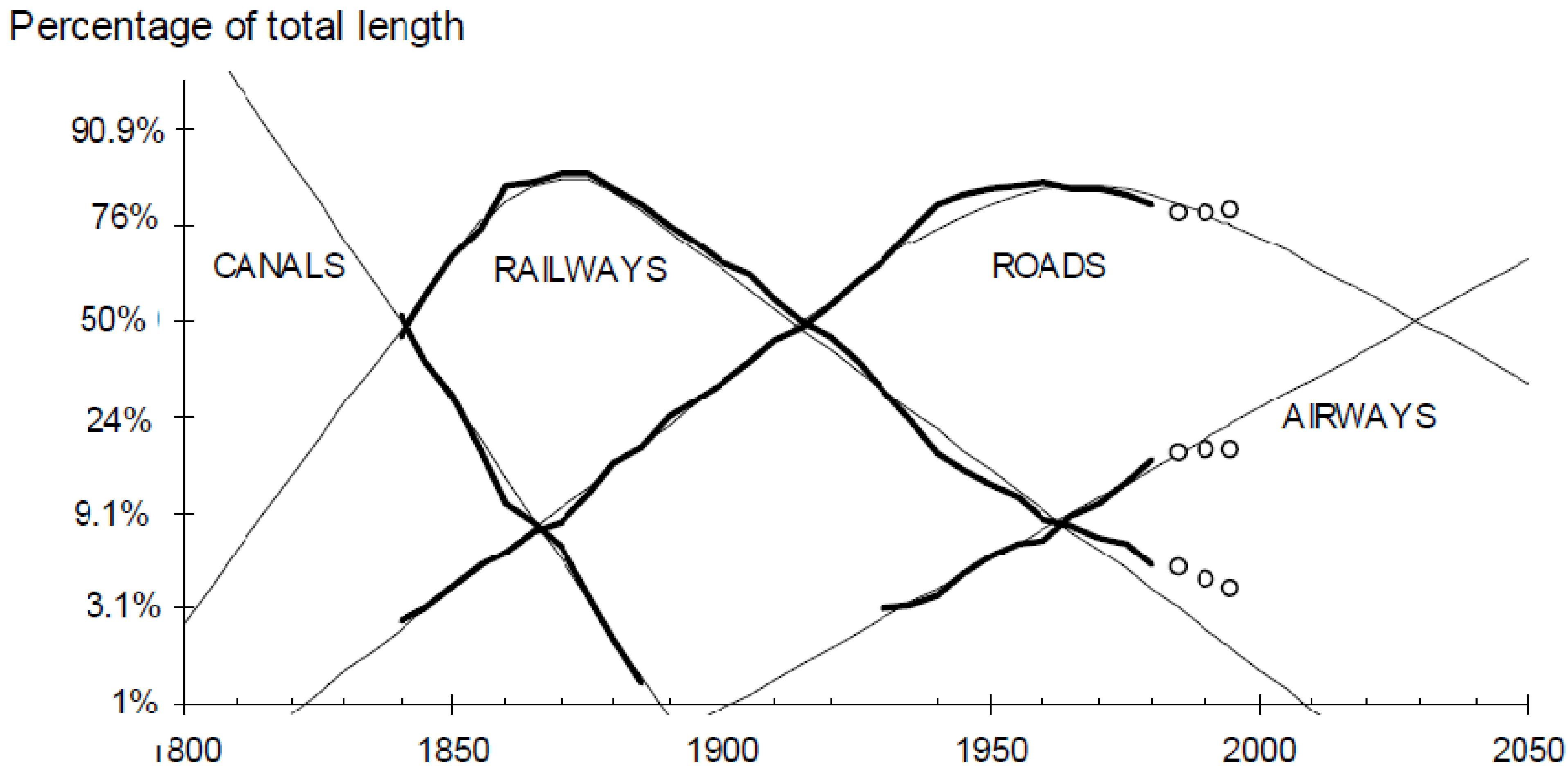
LSM example: substitution of process technologies

[…in global steel manufacturing]



* Source: Grubler, A. Technology and Global Change. (IIASA, Cambridge, 2003), pp.211. ISBN 0 521 54332 0.

LSM example: transport infrastructures in US



* Source: Adapted from a graph by Nebojsa Nakicenovic in "Dynamics and Replacement of U.S. Transport Infrastructures," in J.H. Ausubel and R. Herman, eds, Cities and Their Vital Systems, Infrastructure Past, Present, and Future, (Washington, DC: National Academy Press, 1988).

What are the common features of the three last technology substitution graphs?

Please, discuss and arrange a list of common features.

Place the most important ones high on the list:

1. ____
2. ____
3. ____
4. ____

……………………………………………………………………………….

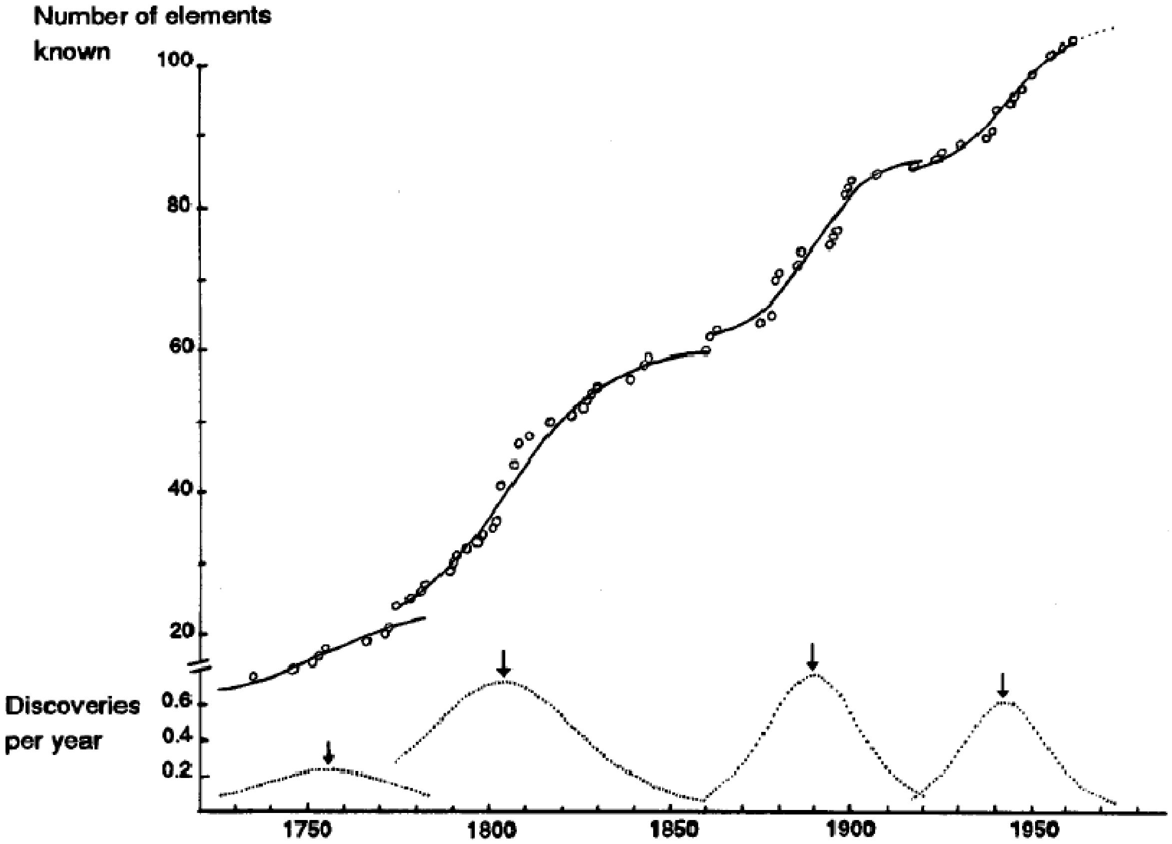
……………………………………………………………………………….

……………………………………………………………………………….

Component logistic model

…growth and diffusion processes consist of several sub-processes…

PROCESS OF DISCOVERY NEW CHEMICAL ELEMENTS (1735-1982)

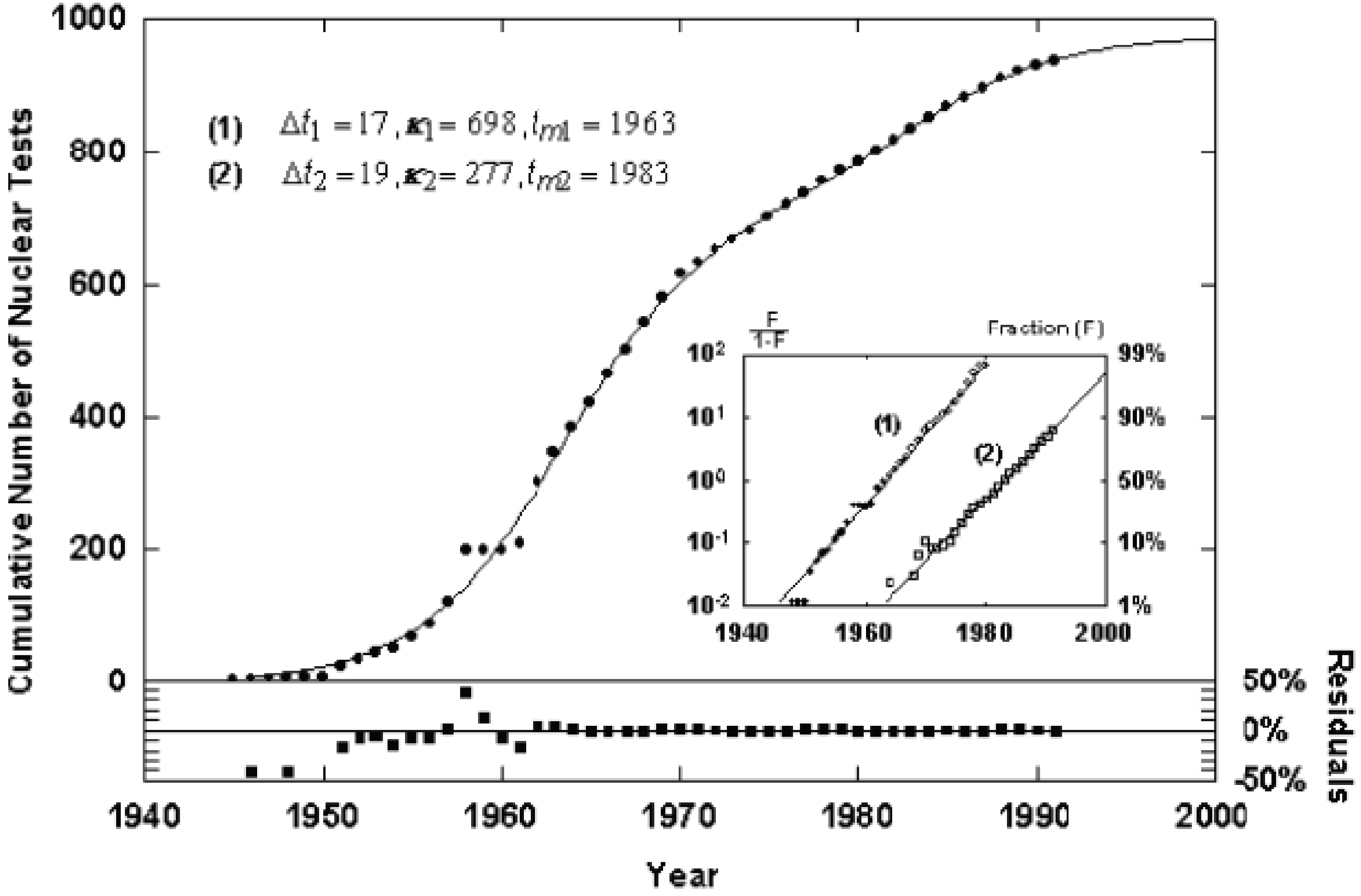


The stable elements were discovered in clusters… (?)

* Source of graph: Modis, T. Predictions - 10 Years Later. (Growth Dynamics, Geneva, Switzerland, 2002), pp. 149. ISBN 2-9700216-1-7.

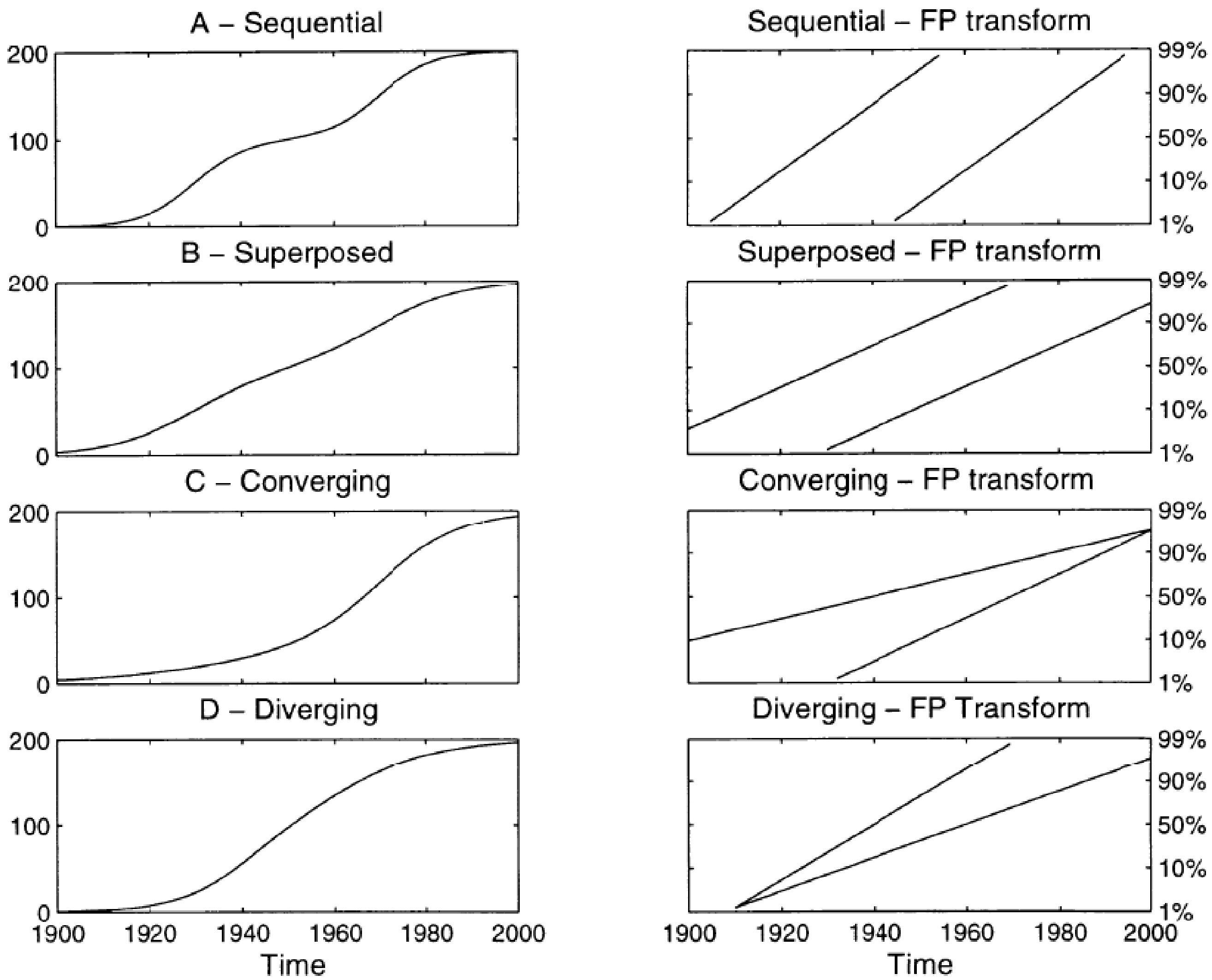
Example: U.S. nuclear weapons tests

[logistic growth pulses]



* Source: Meyer, P.S. Bi-logistic growth Technological Forecasting and Social Change, 1994, 47(1), 89-102.
Data source: Stockholm International Peace Research Institute Yearbook 1992, Oxford University Press, New York, 1992.

taxonomy of bi-logistic processes



* Source: Meyer, P.S., Yung, J.W. and Ausubel, J.H. A Primer on Logistic Growth and Substitution: The Mathematics of the Loglet Lab Software. Technological Forecasting and Social Change, 1999, 61(3), 247-271.

Some rules to fit a logistic curve to the data

1. It is crucial to examine the residuals after a fit .
   - when a fit is "good," the residuals are non-uniformly distributed around the zero axis; that is, they appear to be random in magnitude and sign.
   - a substantial or systematic deviation from the zero axis indicates some phenomenon is not being modeled or fitted correctly.
   - If the residuals are large or systematically distributed, better fits are likely to be attainable, or perhaps the growth is not logistic.
   - "residual analysis could also identify "slices" of data that are especially noise-free and might be more heavily weighted when fitting. "
2. "…it is helpful to treat the data from … "quiet" years, when growth appears to be unfolding without external disturbances such as war or depression…"
3. ".. behavior is often irregular when a market share is less than 5%.."
4. External evidence supports a set value for a particular parameter:
   - the growth of a bacteria culture is limited by the size of the petri dish;
   - because no nuclear tests preceded 1945, leave 0 as the displacement.

* Source: Meyer, P.S., Yung, J.W. and Ausubel, J.H. A Primer on Logistic Growth and Substitution: The Mathematics of the Loglet Lab Software. Technological Forecasting and Social Change, 1999, 61(3), 247-271.

Five steps with an S-curve

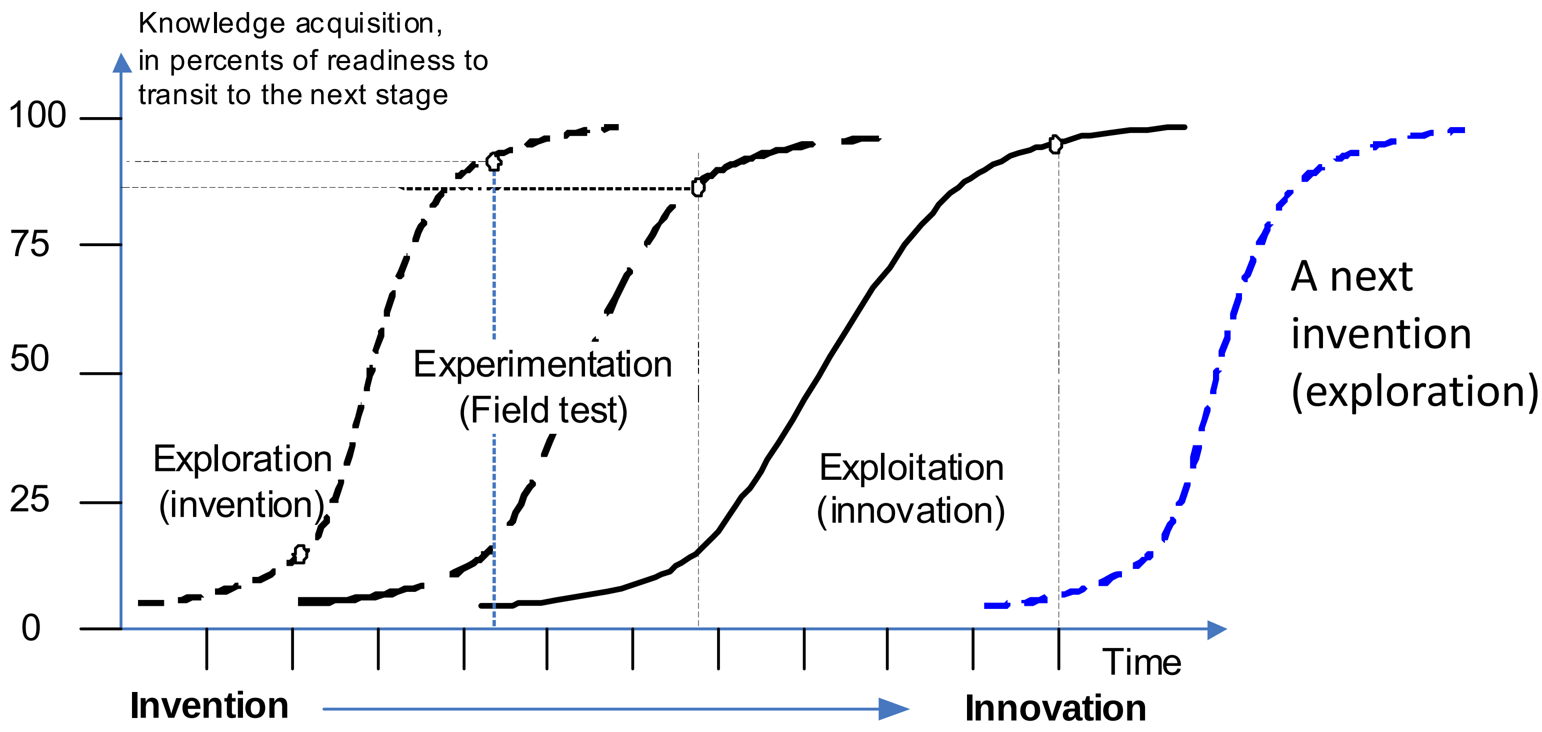
1. To define what is necessary to predict.
2. Define growing variable (parameter).
3. Select data to be applied:
   - to gather data;
   - to refine data;
   - to adapt and arrange data;
4. Fit logistic curve(s) to the data:
   - to determine upper limit (ceiling) for growing variable;
   - fit and bootstrap logistic curve to data (mono-, bi-, multiple-logistics?)
5. To build consistent and reasonable interpretation of obtained curves.

Logistic curve and emerging technologies

How to forecast the *emerging technology* pathway using a simple logistic S-curve?

- before system passes the 'infant mortality' threshold (?)
- before having enough data for growing variable (?)

How to foresee time, place and peculiarity of transition from invention to innovation in advance?



* Source of graph: These ideas have appeared in an informal discussions with Eric Schenk (LGECO/INSA Strasbourg) and Roland De Guio (2006)

“Fractal aspects of Natural Growth” (1994)

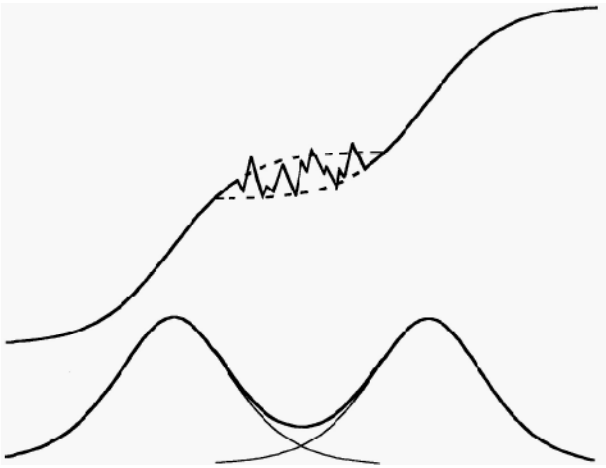


Fig. 1. *A schematic adaptation that connects natural growth and chaoslike states.* [Modis T., Debecker A., 1992]

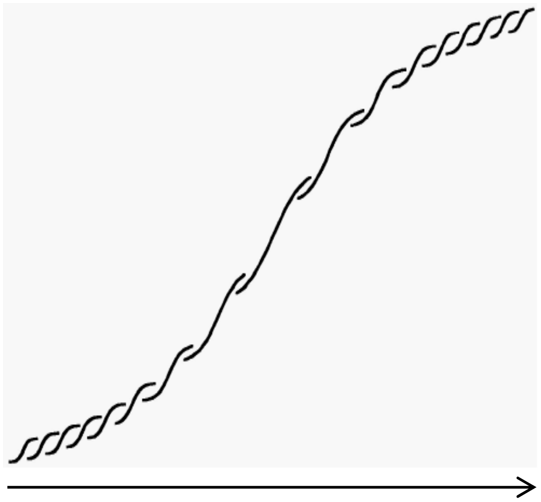


Fig. 2. *An overall logistic pattern is decomposed into constituent logistics.*

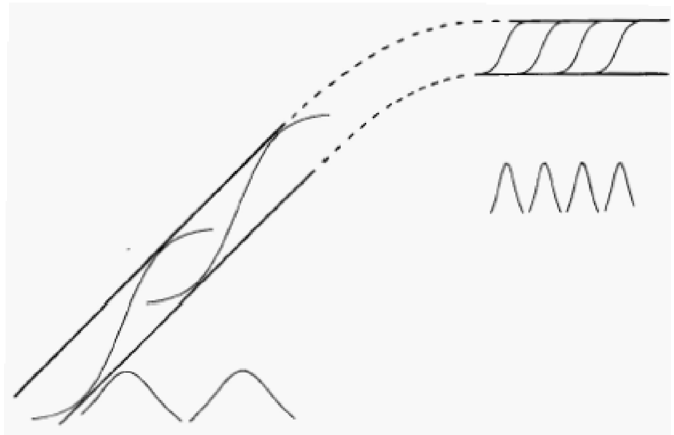


Fig. 3. *An artist’s view of why the end of growth implies shorter life cycles.*

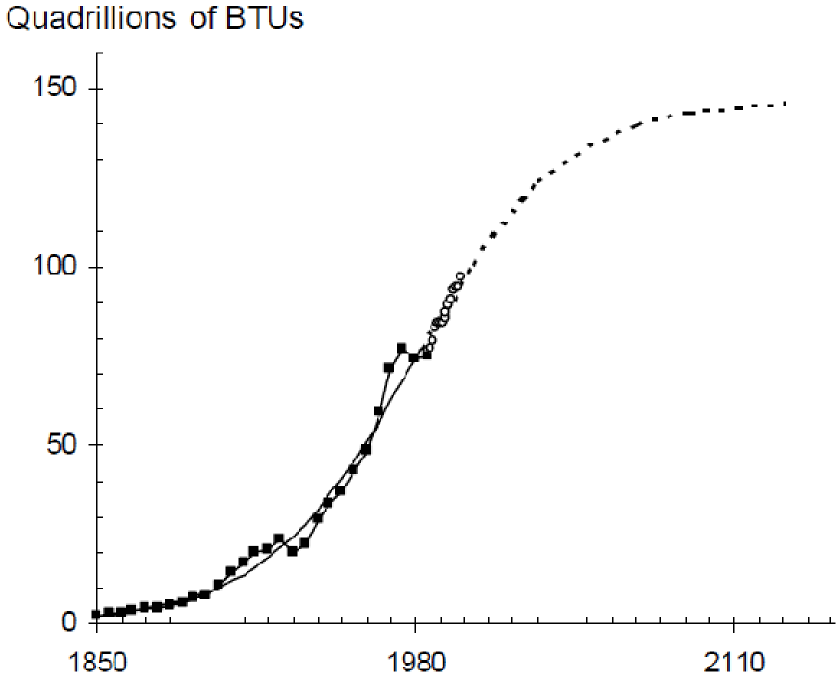
* Source: Modis, T. Fractal aspects of natural growth Technological Forecasting and Social Change, 1994, 47(1), 63-73.

- A cosmic rhythm
- Technology change and cycles
- Waves in technology and economy change

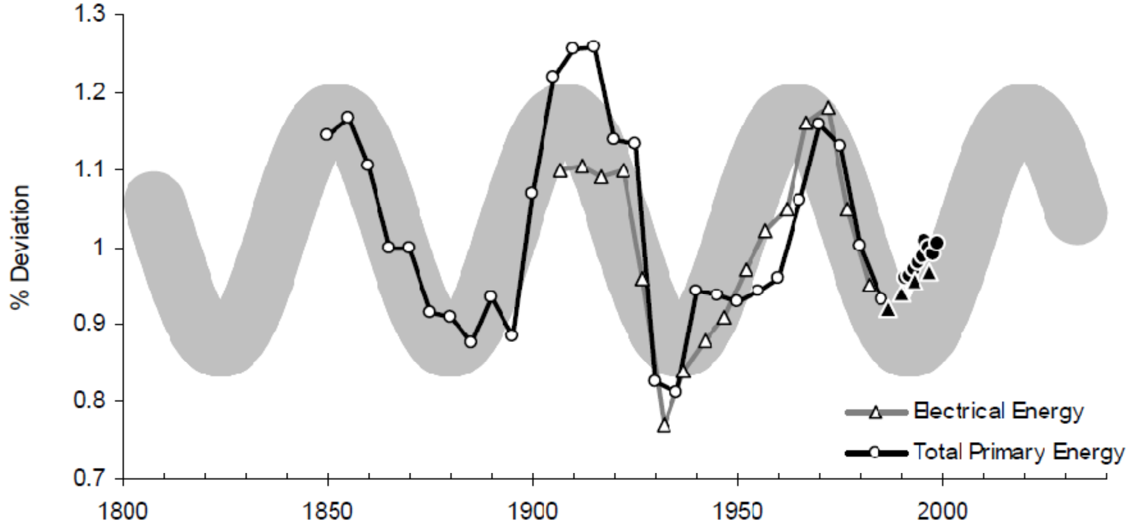
...the system had a schedule, a will, and a clock...

5. WAVES AND CYCLES

Long-run natural growth…



Data and S-curve fit on annual ENERGY CONSUMPTION IN THE UNITED STATES

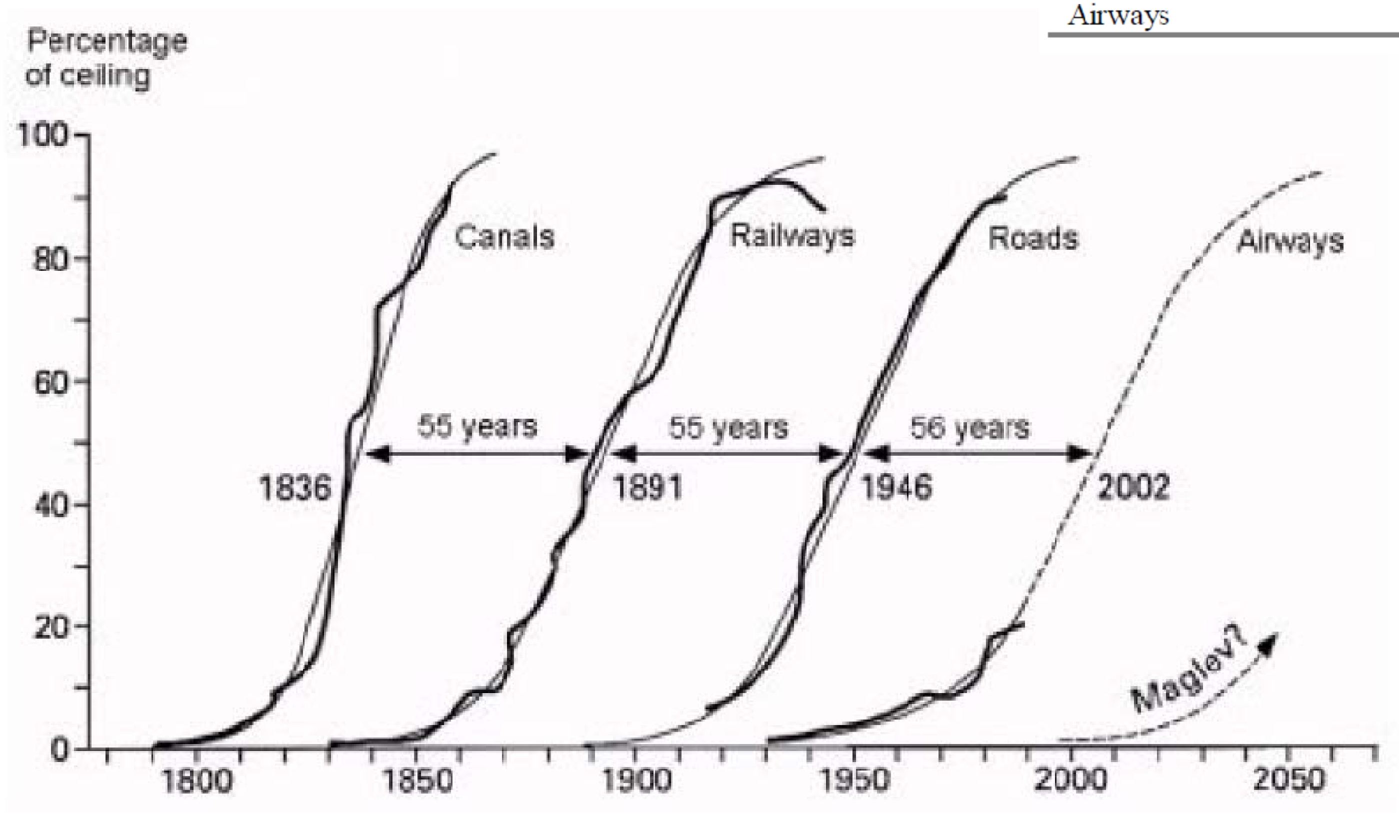


ENERGY CONSUMPTION departed from Natural Growth in a Periodic Way

* Source: Modis, T. Predictions - 10 Years Later. (Growth Dynamics, Geneva, Switzerland, 2002), 335. ISBN 2-9700216-1-7.

Trajectories of transport infrastructures

Infrastructure	*Ceiling (total mileage)*
Canals	4,000 miles
Railways	300,000 miles
Roads	3.4 million miles
Airways	3.2 million miles (estimated)



AN ORDERLY PRECESSION OF U.S. TRANSPORT INFRASTRUCTURES

* Source: Modis, T. Predictions - 10 Years Later. (Growth Dynamics, Geneva, Switzerland, 2002), 335. ISBN 2-9700216-1-7.
*Adapted from a graph by Arnulf Grubler (originally drawn by Nakicenovic) in The Rise and Fall of Transport Infrastructures, (Heidelberg: Physica-Verlag, 1990), excluding the lines labeled “Airways” and “Maglev?”

A cosmic rhythm (some facts)

1608 – *Hans Lippershey* – the first known practically functioning telescope;

1610 – *Galileo Galilei* – started observation and analysis of sunspots;

1843 – *Heinrich Schwabe* noticed the regular variation in the number of sunspots and published his findings in a article entitled "Solar Observations during 1843";

1848 – *Rudolf Wolf* devised the "Zürich sunspot number"; he collected all the available data on sunspot activity back as far as 1610 and calculated a period for the cycle of 11.1 years;

1851 – *Alexander von Humboldt* published 'Schwabe's table' in his encyclopaedic compilation of natural science, "Kosmos."

1922, 1924 – *Alexander Tchijevsky* "Physical factors of the historical process" – it is presented "..the connection between the periodical sunspot activity and 1) behavior of organized human mass and 2) the universal historical process…

1926 – *Nikolai Kondratiev* in work "About the Question of the Major Cycles of the Conjecture" where he proposed a theory that Western capitalist economies have long term (50 to 60 years) cycles of boom followed by depression;

1939 – *Joseph Schumpeter* suggested a model in which the four main cycles, Kondratiev (54 years), Kuznets (18 years), Juglar (9 years) and Kitchin (about 4 years) can be added together to form a composite waveform…

A cosmic rhythm (some facts) #2

1941 - foundation for the Study of Cycles (an international non-profit research organization for the study of cycles of events) incorporated by *Edward R. Dewey*.

1967 – Edward R Dewey. “The Case for Cycles” – more than 500 different phenomena in 36 different areas of knowledge have been found to fluctuate in rhythmic cycles;

. . .

2005 – NATO Advanced Research Workshop: KONDRATIEFF WAVES, WARFARE AND WORLD SECURITY. Covilhã, Portugal 14 - 18 February 2005 (38 presentations)

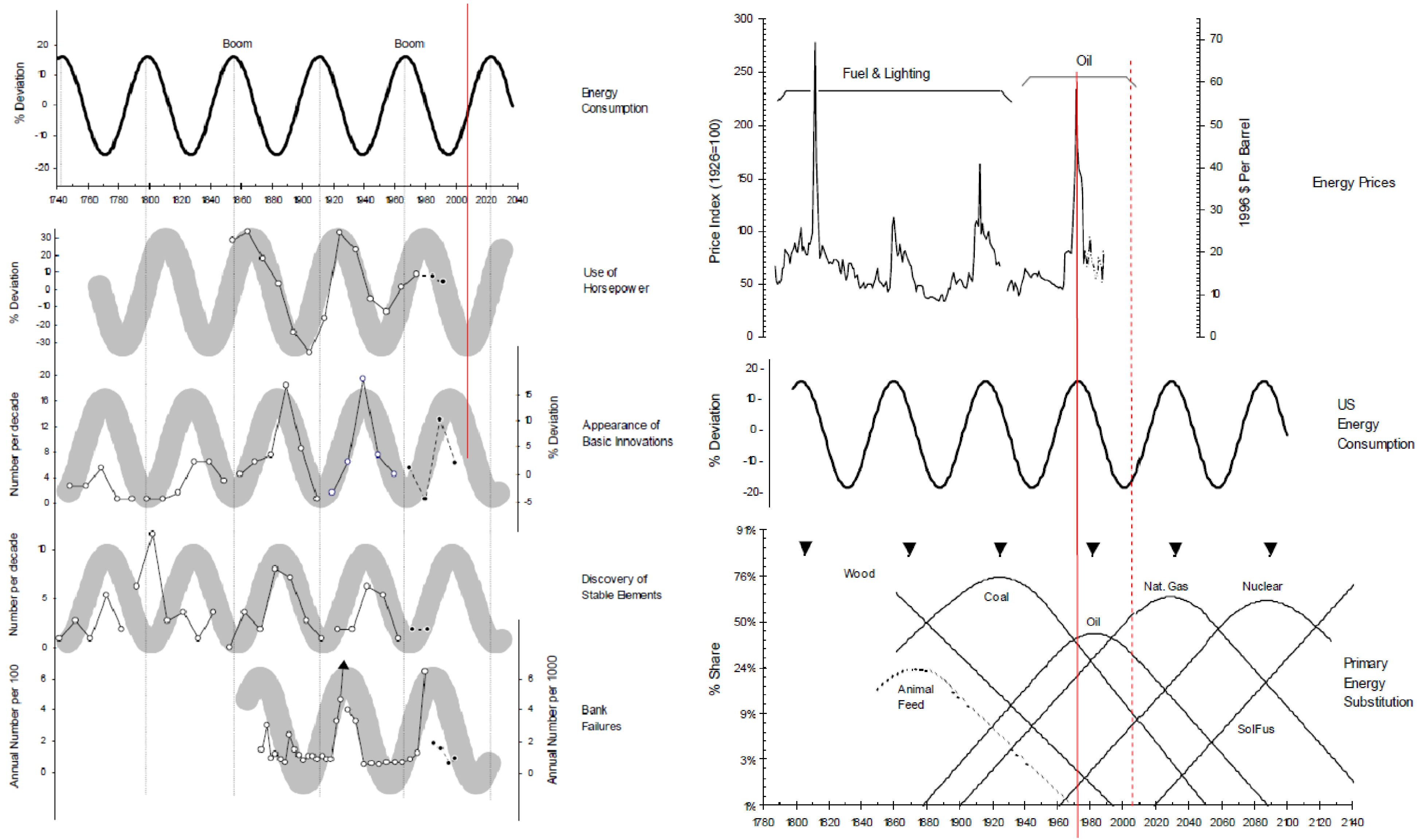
2698 B.C. – the Chinese Emperor *Hoang-Ti* organized the Chinese calendar in a **sixty-year** cycle…

early third millennium BC - *Aubrey Holes* are a ring of **56 pits** at Stonehenge … in his *Stonehenge Decoded*, Hawkins argued that the Aubrey Holes were used to keep track of long time period and could accurately predict the reoccurrence of a lunar eclipse on the same azimuth, that which aligned with the Heel Stone, every **56 years**.

6th century B.C. – the *Maya* calendar: “because the two calendars were based on 260 days and 365 days respectively, the whole cycle would repeat itself every **52** years. This period was known as a Calendar Round…

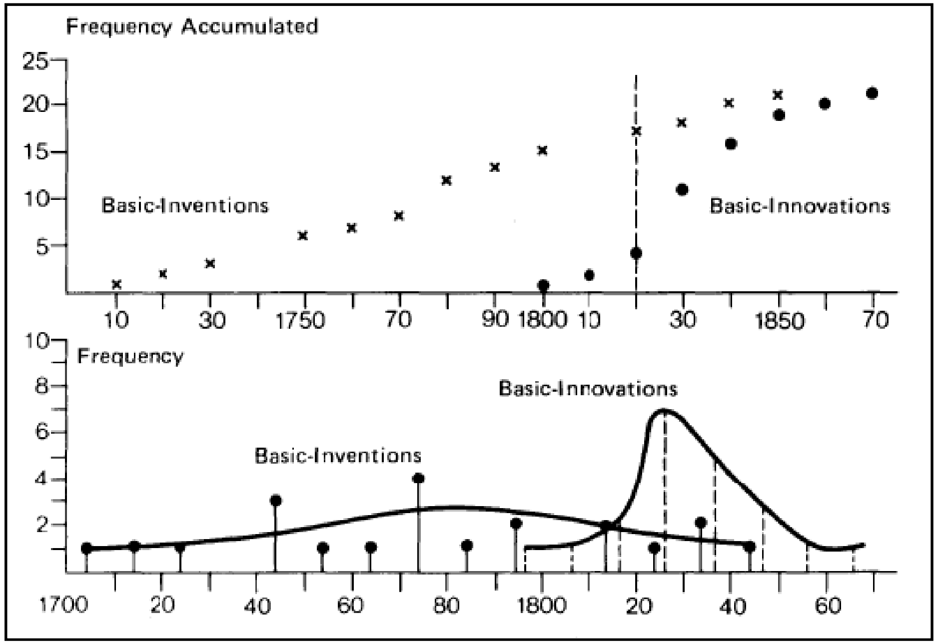
432 B.C. – *Meton of Athens* introduced the 19-year Metonic cycle; it incorporates two less accurate sub-cycles, for which 8 years… and 11years…

echo of the energy consumption cycle

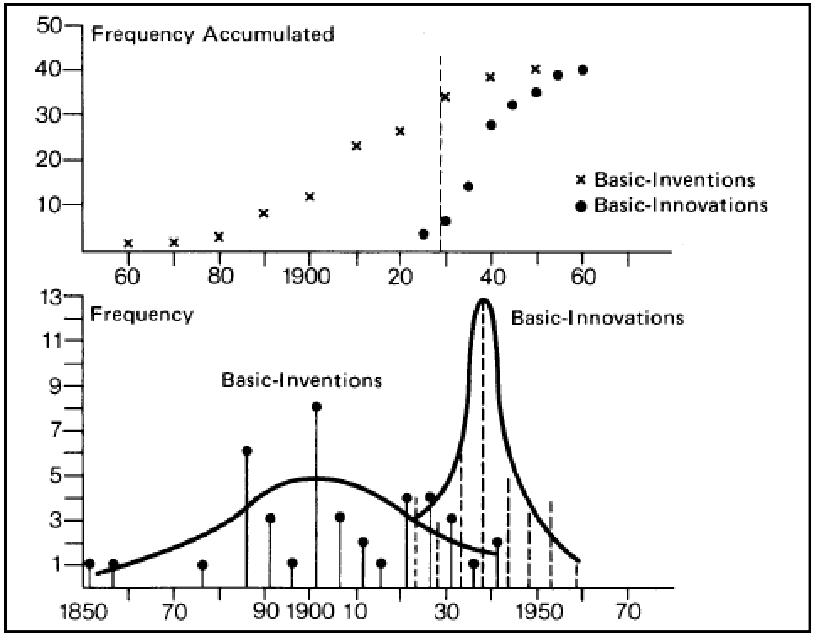


* Source: Modis, T. Predictions - 10 Years Later. (Growth Dynamics, Geneva, Switzerland, 2002), 335. ISBN 2-9700216-1-7.

Frequency of Inventions and Innovations



Basic-Inventions and Basic-Innovations.
First Half on Nineteenth Century

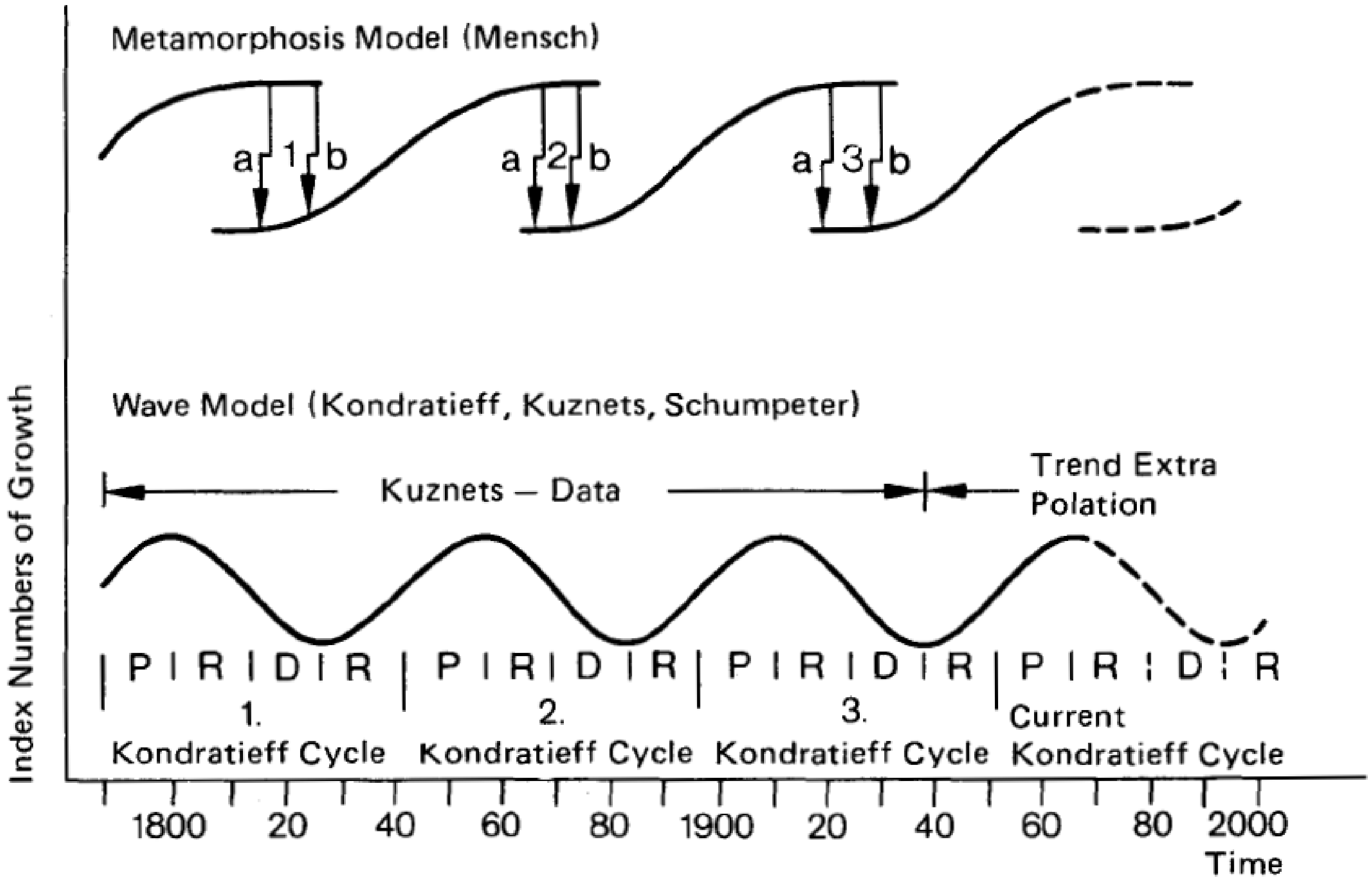


Basic-Inventions and Basic-Innovations.
First Half on Twentieth Century

* Source: Mensch, G. Stalemate in Technology: Innovations Overcome the Depression (Ballinger Pub Co, Cambridge, Massachusetts, **1978**), 241. ISBN 088410611X.

The Metamorphosis Model of Industrial evolution*

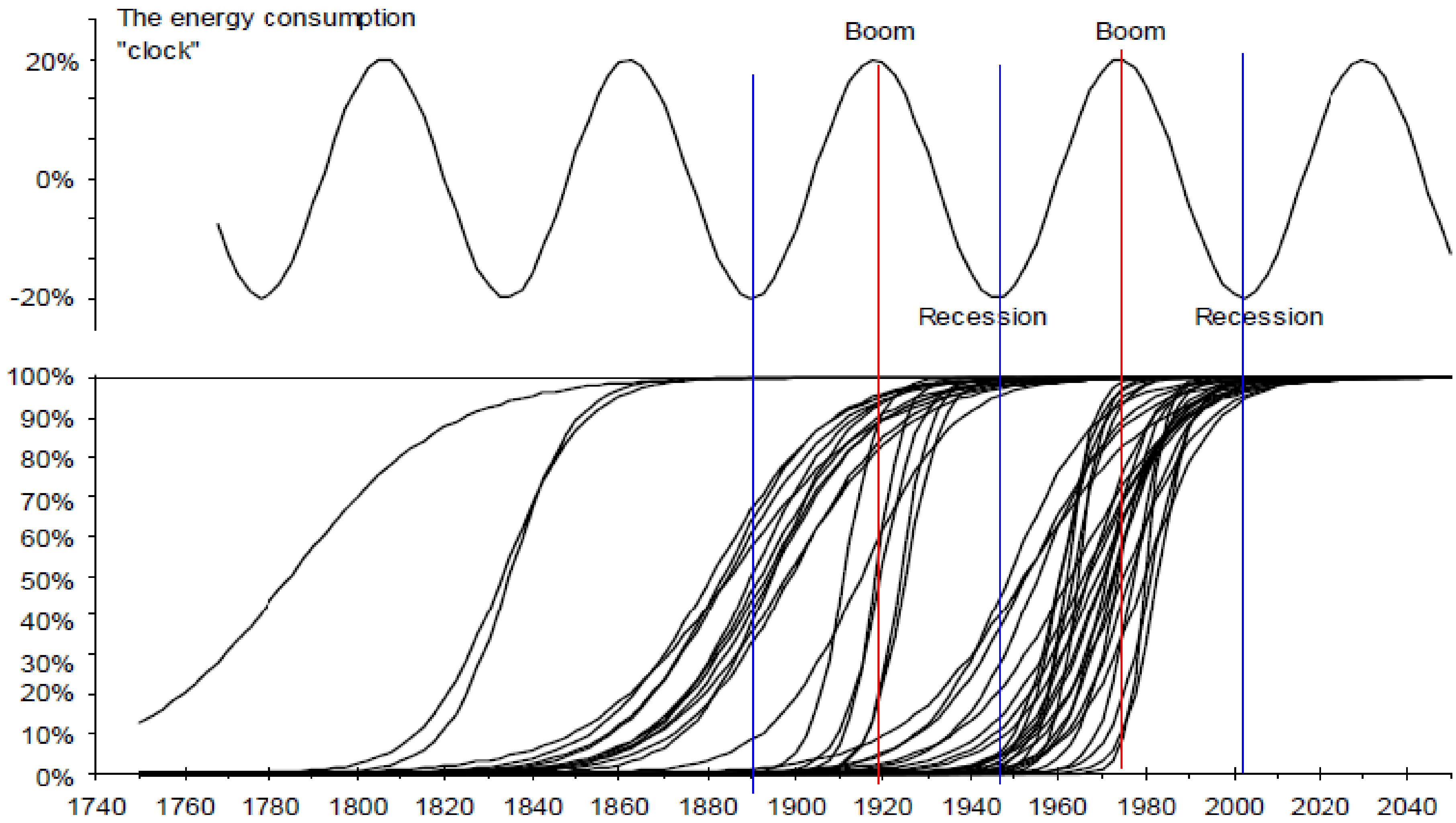
...Innovations carry the Kondratieff...
A.Schumpeter



[P] – prosperity; [R] – recession; [D] – depression; [R] - recovery

* Source: Mensch, G. Stalemate in Technology: Innovations Overcome the Depression (Ballinger Pub Co, Cambridge, Massachusetts, **1978**), 241. ISBN 088410611X.

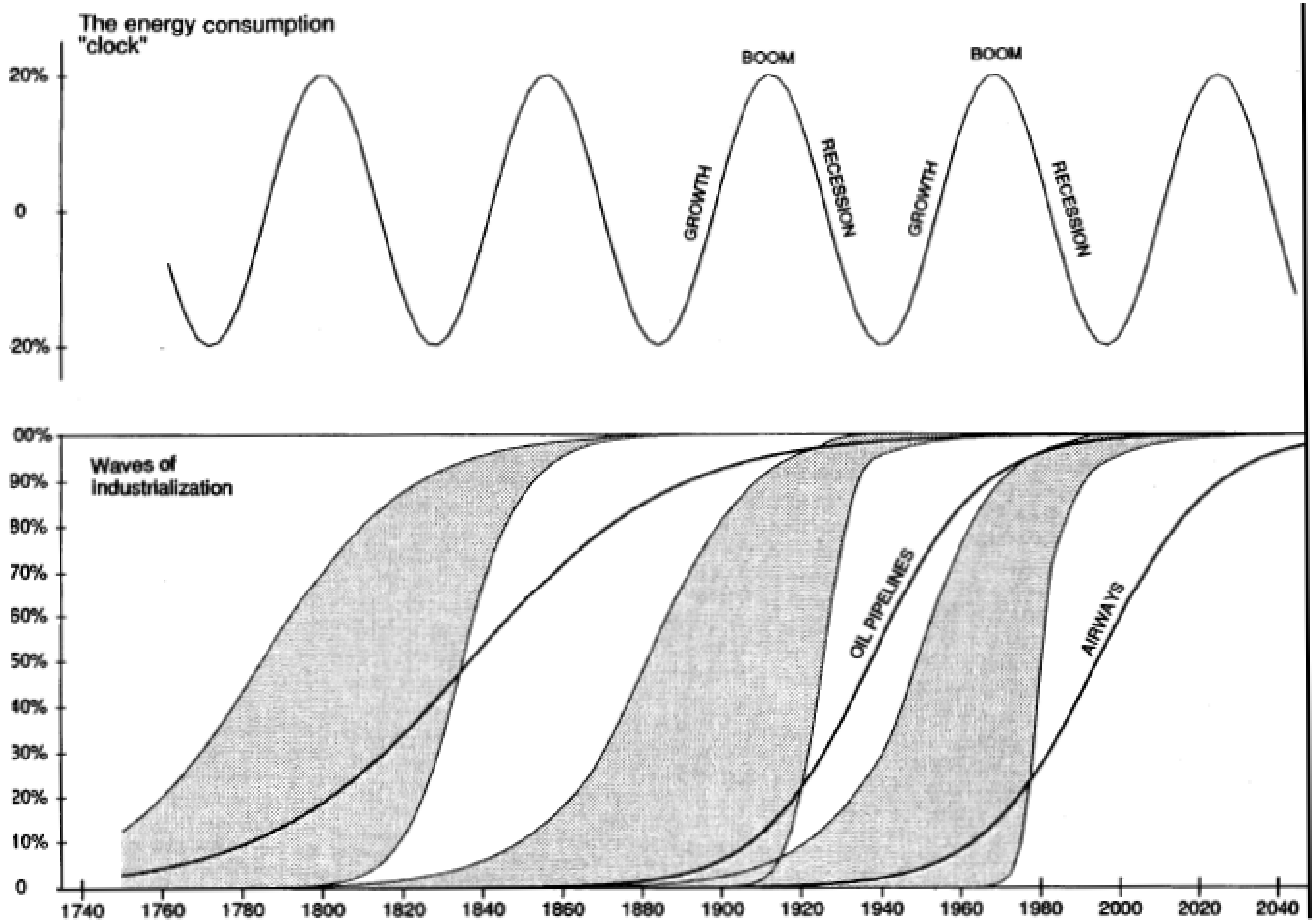
The long-run of a technology change



When many technological processes reach saturation together they produce a recession

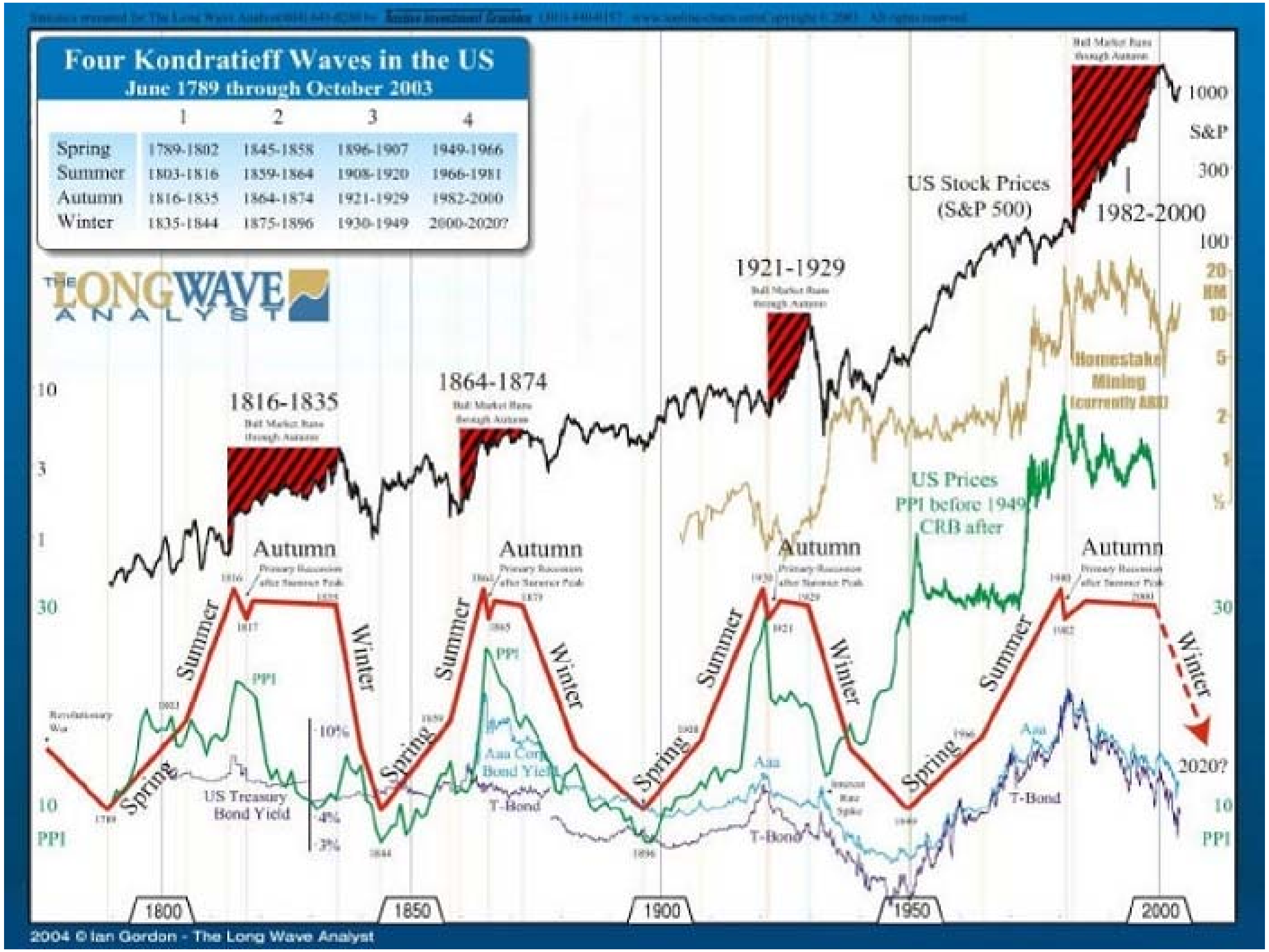
* Source: Modis, T. Predictions - 10 Years Later. (Growth Dynamics, Geneva, Switzerland, 2002), 335. ISBN 2-9700216-1-7.

Technologies tunnel through the economic recession



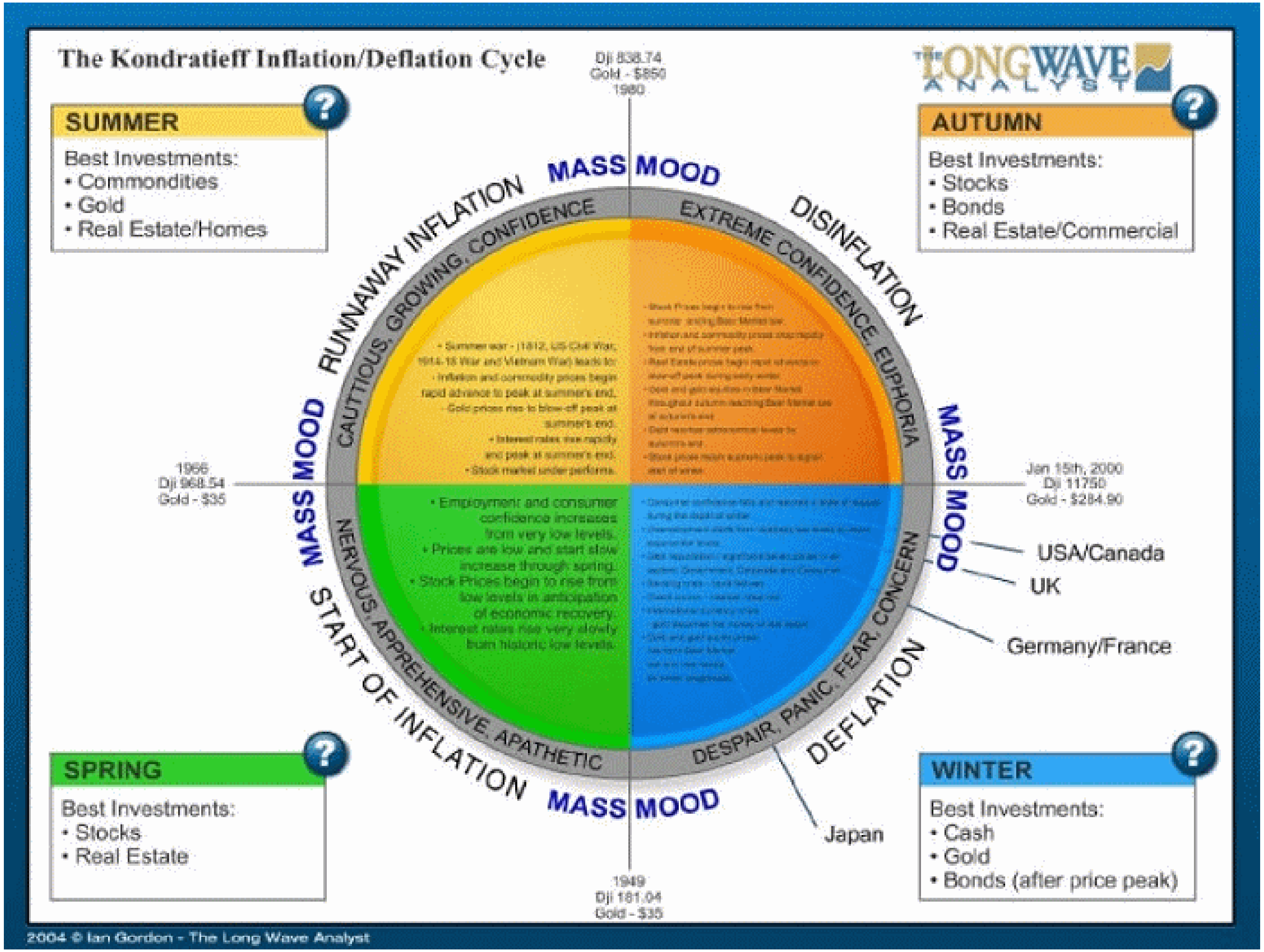
* Source: Modis, T. Predictions - 10 Years Later. (Growth Dynamics, Geneva, Switzerland, 2002), 335. ISBN 2-9700216-1-7.

Kondratieff cycles and US economy



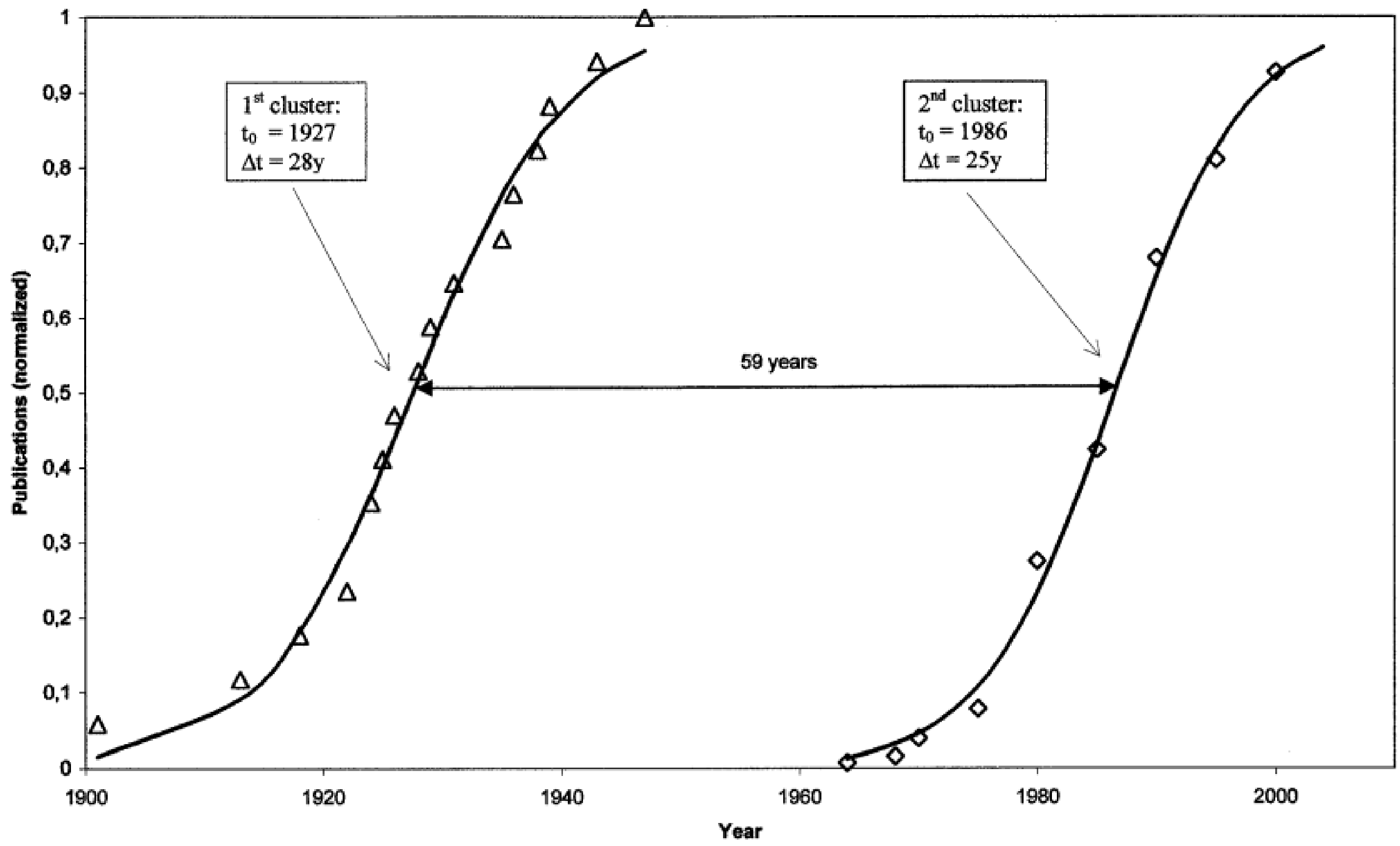
* Source: http://www.thelongwaveanalyst.ca/cycle.html

Kondratieff Inflation/Deflation cycle



* Source: http://www.thelongwaveanalyst.ca/presentation.html

Clustered publications on long-waves



"The points for the first cluster correspond to all 17 works published between 1901 and 1947. The count for the second cluster was made cumulatively in 5-year intervals from 1970 onward."

* Source: Devezas, T.C. and Corredine, J.T. The biological determinants of long-wave behavior in socioeconomic growth and development. Technological Forecasting and Social Change, 2001, 68(1), 1-57.

- How to measure the results?
- Obstacles for forecasting
- Contradictions of forecasting

A problem well stated is a problem half-solved.
attributed to Charles Kettering

6. PROBLEMS OF FORECASTING

We fail more often because we solve the wrong problem than because we get the wrong solution to the right problem.

Russell Ackoff

Professor Emeritus Wharton School,
University of Pennsylvania,
(Author of Redesigning Society)

how to measure the result?

...How to distinguish the difference between valid and invalid forecasts?...

$$\text{Efficiency of Technological Forecast} = \frac{\text{Reliable Forecast}}{\text{Aggregated Expenses}}$$

Where,

Reliable forecast is characterized by the *accuracy* of the forecast and *transparency* of the forecasting process.

Aggregated expenses include *resources* spent on the development and *communication* of the forecast results.

Starting statements

1. Despite many existing methods, middle 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.
2. Most applied methods used to satisfy the needs of a long-term technology forecast are modifications of Delphi surveys and scenarios building.
3. Knowledge from the Theory of Inventive Problem Solving (TRIZ) and its posterior generations may contribute to the accuracy of the technology forecasting.
4. Complex forecasting methods do not necessarily provide a more accurate forecast than simple ones.
   Simple methods are less affected by data inaccuracy than complex ones and expenses to implement simple methods are lower.
5. The choice of a forecast method frequently depends on data. Formal methods are reproducible, however they do not work well with qualitative parameters.
6. The efficiency of the existing forecasting methods depends upon a forecasting horizon.
7. The efficiency of forecasting depends not only on the methods applied but also the management of the whole forecasting process.

* Source: Kucharavy, D. and De Guio, R. Problems of Forecast. ETRIA TRIZ Future 2005, pp. 219-235Graz, Austria, 2005).

ENV-model of Forecasting and Forecast

FORECASTING PROCESS

– High degree of reliability
– Repeatability
– Cost effective in practice
  - profitability (computer, human resources, etc.);
  - time efficient.
– Flexibility in application and adaptability
– Easy in using available data
– Transparency for all participants of forecasting
– Operability
  - easy-to-implement;
  - easy-to-use;
  - sensitivity for input data;
  - easy-to-develop or universality (e.g. using extensions without changing the main procedure);
  - stable in time.

FORECAST (result)

– Accuracy is better than simple guessing
– High degree of credibility & certainty
– Visionary capacity for effective decisions
– Ease of interpretation & readability
– Adequate resolution, confidence & validity
– Ease to update.
– Describes a technology change at requested timeframe:
  - Emergence; Performance;
  - Features; Impacts;
– Consists of: emerging technology characteristics, pathways of development; potential impacts on social, economic and environmental contexts.
– Explains interactions between: events, trends, and actions.
– Bias-free. Does not include personal biases, personal and organizational agendas of the experts.
– Provide perspectives on trends, gaps, and critical factors for achieving pathways that will enable some contribution to the future (e.g. electricity enterprise)
– Lay out plausible pathways and scenarios of the industry's vision for the future technology of end-use vision…

* Element-Name of Feature-Value of Feature (ENV-model). See. Khomenko N. (2001) for details.

Forecasting and major obstacles

Formulate Problem	→ Preconceived limitations, biases, and personal and organizational agendas of the experts
Gather Information	→ Noise and Signal Problem
Select Methods	→ Limited knowledge
Perform Forecast	→ Social, Economic, and Environmental contexts; completeness of system to foresee;
Validate Results	→ Learning and interpretation capacity limitations of human being
Apply Forecast	→ Rational vs. Intuition

Difficulties and Problems of forecasting

- **Gather information & data**:
  How to select information and knowledge from myriad inputs?
  Noise and Signal Problem.

- **Identify Key Applications & Key Technologies**:
  How to detect future application and non-existent needs?
  Social, Economic, and Environmental contexts foresee.

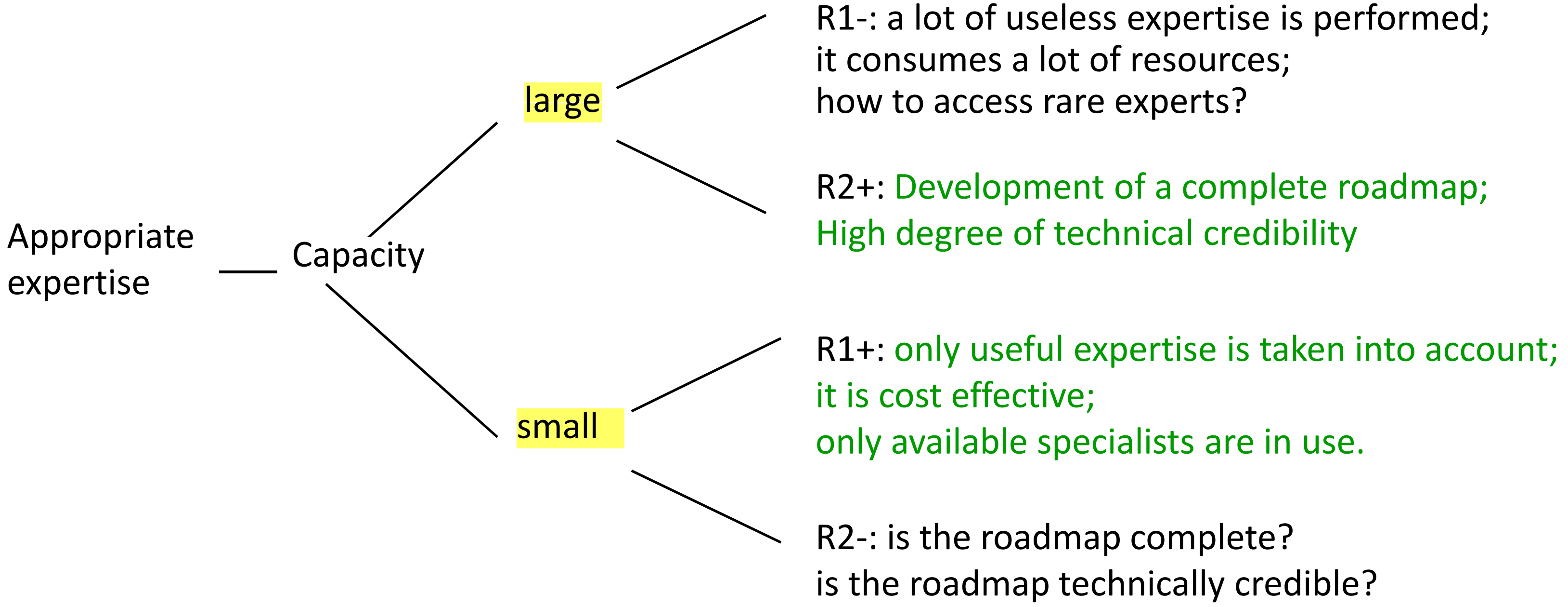
- **Determine drivers & technical barriers**:
  How to assess pros and cons of emerging technologies before experience them?
  Preconceived limitations, biases, and personal and organizational agendas of the experts.

- **Describe results in shape of S&TRM**:
  How to select the final roadmap elements from a multitude of inputs?
  Learning and interpretation capacity limitations of human being.

* Source: Kucharavy, D. and De Guio, R. Problems of Forecast. ETRIA TRIZ Future 2005, Graz, Austria, 2005

Selected problem #1

Known from practice:
The appropriate expertise must be employed to develop a roadmap, but the appropriate expertise becomes fully known only after a complete roadmap has been constructed.



Selected problem #2

How to perform a forecast without experts' biases?

Biases-free Assessment of Technology barriers

- Technology barriers — Assessment
  - full-of-biases (unrealistic)
    - R1-: it is very limited time for development an adequate technology in response to new demands
    - R2+: known (easy-to-apply) methods for assessment can be applied (e.g. interview of experts etc.)
  - biases-free (realistic)
    - R1+: it is enough time for development an adequate technology in response to new demands
    - R2-: new methods for assessment of technology barriers should be developed and applied

Selected problem #3

How to perform a forecast without experts' biases? Biases-free Assessment of Technology barriers.

A typical solution: Instead of qualitative intuitive methods to apply quantitative formal ones.

Methods to assess technology barriers — Analysis

- qualitative
  - R1-: Each team produce a new results;
    High cost;
    Low frequency to update;
    Results consist a lot of biases.
  - R2+: Compatible with "law of transformation quantity to quality" (?)
    Can be applied for long-term forecast.
- quantitative
  - R1+: Repeatable result;
    Cost effective;
    High frequency to update;
    Less biases and more objectivity.
  - R2-: Incompatible with "law of transformation quantity to quality (?);
    Applicable for short-term forecast only.

Example of a contradiction

If a forecasting method applies **qualitative** analysis, then it can be applied for long-term forecast due to compatibility with law (of dialectic) of transformation quantity to quality; however, it is difficult to achieve repeatable results from experts, it costs a lot, it takes a lot of time (low frequency to update results), the results contains a lot of biases.

If forecasting method applies **quantitative** analysis, then the results can be obtained a reproducible way, the process is cost effective, it is possible to update result frequently, the results consist less biases; however, it is not compatible with law of transformation 'quantity to quality', consequently it is mostly applied for short-term forecast.

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

So What?

…Everything has been said before, but since nobody listens we have to keep going back and beginning all over again…

a French author (1869-1951) and winner of the Nobel Prize in Literature in 1947

- Systems evolve in accordance with law of nature… in competition with limit of resources…
- These laws can be revealed from accumulated knowledge about systems evolution…
- These laws should be represented computable way… in order to apply them reproducible mode…
- The scientific method seeks to explain the events of nature in a reproducible mode, and to use these reproductions **to make useful predictions**…

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

Theodor Modis

Physicist, futurist, strategic analyst, and international consultant.

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Science penetrates into the big block of ignorance as a root of a tree in the soil, branching and branching again, but leaving large part of the soil unexplored.

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