Technology foresight: types and methods

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Abstract: This paper posits nine dimensions to distinguish the types of foresight studies. It arrays a rich repertoire of 13 families of foresight methods. It then suggests considerations in deciding which of those methods suit the various types of foresight endeavours. There is no one way to conduct effective foresight studies.

Keywords: foresight type; S&T policy; methodology.

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1 Introduction

'Technology Foresight' conveys multiple meanings. Even more importantly, those different meanings encompass a variety of different objectives. Meeting those different objectives requires a variety of methods. This paper strives to lay out the key dimensions on which technology foresight activities differ and to suggest how those imply different ways to perform the requisite analyses.

Two of us have just finished a chapter on foresight in the USA (Porter and Ashton, 2008). That exercise brings to the forefront the range of interpretations of 'foresight'. For some, technology foresight means national level, participative planning endeavours with important emphases on Science and Technology ('S&T') elements. Not so in the USA. The USA distinctly avoids centralised national S&T planning. But that does not mean that Americans do not perform analyses closely related to foresight. Selected American variants suggest the variety of 'technology foresight' forms conceivable:

- Identification of national 'critical technologies'

  [A series of such exercises conducted through the 1990s; for more information, see Wagner and Popper, 2003]

- Comprehensive, future-oriented technology assessment performed by the now defunct US Office of Technology Assessment

  [Two examples: Arms Control in Space; Life-Sustaining Technologies and the Elderly; to access OTA's some 500 publications, visit www.wws.princeton.edu/~ota/

- National Academies studies with significant technology components

  [Two examples from their recent best sellers list: *How Students Learn: History, Mathematics, and Science in the Classroom; Dietary Reference Intakes for Water, Potassium, Sodium, Chloride*, and Sulphate – see www.nationalacademies.org/]

- Agency level studies

  [E.g., the Environmental Protection Agency's (EPA) 1995 report: *Beyond the Horizon: Using Foresight to Protect the Environmental Future*; and the Department of Energy (DOE), Office of Industrial Technologies' eight 'industry of the future' roadmaps out to 2020].

Briefly reflecting on these four types, note how their purposes differ. The critical technologies lists were intended to help orient US R&D investment towards areas of economic importance. This functioned to a degree, but mainly via general awareness, not explicit mandate setting. The OTA studies primarily served to inform Congressional interests as they considered legislative policy options. One reason given for ceasing to fund OTA was that the studies did not fit well with the pacing of legislative activities (they took too long to prepare). OTA studies were public and they did serve to generally inform all interested parties as quite unbiased, carefully reviewed précis that addressed the state-of-the-art and future prospects. Agency level exercises vary widely in their purposes. The EPA example sought to identify future environmental stressors to orient their R&D prioritisation. The DOE effort involved joint government-industry goal-setting and program planning for their R&D activities.

This paper looks at foresight types in conjunction with methods. Which methods best serve different technology foresight endeavours? This prompts us to consider alternative analytical forms of Future-oriented Technology Analyses (FTA), of which technology foresight is a subset as well:

- technology intelligence
- technology forecasting
- technology roadmapping
- technology assessment.

This list could be extended, with many variations. In preparing for the EU-US "Future-oriented Technology Analyses" (FTA) symposium of 2004, two overviews of the methodological arena considered these forms, together with 'Technology Foresight' (Coates et al., 2001; Porter et al., 2004). They found both important commonalities and differences. In reflecting on foresight, we need to avoid a singular perspective.

2 Foresight types

Here are important dimensions that differentiate foresight forms, with implications for their conduct. These build on a presentation in Peru (Porter, 2005). I see these as nine dimensions that help categorise a given foresight activity (Table 1).

Table 1 Technology foresight typology

Issues	*Dimension*	*State values*			
Content	Motivation	Extrapolative	Normative		
	Drivers	Science (Research)	Technology (Development)	Innovation	Context
	Scope	Single topic or technology	Multiple technologies	Wide-ranging planning	
	Locus	Institution	Sector	Nation/Region	Global
	Time horizon	Short (1–2 year)	Mid-range (3–10 year)	Long (15 + years)	
	Purpose	Informational	Action-oriented		
Process	Target users	Few; knowledgeable	Diverse		
	Participation	Narrow mix, closed process	Intermediate	Diverse mix, representative process	
	Study duration	Day(s)	Month(s)	Year(s)	

This typology works by picking one value for each dimension. It could certainly be expanded or modified to suit situations. It is not hard to come up with additional state values for these dimensions or to add dimensions. To illustrate its application, let us consider an actual US foresight study.

The National Reconnaissance Office (NRO) initiated an intriguing project in 1998 called 'Proteus'. It strove to develop truly fresh perspectives on intelligence needs and technologies to fulfill them. It did so using the scenario planning approach of a commercial facilitator, Deloitte Consulting. Focusing out to the year 2020, the project generated nine insights – i.e., fresh lenses different from Cold War themes. These provided new ways to consider (and then plan to address) issues in a changing world. Three workshops involving a range of intelligence professionals and outsiders helped compose five scenarios – characterisations of the world of 2020 to stimulate consideration of issues and solutions. For instance, one was named 'Amazon.plague', wherein mutating viruses wrack the world, shrinking trade and the world's economy, with governments turning authoritarian or chaotic, and reliance on the global information grid in lieu of reduced physical interchanges. Follow-on stages aimed to transfer Proteus thinking to other agencies, implement gaming environments, and assess the potential of emerging technologies to contribute to multiple future environments (Loesche et al., 2002).

Let us apply the typology. Table 2 offers my outsider's assessment of the NRO foresight effort. The motivation is *extrapolative* – it seeks to anticipate potential changing world contexts, not to project desired states of affairs (a normative approach). The exercise is driven, not by S&T advances per se, but by the socio-economic-environmental context evolution (or revolution as the case may be). This is global, long range, informational foresight. The process is quite diverse, but not broadly representative. My premise is that this characterisation provides vital clues on how to perform the foresight exercise in question and what methods are more suitable. The creative bent of Proteus suggests that some will find the foresight activities or outputs more palatable than will others.

Table 2 Typology applied to Proteus

Issues	*Dimension*	*State values*			
Content	Motivation	*Extrapolative*	Normative		
	Drivers	Science (Research)	Technology (Development)	Innovation	*Context*
	Scope	Single topic or technology	Multiple technologies	*Wide-ranging planning*	
	Locus	Institution	Sector	*Nation/Region*	*Global*
	Time horizon	Short (1–2 year)	Mid-range (3–10 year)	*Long* (*15 + years*)	
	Purpose	*Informational*	Action-oriented		
Process	Target users	Few; knowledgeable	*Diverse*		
	Participation	Narrow mix, closed process	*Intermediate*	Diverse mix, representative process	
	Study duration	Day(s)	*Month*(*s*)	Year(s)	

For the sake of contrast, let us consider an OTA study, Office of Technology Assessment, US Congress (1980), concerned particularly with US support for continuing development of an 'SST' (supersonic transport). Table 3 casually characterises it, again by an outsider. Key aspects are that it is *normative, technology-focused, national level, action-oriented, and targeted to diverse users*. This study examined both what 'would be' (extrapolative), and what 'should be' (normative) implications; I think the normative aspects are most prominent. The timespan is not precise. This is a technology policy analysis, in contrast to Proteus, a creative exploration of alternative futures.

Table 3 Typology applied to OTA's *Advanced High-Speed Aircraft Study*

Issues	*Dimension*	*State values*			
Content	Motivation	Extrapolative	*Normative*		
	Drivers	Science (Research)	*Technology (Development)*	Innovation	Context
	Scope	*Single topic or technology*	Multiple technologies	Wide-ranging planning	
Content	Locus	Institution	Sector	*Nation/Region*	Global
	Time horizon	Short (1–2 year)	*Mid-range (3–10 year)*	*Long (15 + years)*	
	Purpose	*Informational*	*Action-oriented*		
Process	Target users	Few; knowledgeable	*Diverse*		
	Participation	Narrow mix, closed process	*Intermediate*	Diverse mix, representative process	
	Study duration	Day(s)	Month(s)	Year(s)	

Section 3 puts such foresight typing to use in helping guide the selection of appropriate methods.

3 Foresight methods

What are the candidate methods for use in technology foresight? The answer depends on what we mean by foresight. I choose a 'middle road' approach. I take technology foresight to include both the grand national S&T planning exercise and more modest variations. On the other extreme, I do not think we want to address all instances of technology intelligence, forecasting, roadmapping, and assessment. I have in mind major studies, not restricted to immediate, sharply delimited technology issues.

We also can be relatively broad or specific in distinguishing methods. This paper's objective is to help guide selection of methodological approaches more than specific, 'right' methodological variants to select. The paper by Porter et al. (2004) arrayed 51 methods applicable in FTA in nine families. Table 4 reflects my 'twist' on this framework. I have extended the set of families to 13, including 'Combinations' of method types, and mentioning some 48 methods. Assignment of methods to families is debatable; many could be placed in more than one family. So, the table is best considered as a 'shopping list' to encourage us to consider a wide range of possible techniques.

The Porter et al. (2004) paper provides selective pointers to sources for each method. My (biased) suggested sources that treat multiple methods are: Glenn and Gordon (2002), IPTS (2004), Martino (1993), Porter and Fittipaldi (1998), Porter et al. (1980, 1991), Ashton and Klavans (1997) and Porter and Cunningham (2005).

Methodological families in Table 4 are roughly ordered from descriptive towards prescriptive. Many emphasise gathering and portraying data. Creativity approaches intend to broaden our consideration; to prod us "out of the box". Monitoring and intelligence methods draw in and profile available information. Descriptive methods and Matrices massage that information to facilitate interpretation. Descriptive statistics are embedded in several of the approaches (e.g., trend analyses), but Foresight is not overly reliant on extensive statistical manipulations. Trend analyses – historical time series data and their projection into the future – are basic foresight tools. Expert opinion sometimes stands alone; even better, it can be combined with empirical approaches to help integrate and interpret.

In the remaining methods, families entail more manipulation of the data. Modelling and Simulation cover a wide gamut – from qualitative modelling ('boxes and arrows' pointing towards the Logical/Causal analyses) to intricate, quantified, computer modelling. Logical/Causal analyses trace 'if/then' relationships to help draw implications. Roadmapping weaves these into future progressions, particularly to inform S&T planning. Scenarios combine multiple elements to convey alternative futures. These and the Valuing/Decision-aiding/Economic analyses point towards assessing policy/action options. Combinations are just that – interesting ways to integrate different tools to gain perspective for better foresight.

Table 4 Future-oriented technology analysis methods

Methods families	*Sample methods*
Creativity approaches	TRIZ, future workshops, visioning
Monitoring and intelligence	Technology watch, tech mining
Descriptive	Bibliometrics, impact checklists, state of the future index, multiple perspectives assessment
Matrices	Analogies, morphological analysis, cross-impact analyses,
Statistical analyses	Risk analysis, correlations
Trend analyses	Growth curve modelling, leading indicators, envelope curves, long wave models
Expert opinion	Survey, delphi, focus groups, participatory approaches
Modelling and simulation	Innovation systems descriptions, complex adaptive systems modelling, chaotic regimes modelling, technology diffusion or substitution analyses, input-output modelling, agent-based modelling
Logical/Causal analyses	Requirements analysis, institutional analyses, stakeholder analyses, social impact assessment, mitigation strategising, sustainability analyses, action analyses (policy assessment), relevance trees, futures wheel
Roadmapping	Backcasting, technology/product roadmapping, science mapping
Scenarios	Scenario Management, Quantitatively based scenarios
Valuing/Decision-aiding/economic analyses	Cost-Benefit Analysis (CBA), Analytical Hierarchy Process (AHP), Data Envelopment Analysis (DEA), Multicriteria Decision Analyses
Combinations	Scenario-simulation (gaming), Trend impact analysis

4 Putting the pieces together: foresight methods and types

Different types of foresight demand different methods. As per Tables 1 and 4, the types and methods are too complex to make a simple prescription of what to do, and when.

My main message is to reflect on the foresight at hand to consider alternative methods (tools, processes, etc.). Then, weigh the pros and cons of different approaches.

To this end, I offer some observations on the foresight types and suitable methods. Considering the Type dimensions (Table 1):

- Motivation
  - Normative foresight warrants more emphasis on the prescriptive methods (i.e., Valuing/Decision-aiding/Economic.
- Drivers
  - Science-centred foresight requires substantial rethinking of tools devised to forecasting more incremental technological development processes. It is more subject to drastic change – i.e., breakthroughs. This suggests inclusion of Creativity approaches, with heavy emphasis on monitoring and intelligence. Rapid foresight also becomes essential to respond quickly to discoveries.
  - Innovation-oriented foresight also differs from traditional technology forecasting. It demands more attention to socio-economic contextual forces interacting with emerging technical capabilities to affect commercial products and services. Competitive technical intelligence approaches come to bear. Description, Modelling, and Logical/Causal analyses of competitive environments are vital.
  - Studies driven by contextual factors shift the focus to non-technical influences, requiring different sorts of expertise. Methods such as Scenarios come prominently into play.
- Scope
  - Tighter foci enable more data based analyses.
- Locus
  - Institution-oriented studies enable tailoring of issues. For instance, exploration of emerging technology opportunities can be crossed against the institution's relative strengths, using matrices.
  - Expanding locus interacts with process dimensions importantly – i.e., Participation considerations and suitable means to achieve these change drastically from institutional to national or trans-national (e.g., European Union) loci.
- Time horizon
  - Suitable methods shift as the time frame stretches. For instance, trend analyses long-term become very unreliable.
- Purpose
  - Action-oriented foresight leans towards assessment of policy options. Creativity approaches can aid in identifying a wider range of alternatives to consider. More prescriptive methods can help expose the advantages and disadvantages of these.

- Target users
  - As the intended users become more varied and numerous, increased attention to effective communication is critical. As a generalisation, we invest way too high a portion of our resources in analyses, with too little in communication. Roadmapping and scenarios may be particularly beneficial.
- Participation
  - More inclusive foresight processes exert pressures on which methods are apt to work well. Participants like to understand; 'black boxes' do not go over well, so transparency is important. For instance, highly elaborate modelling is probably unsuitable unless it can be simply explained. Suitable information visualisation techniques may help convey information and analyses.
- Study duration
  - While we are not emphasising 'needed in a day' foresight exercises, quick response to queries and challenges can be helpful. For instance, in dialogues among foresight process participants or with foresight users, interactivity is most helpful. Try to enable 'What if' analyses, done real-time, so that someone can ask about an alternative, and in a minute have a simulation run to reflect it.

5 Conclusions

This paper suggests that we consider technology foresight as a multi-dimensional activity. Thus, the conduct of foresight analyses needs to be tailored to the type. I offer an extensive list of methods and methods families, with some suggestions on factors to consider in fitting these to the type of foresight being undertaken. We need to avoid thinking of foresight as a singular activity with "one size fits all" methodology.

Certain things to note about these FTA methods and their application:

- These techniques reflect both qualitative and quantitative approaches; combining both is usually desirable.
- It can be helpful to consider the triad of Data, Theory, and Methods. To analyse a given issue, suitable methods must be selected on the basis of Data availability. The complexity of many socio-technical developments exceeds our causal/predictive Theory, constraining our attempts at causal reasoning or other intricate methodology.
- Given the Data/Theory/Methods concerns, it is advisable to use multiple methods that counterbalance each other's weaknesses.
- Study resources and the time available also need to be factored into determination of what methods to use. Foresight results must be available in a timely manner or they are essentially worthless (recall the US OTA situation).
- Some of the methods are intuitive; others benefit from experience and training.

Looking ahead, the Institute for Prospective Technological Studies (IPTS) is building upon the ‘new FTA methods’ seminar held in 2004 to generate a biennial series. The third seminar on FTA was held in October, 2008.

We also need to recognise the inherent limitations of foresight. In our review of US foresight activities (Porter and Ashton, 2008), we reflected on the pros and cons of the US ‘anti-foresight’ stance. US institutions certainly conduct many FTA, but the country has a distaste for centralised R&D priority setting or innovation planning (Wagner and Popper, 2003). What is to be said for an anti-foresight approach? The more an innovation system is subject to unpredictable, rapid changes, the more advantage to the pluralistic approach. Good technological intelligence to pick up quickly on emergent opportunities may outweigh careful foresight. As our emerging technologies become more science-based (e.g., biotech, nano), we need to rely more heavily on creativity approaches and monitoring and intelligence; less on trend analyses. A messy, pluralistic (i.e., not heavily planned) approach may especially do better at seizing sudden opportunities. Pursuing ‘Radical Innovation’ calls for less foresight, per se, than does pursuing incremental innovation (Dismukes et al., 2005).

Three themes for foresight methods development merit consideration. First, the increasingly widespread availability of data of all sorts is not likely to abate, making advanced tools that help process, search, mine, organise, display and interpret electronic information resources essential (Porter and Cunningham, 2005). Second, the need for better methods of extracting, organising, comparing and combining a wide variety of human judgements warrants attention. Taking a vast array of expressed interests and opinions into account seems to be a continuing driver to improve foresight studies. Third, proliferation of rapid communication tools (e.g., internet-based) will permit vast numbers of ‘anywhere’ participants in foresight studies. Electronic voting processes could contribute to foresight processes. Networking and collaboration tools should facilitate contributions from diverse stakeholders. Foresight types and methods can look towards a dynamic future in their own right!

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