DLR Deutsches Zentrum für Luft- und Raumfahrt

Technical Note 2:
Evaluation Guidelines Development

Disruptive Technology Search for Space Applications

4000101818/10/NL/GLC

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DISRUPTIVE
SPACE TECHNOLOGIES

esa

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1.1	25.11.2011	All	New Criteria Definition
2.0	15.11.2012	Executive Summary	Final Changes

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References

[RD 1] Vanston, J.H., Vanston, L.K., (2004) *TESTING THE TEA LEAVES: EVALUATING THE VALIDITY OF FORECASTS*, Research Technology Management, September—October 2004, 33-39

[RD 2] Christensen, C., Anthony, S.D., Roth, E.A. (2006*) Seeing what's next: Using the theories of innovation to predict industry change*, Harvard Business School Press, Boston.

[RD 3] Henshel, R.L., (1982) *The boundary of the self-fulfilling prophecy and the dilemma of social prediction.* The British Journal of Sociology. Vol 33. 155-165

[RD 4] Jackson, M.C. (2000) *Systems approaches to management*, Kluwer Academic/Plenum Publishers, New York

[RD 5] Greentechmedia: http://www.greentechmedia.com/articles/read/varian-looks-to-enforce-moores-law-in-solar/ accessed on 29.09.2011

[RD 6] Fisher, J.C. and Pry, R.H. (1971), *A simple model of technological change*, Technological Forecasting and Social Change, Vol. 3, pp. 75-81.

[RD 7] Bhargava, (1995) *A generalized form of the fisher-pry model of technological substitution*, Technological Forecasting and Social Change, Vol. 49, pp. 27-33

[RD 8] Beer, S. (1981). *Brain of the Firm*, John Wiley & Sons

[RD 9] Technology Futures, Inc http://www.tfi.com/pubs/ntq/articles/view/98Q1_A2.html accessed on 29.09.2011

[RD 10] Harrel, G. & Daim, T.U. (2009) "*Forecasting energy storage technologies*", foresight, Vol. 11 Iss: 6, pp.74 – 85

[RD 11] Astronautix: http://www.astronautix.com/articles/costhing.htm accessed on 29.09.2011

[RD 12] Tellis, G. J. (2006), *Disruptive Technology or Visionary Leadership?* Journal of Product Innovation Management, 23: 34–38. doi: 10.1111/j.1540-5885.2005.00179.x

[RD 13] Routio: http://membres.multimania.fr/routio/190.htm accessed on 29.09.2011

[RD 14] Agarwal, R., Bayus, B.L. (2002) *Market Evolution and Sales Takeoff of Product Innovations*. Management Science, Vol 48, 1024–1041

[RD 15] Ayres, R.U., (1969) *Technological forecasting and long range planning*. McGraw-Hill, New York

[RD 16] Google trends: http://www.google.com/trends?q=space accessed on 29.09.2011

[RD 17] Stakeholdermap: http://www.stakeholdermap.com/stakeholder-analysis.html accessed on 29.09.2011

[RD 18] Daim, T. Jordan, S (2008) "*A foresight based on scientific indicators: a framework drawn from the case of laptop battery alternatives*", foresight, Vol. 10 Iss: 3, pp.43 – 54

[RD 19] Organisation for economic co-operation and development. (2004) *Space 2030: Exploring the future of space applications*, OECD Publications, Paris

[RD 20] Saaty, T.L. (1980) *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation,* , McGraw-Hill

[RD 21] Teknomo, Kardi. (2006) *Analytic Hierarchy Process (AHP) Tutorial*. http://people.revoledu.com/kardi/tutorial/ahp/

[RD 22] Ulrich, K.T. & Eppinger, S.D. (2003) *Product design and development*. McGraw-Hill, New York.

[RD 23] Hsu, C. & Sandfort, B.A. (2007) *The Delphi Technique: Making Sense Of Consensus. Practical assessment*, research & evaluation, vol 12, no. 10, 1-8

[RD 24] Wechsler, W., (1978*): Delphi-Methode, Gestaltung und Potential für betriebliche Prognoseprozesse*, Schriftenreihe Wirtschaftswissenschaftliche Forschung und Entwicklung, München.

[RD 25] Vojak, B.A., Chambers, F.A. (2004) *Roadmapping disruptive technical threats and opportunities in complex, technology-based subsystems: The SAILS methodology*. Technological Forecasting & Social Change, Vol. 71, 121-139

[RD 26] Schmidt, G.M., Dreuhl, C.T. (2008) *When Is a Disruptive Innovation Disruptive?* Product Development & Management Association. Vol 2. 347-369

[RD 27] Adner R, (2002). *When are Disruptive Technologies disruptive? A demand-based view of the emergence of competition*. Strategic Management Journal, vol. 23, 667-688J.

[RD 28] Drew, S.A.W. (2006) *Building technology foresight: using scenarios to embrace innovation.* European Journal of Innovation Management. Vol. 9 No. 3. 241-257

[RD 29] Govindarajan, V., Kopalle, P.K. (2006) *The Usefulness of Measuring Disruptiveness of Innovations Ex Post in Making Ex Ante Predictions*. Journal of Product and innovation management. Vol 23. 12-18

[RD 30] Sainio, L.-M., Puumalainen, K. (2007): *Evaluating technology disruptiveness in a strategic corporate context: A case study*, Technological Forecasting and Social Change, pp. 1315-1333, No. 74.

[RD 31] Paap, J. & Katz, R. (2004) *Predicting the "Unpredictable": Anticipating Disruptive Innovation*. Research Technology Management. 13-22

[RD 32] Technology and Innovation Introduction presentation by Alberto Tobias for the techno/innovation days at ESA. Source: http://www.congrex.nl/10m14/ [Accessed on 16-03-2010]

[RD 33] ESA Technology Strategy and Long-Term Plan (2009)

[RD 34] Suzuki, K., (2003) *Policy logistics and institutions of European space collaboration*, Ashgate, Burlington

[RD 35] Giannopapa, C. (2010) *Key Enabling Technologies and Open Innovation*, European Space Policy Institute (ESPI) report

[RD 36] Danneels, E. (2004), *Disruptive technology Reconsidered: A Critique and Research Agenda*, Journal of Product Innovation Management, vol 21, 246-258

[RD 37] Christensen, C. (2000) *The Innovator's Dilemma*, HarperBusiness, Harvard Business School Press, Boston.

[RD 38] Francis, D. & Bessant, J. (2005). *Targeting innovation and implications for capability development*. Technovation, vol 25, 171-183

[RD 39] Abernathy, W.J. & Utterback, J.M. (1978) *Patterns of Innovation in Technology*, Technology Review, vol 80(7), 40-47

[RD 40] ESA (2008) European Space Technology Master Plan

[RD 41] Tobias (2008) Technology and Innovation Introduction presentation for the techno/innovation days at ESA Source: http://www.congrex.nl/10m14/ [Accessed on 16-03-2010]

[RD 42] ESA (2009) Technology Strategy and Long-Term Plan

[RD 43] Phaal, R., Farrukh, C.J.P, Mills, J.F. and Probert, D.R. (2003), '*Customizing the technology roadmapping approach*', Proceedings of Portland International Conference on Management of Engineering and Technology (PICMET), Portland, 20-24th July.

[RD 44] Phaal, R., Farrukh, C.J.P, Mills, J.F. and Probert, D.R. (2005) *"Developing a Technology Roadmapping System"*, Engineering Department, University of Cambridge, CB2 1RX, UK

[RD 45] Ringland, G. (1998), *Scenario planning: managing for the future*, John Wiley & Sons, Chichester.

[RD 46] Teknomo, K. (2006) Analytic Hierarchy Process (AHP) Tutorial; http://people.revoledu.com/kardi/tutorial/ahp/, accessed 16th November 2011

[RD 47] Dalkey, N. C. (1969). *The Delphi Method: An Experimental Study of Group Opinion.* Santa Monica, California: The Rand Corporation.

[RD 48] Dalkey, N., & Helmer, O. (1963). *An Experimental Application of the Delphi Method to the Use of Experts*. *Management Science, 9*(3), 458-467.

[RD 49] Häder, M., & Häder, S. (1998). *Neuere Entwicklungen bei der Delphi Methode: Literaturbericht II.* Mannheim: ZUMA-Arbeitsbericht 98/05.

[RD 50] Helmer, O. (1975). Foreword. In H. A. Linstone, & M. Turoff, *The Delphi Method: Techniques and Applications* (p. xix). Reading, Massachusetts: Addison-Wesley Publishing Company.

[RD 51] Hsu, C.-C., & Sandford, B. A. (2007). *The Delphi Technique: Making Sense of Consensus*. *Practical Assessment Research & Evaluation, 12*(10).

[RD 52] Jillson, I. A. (1975). The National Drug-Abuse Policy Delphi: Progress Report and Findings to Date. In M. T. Harold A. Linstone, *The Delphi Method: Techniques and Applications* (pp. 124-159). Reading, Massachusetts: Addison-Wesley Publishing Company.

[RD 53] Linstone, H. A., & Turoff, M. (1975). *The Delphi Method: Techniques and Applications.* Reading, Massachusetts: Addison-Wesley Publishing Company.

[RD 54] Rowe, G., & Wright, G. (1999). *The Delphi Technique as a Forecasting Tool: Issues and Analysis. International Journal of Forecasting, 15*, 353-375.

[RD 55] Turoff, M. (1970). The Design of a Policy Delphi. *Technological Forecasting and Social Change, 2*(2).

[RD 56] Wechsler, W. (1978). *Delphi-Methode: Gestaltung und Potential für betriebliche Prognosenprozesse*. München: Florentz.

[RD 57] Carstensen, L.L., Isaacowitz, D.M. & Charles S.T. (1999). *Taking time seriously: a theory of socioemotional selectivity*. American Psychologist, vol. 54(3), 165-181.

[RD 58] Fingerman, K.L. & Perlmutter, M. (1995) *Future time perspective and life events across adulthood. Journal of General Psychology*, vol 122, 95-111.

[RD 59] Clarke, A.C. (1962) *Hazards of Prophecy: The Failure of Imagination, Profiles of the Future: An Enquiry into the Limits of the Possible*

[RD 60] Lam et. al, (2005) *Cultural Differences in Affective Forecasting: The Role of Focalism. Personality and Social* Psychology Bulletin, vol 31, 1296-1309

[RD 61] Bond, M. H., & Cheung, M.K. (1984). *Experimenter language choice and ethnic affirmation by Chinese trilinguals in Hong Kong.* International Journal of Intercultural Relations, vol 8, 347-356.

[RD 62] Peng, G.C. and Nunes, M.B. (2007) *Using PEST Analysis as a Tool for Refining and Focusing Contexts for Information Systems Research.* 6th European Conference on Research Methodology for Business and Management Studies, Lisbon, Portugal, pp. 229-236

[RD 63] Kamien, M.I., Schwartz, N.L., (1982) *Market structure and innovation*, Cambridge university press: New York

Applicable Documents

[AD 1] Christensen, C., Rosenbloom, R. (1995) Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network, Res. Policy 233-257.

[AD 2] Daim, T.U., Rueda, G., Martin, H., Gerdsri, P., (2006) Forecasting emerging technologies: Use of bibliometrics and patent analysis, Technological Forecasting and Social Change, Vol. 73, pp. 981-1012.

[AD 3] Porter, A.L., Roper, A.T., Mason, T.W., & Rossini, F.A. (1991) Forecasting and Management of Technolgoy. John Wiley and sons, 192

[AD 4] Sood, A., Tellis, G.J. (2010) Demystifying Disruption: A New Model for Understanding and Predicting Disruptive Technologies, Marketing Science, Articles in Advance, pp. 1-16, Vol. 30, No. 2, 339-354

List of Abbreviations

Acronym	**Explanation**
AHP	Analytic Hierarchy Process

BEE	Best Engineering Estimate
CI	Consistency Index
COTS	Commercially available Off-The-Shelf
CR	Consistency Ratio
CRT	Cathode Ray Tube
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)
DST	Disruptive Space Technology
DSTs	Disruptive Space Technologies
DT	Disruptive Technology
EC	European Commission
ESA	European Space Agency
EU	European Union
LCD	Liquid Crystal Display
MTR	Mid-Term Review
OECD	Organization for Economic Co-operation and Development
PC	Personal Computer
PDA	Personal Digital Assistant
RI	Random Consistency Index
RoM	Rough order of Magnitude
SAILS	Standards, Architectures, Integration, Linkages and Substitutions
SMT	Scanning, Monitoring and Tracking technique
STEP analysis	Social, Technical, Economic and Political analysis
SWOT	Strength, Weaknesses, Opportunities and Threats
TBD	To Be Defined
TN	Technical Note
TRL	Technology Readiness Level
TV	Television
WP	Work Package

Executive Summary

This Technical Note (TN) reports on Work Package 3000 of the proposal, which is the *Evaluation Guidelines Development*. The aim of this Work Package is to develop evaluation guidelines for Disruptive Space Technology (DST) candidates, using a theoretical framework. It fits within the overall project structure as the evaluation Guidelines Development part, as highlighted in the overall structure of the project depicted in Figure 1. In this figure, the second chapter focusses on a literature study, which evaluates the different tools and techniques used for evaluating and forecasting technologies. The third chapter involves an evaluation criteria resulting from a literature review of DTs. The fourth chapter describes and evaluates a list of criteria resulting from the theory in Chapter 3 and the Theory of DSTs from TN01. The fifth chapter combined the highest rated methods and criteria in a customized DST evaluation method. These chapters are elaborated in more detail below.

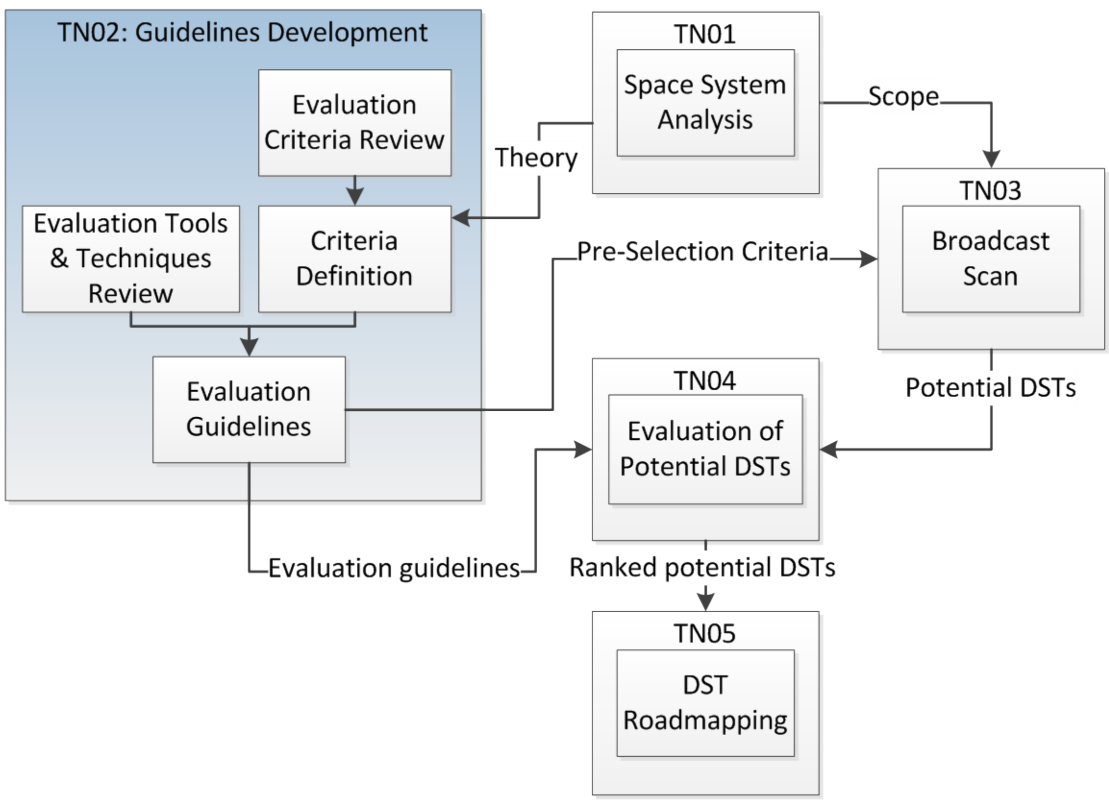

Figure 1: Overall structure of research

Chapter 2: Evaluation Tools & Techniques Review

This chapter focusses on the review of evaluation tools and techniques to create a theoretical framework for the evaluation guidelines.

The first task involves a review of the evaluation or forecasting methods already used inside and outside the space sector. This is done by analyzing established consultancies and institutions and analyzing their methodologies.

The second part elaborates on the general mechanisms of evaluation methods to show how they work, how they can be categorized and what their advantages and disadvantages are. This is done by analyzing the key features of evaluation methods and proposing a categorization framework.

The third part includes a review of the most commonly used evaluation methods and their applicability to DSTs. In Table 2-4 (Section 2.6), the conclusions with respect to evaluation methods are summarized. This table contains the discussed methods along with the required information input, type of forecast, applicability in forecasting DSTs, work effort and pro's and con's. The most promising methods are used for the creation of the evaluation guidelines for DST candidates. The Scanning Monitoring and Tracking techniques (SMTs), Analytic Hierarchy Process (AHP) and Delphi Method are ranked highest on their applicability to DSTs.

SMTs are deemed impractical within the scope of the present research as they require an extensive time investment. It would, nonetheless, be advisable to implement SMTs in future DST searches, as they will mitigate chances of unexpected DSTs arising. In addition, they can be used to track other kind of innovations (e.g. incremental, radical, game-changing, cross-cutting). This can be done by expanding the technology database created in TN03 and implementing a technology tracking system. SMTs are also used by NASA in their External Governmental Technologies (EGT) database. Because of the obvious benefits they provide, SMTs will still be taken into consideration when selecting criteria for the evaluation guidelines. The other two methods, AHP and Delphi, are used for the creation of the evaluation guidelines for potential DSTs.

Chapter 3: Evaluation Criteria Review

This chapter focusses on a review of forecasting and evaluation methods, from which criteria might be derived and used in the selected evaluation methods. Criteria relate to factors that determine if a technology will be disruptive or not. Besides the perceived performance mix, which was determined in TN01 of the present project as a viable framework for performance criteria, several other factors might be applicable as criteria in the evaluation guidelines.

Business management literature has already produced several papers and books on evaluating, forecasting, and predicting disruptive technologies. Chapter 3 analyzes these sources and their corresponding methods in order to determine if their view on DTs fits with the theory of DSTs, what their evaluation methodology is and whether or not the methodology is applicable for evaluating DSTs. The result of this analysis is summarized in Table 3-2. (Section 3.8), which lists the different methods and their criteria as well as applicability to DST. The most promising criteria are used in the evaluation guidelines for DSTs.

Chapter 4: Criteria Definition

This chapter describes the evaluation criteria that measure the disruptiveness of space technology concepts. Sources of these criteria are the theory of DSTs elaborated in TN01 and the criteria from different DT prediction methodologies (cf. Chapter 3). The different criteria from these sources are sorted into the four categories of the macro-environmental domains of the STEP analysis:

- Social Domain
- Technological Domain
- Economic Domain
- Political Domain

The goal of this chapter is to gather the criteria that indicate a potential for disruptiveness within space technologies. Only the ones with the highest potential to measure disruptiveness are used in the DST evaluation guidelines and therefore not all criteria are used. Some of them aim at measuring the disruptiveness of a DST candidate while others have more of a classification purpose. Additionally, some criteria require a higher workload than others or need to be applied for an extended period of time in order to act as an indicator for the measurement of disruptiveness. Nevertheless, the identified criteria can also be used as a general guideline handbook for evaluating DST candidates. This can be helpful in regard to later technology evaluation activities within ESA.

In the conclusion of this chapter, the criteria are assessed with respect to the strength of their disruption indication and the required workload to measure it. Additionally, they are ordered according to the most promising methods for evaluating DSTs (cf. Chapter 2). The results of the criteria analysis is illustrated in the graph in Figure 4-5 (Section 4.5). This graph lists the criteria on a measuring strength versus work effort axis.

Chapter 5: Evaluation Guidelines

In this chapter, the evaluation guidelines used to assess space technology concepts for their disruptiveness are described. These guidelines are created using the methods and criteria researched and elaborated on in previous chapters. All of these methods and criteria have been appraised on their applicability to DST concepts and the most promising methods and criteria are combined within the evaluation guidelines. The evaluation process starts with a database of potential DSTs, the steps involved in creating this database are described in TN03.

The AHP is used in order to pre-select the most promising technologies out of the potential DST database. The result of the AHP is a ranking of the technologies according to the technology domain they belong to. An overview of AHP with respect to the pre-selection of technologies is depicted in Figure 2.

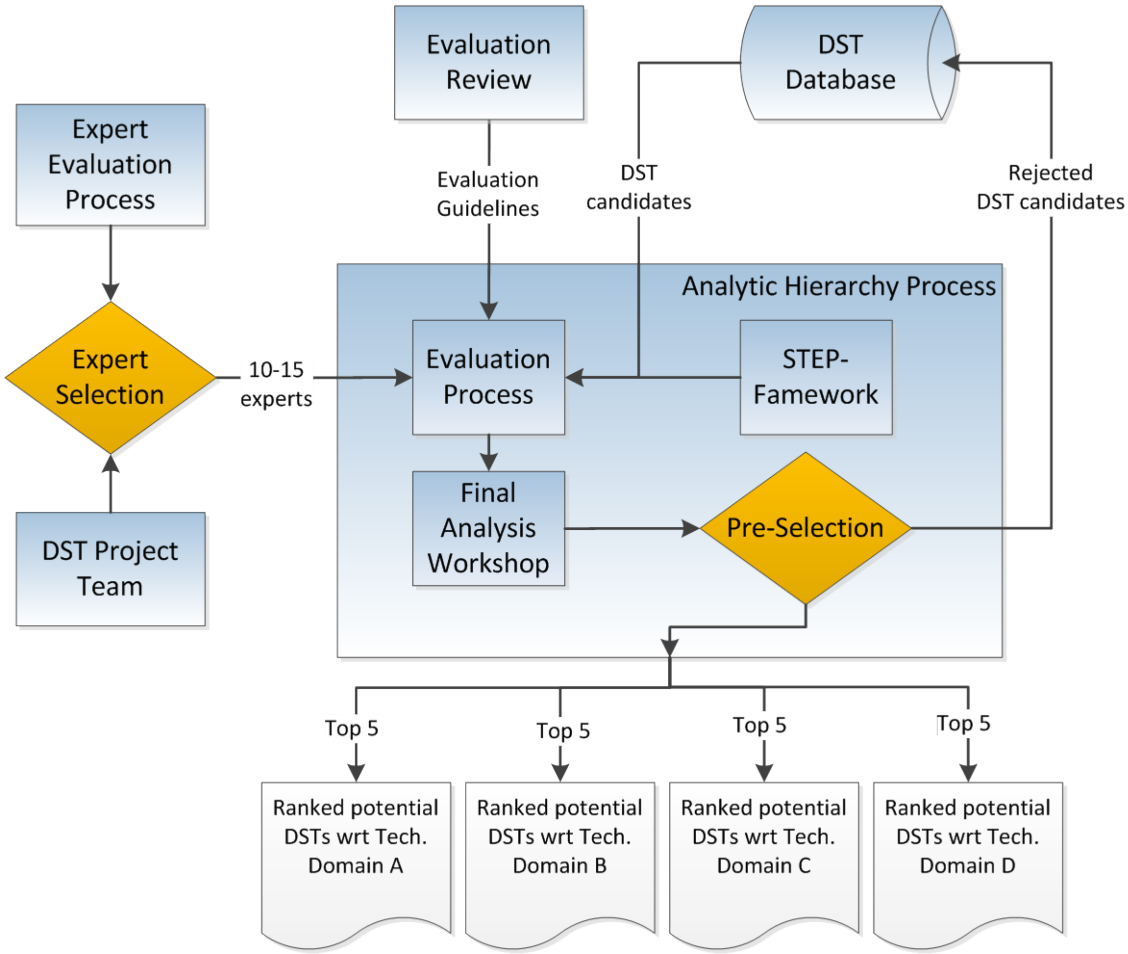

Figure 2: AHP with respect to the pre-selection of technologies overview

From each technology domain set in the search scope of TN01 (Spacecraft Electrical Power, Materials & Processes, Propulsion and On-Board Data Systems), the top 5 potential DSTs are selected and used as input for the Delphi method. Experts from each domain are identified and their participation in the method is requested. The Delphi involves several iterative rounds, whose aim it is to achieve a consensus among the experts. The iterative rounds are supported by desk research, which is providing background information on the technologies. The process of Delphi and the supportive desk research is depicted in Figure 3.

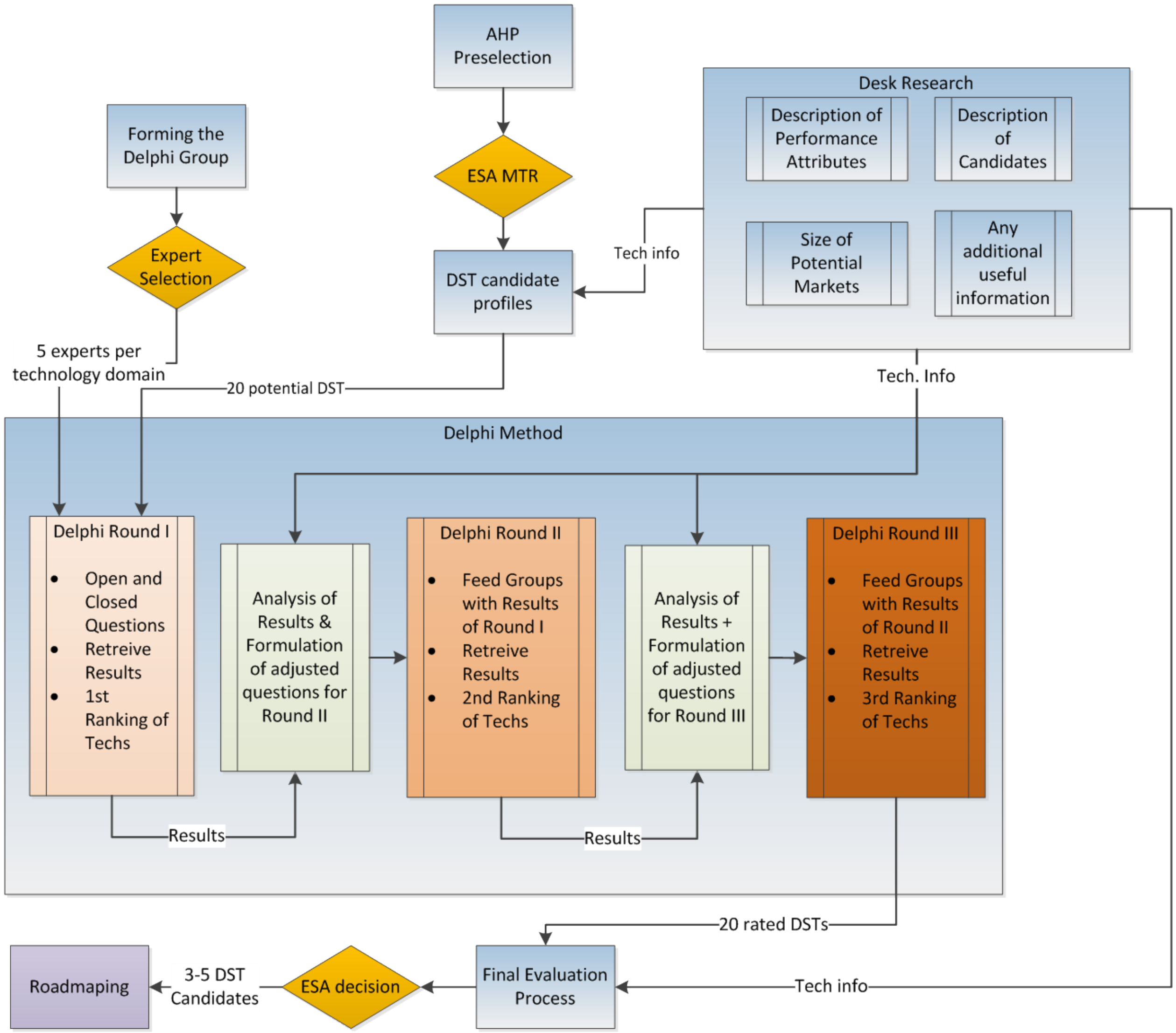

Figure 3: Delphi overview

Conclusion & Further Research

The evaluation guidelines for potential DSTs, which are developed in this TN, are based on the theoretical framework of DSTs developed in TN01. They are structured according to the STEP framework while the methods used are: AHP, Delphi, and a supportive desk research. The overall logic of the evaluation guidelines is depicted in Figure 4. The evaluation guidelines are used on the technology database, which is created using a customized DST search strategy developed and implemented in TN03, which documents on WP4000: Broadcast scan. In TN03, the first part of the evaluation guidelines, the AHP, is also utilized as a pre-selection and ranking method.

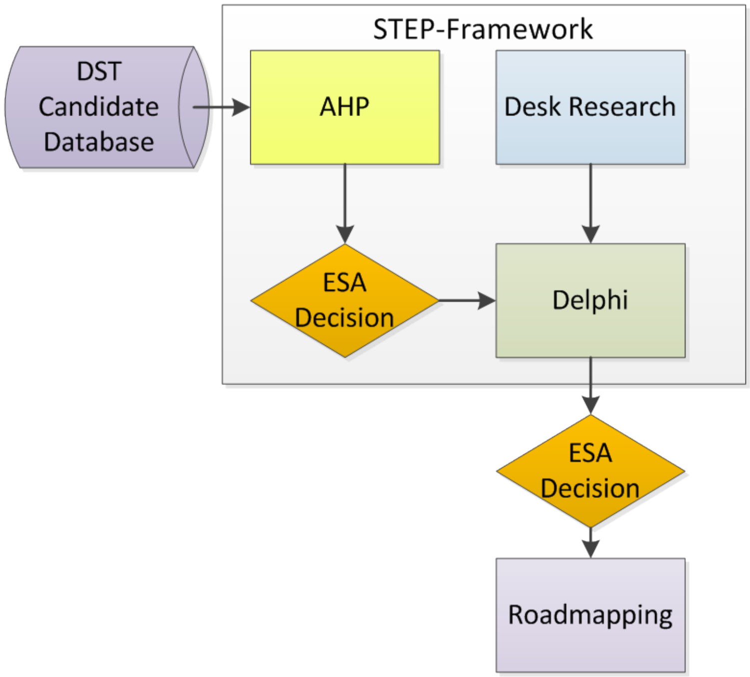

Figure 4: Overview of Evaluation Guidelines

After this pre-selection, the AHP results are presented to ESA in the mid-term review. ESA is offered the opportunity to select several technologies from the ranked potential DST list. These selected potential DSTs are then further evaluated using the Delphi method and supportive desk research in TN04. This part evaluates the technologies in much greater detail and results in a second ranked list, which is again presented to ESA for selection. The final lists of technologies per domain are then subjected to a Roadmapping process, which is described in TN05.

1 Introduction

This Technical Note (TN) reports on Work Package 3000, which is the *Evaluation Guidelines Development* of Project 4000101818/10/NL/GLC. The aim of this Work Package is to develop evaluation guidelines for Disruptive Space Technology (DST) candidates, using a theoretical framework. It fits within the overall project structure as the evaluation guidelines development part, as highlighted in the overall structure of the project depicted in Figure 1-1.

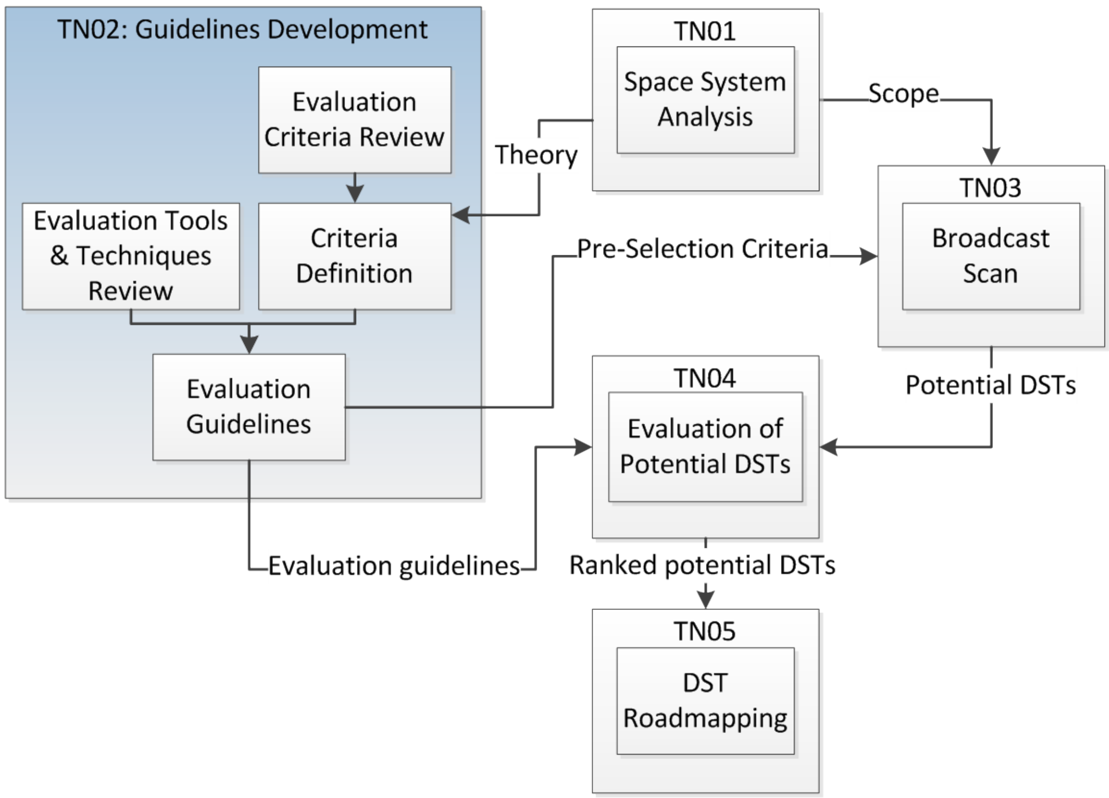

Figure 1-1: Overall structure of research

The Evaluation Method Review is described Chapter 2, covering WP 3100 displayed in the Management Proposal. Within this chapter, a range of key evaluation groups are identified and analyzed. After this, the key features of evaluation methods are analyzed and an overview of the different evaluation and forecasting methods is given. This involves a review of twenty-two methods structured according to a strategic analysis framework. This review contains a description of the methods and analyses their applicability to evaluating potential DSTs.

In Chapter 3, the evaluation or forecasting methods for Disruptive Technologies (DTs), described in literature are analyzed upon their evaluation criteria. Most of these methods encompass a view on DTs, which is different from the classical by Christensen [RD 2]. As the theory of DSTs is also different from the classical view, these methods and their criteria are analyzed on their applicability to DSTs.

In Chapter 4 the most applicable criteria from Chapter 3 are applies, as well as the theory of DST described in TN03, to create a range of criteria which measure a DST. In addition, the criteria are ordered according to their applicability to the methods which were identified as most applicable in Chapter 2. Chapter 3 and 4 cover WP3200 of the management proposal: Criteria definition.

The 5th and final chapter involves the creation of the evaluation guidelines and covers WP3300 of the management proposal. This chapter combines the methods and criteria with the highest applicability to DSTs, identified in the chapters before. These guidelines will be used to evaluate technologies with high potential for disruption identified through the search method to be developed in TN03.

2 Evaluation Tools & Techniques Review

This chapter focusses on the review of evaluation tools and techniques to create a theoretical framework for the evaluation guidelines.

The first task involves a review of the evaluation or forecasting methods already used for technology evaluation in- and outside the space sector. This is done by analyzing consultancies and institutions working on evaluation and forecasting methods both in- and outside of the space sector and analyzing their methodologies. This part serves as a theoretical framework for the development of an evaluation guideline for Disruptive Space Technologies.

The second part elaborates on the general mechanisms of evaluation methods to show how they work, how they can be categorized and what their pit falls are. This will be done by analyzing the key features of evaluation methods and proposing a categorization framework.

The third part includes a review of the most commonly used evaluation methods and their applicability to DSTs.

The present chapter starts by elaborating on a search of key evaluation groups. They are identified as being key forecasting & technology evaluation groups both in and outside of the space sector. The methods being used by them will give an insight in their different focus areas and what is applicable to the space sector. Only the most important groups are listed, which have a dominant position in evaluation and forecasting of technologies. In addition, the analysis focusses on European actors as this might be most applicable.

Table 2-1 shows groups which are working on evaluation and forecasting outside the space sector. As can be seen, most focus on technology assessment, especially the organizations that focus on policy seem to prefer technology assessment methods. From this, it can be concluded that technology assessment methods are most applicable for this area. For groups within the technology focus area, Delphi is the preferred method.

Table 2-1: Technology evaluation groups

Name	Type of method used	Focus area	Type	Country
Association of Professional; Futurists (APF)	Variable	Variable	Association	US - Int
Committee for the Future	Evaluate white papers	Policy	Advisory	Fi
European Parliamentary Technology Assessment	Technology assessment	Policy	Advisory	EU
Fast future	Predicting the state of markets in the future	Economic	Consultancy	UK
Forecast Pro	Extrapolation	Demand	Software	US
Foresight consulting	Predicting state of policies	Politic	Consultancy	UK
Future directions GmbH	Multi-client study, R&D evaluation Trend identification	Technology	Consultancy	DE
Future Management group	The five futures glasses	Marketing	Consultancy	DE
Futurestudies	Forecasts	Economic/Social	Consultancy	UK
Global Foresight Network	Expert opinions	Diverse	Network	US - Int
Infinite futures	Scenario	Economic	Consultancy	UK
Institute of Technology Assessment	Technology assessment	Policy	Advisory	AT
IST	Technology assessment	Policy	Advisory	BE
Kate Thomas & Kleyn	Future Management™	Behaviour change	Consultancy	BE
Leading futurists	Scenario, state of markets	Marketing	Consultancy	US
Norwegian Board of Technology	Technology assessment	Policy	Advisory	NO
OPECST	Evaluating technological options	Policy	Advisory	FR
Outsights	Value metrics	Technology	Consultancy	UK
Parliamentary Office of Science and Technology	Technology assessment	Policy	Advisory	UK
Rathenau Instituut	Technology assessment	Policy	Advisory	NL
Shaping Tomorrow -The Foresight Network	Futures, strategy or change management article	Policy	Network	US - Int
TAB Technology Assessment at the German Parliament	Scenario	Policy	Advisory	DE
TA-Swiss	Technology assessment	Policy	Advisory	CH
Techcast	Continuous delphi method	Technology	Online community	US - Int
Technology Futures Inc	Five Views of the Future™	Technology	Consultancy	US - Int
The Futures Group	Unknown	Social	Consultancy	US
ZUKUNFTSINSTITUT	Desktop Research, Delphi, Trend database, Trend scouting	Technology	Institute	DE

Table 2-2 lists the evaluation groups inside the space sector. Within the space sector, the preferred methods seem to be more qualitative because expert opinions and decision analysis techniques seem to be predominant. The organizations can be contacted for information concerning their methods and possible to gain access to their methods results.

Table 2-2: Technology evaluation groups within the space sector

Name	Type of method used	Focus area	Type	Country
ACT	Proposal evaluation	Advanced concepts	Agency	NL
Analysis	Market analysis	Strategic insights for satellite operators	Consultancy	UK
DESE	Decision analysis	Technology assessment	Consultancy	US
Euroconsult	Expert reviews	Strategic planning & Market analysis	Consultancy	FR
Futron	Decision-support models	Decision management	Consultancy	US
Innovation Triangle Initiative	Stage gate evaluation of disruptive concepts + Expert opinions	Breakthrough concepts	Agency	NL
NIAC	Pizza bin approach for technology assessment	Technology assessment	Agency	US
OECD	Scenario analysis	Future market forecast	Organisation	FR
Scientific Consulting	Evaluation of investments	Market analysis	Consultancy	DE
SEA	feasibility studies for future instruments and missions	Feasibility studies	Consultancy	UK
Space Angels Network	Investment in space ventures	Business incubation	Investment	US
Tauri Group	Scanning, Monitoring and tracking	Advanced Concepts	Consultancy	US
Teal group	Scenarios	Market forcast	Consultancy	US
W. L. Pritchard & Co.	Decision analysis	Technology assessment	Consultancy	US

Technology evaluation methods are used to justify decisions in technology investments. After evaluating technologies for their potential for future success, a forecast can be made. Because of this, forecasting methods are often used as a synonym for technology evaluation methods. Forecasting methods use information from the past to forecast events in the future as depicted in Figure 2-1. This information can come in many forms like e.g. experience, performance data, intuition, trends and patterns. This process is based on the assumption that powerful feedback mechanisms in human society cause repetitive processes (i.e. future trends and events to occur in identifiable cycles and predictable patterns based on the past).

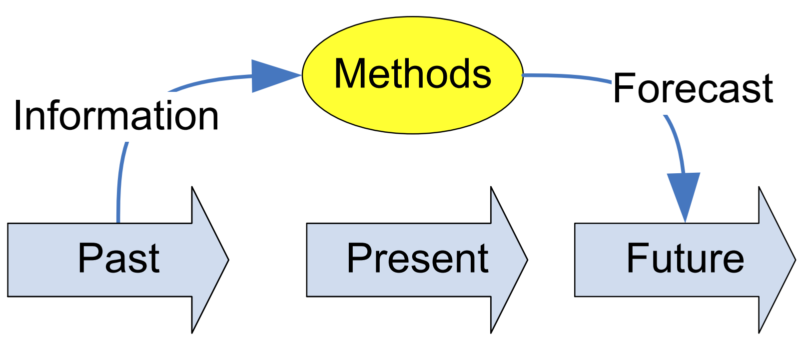

Figure 2-1: Overall logic of evaluation methods

Accurate evaluation methods can contribute to the selection of the best alternatives leading to the a better state of a system. In here lays the forecasting dilemma: Selecting a technology for development is essentially a self-fulfilling prophecy as it tries to measure if it gets developed in order to decide if it gets developed [RD 3]. Ergo, a space technology which is identified as a high potential of becoming a DSTs will be invested in and in this way become disruptive. In light of this, the term evaluation might be most appropriate because a technology concept will be evaluated on what its possible future will be and how beneficial this will be to the actors involved.

Because of the clear benefit of evaluation, there is an extensive amount of literature on this subject. Within this literature, different approaches of creating views on the future can be identified. In general, these views on systems can be categorized as being either quantitative, qualitative or a combination of both.

In general, there are two different approaches of viewing systems: a hard systems approach and a soft systems approach according to Jackson [RD 4], which will be explained hereafter.

Hard system approach involves mostly simulations and mathematical techniques. The underlying view of hard system approaches is that reality can be quantified and analyzed on these quantitative variables. The benefit of these approaches is that they are highly accurate. They can however only take simple elements into account and not complex human factors like opinions, culture and politics. Hard systems approaches are applicable to situations which are governed by certain rules, like physics in engineering or economic changes.

Soft system approach is used for complex systems with many human factors, which cannot easily be quantified. It is especially useful for systems where complex human factors define interactions and relationships. The effect of a political decision on it citizens might be an example of this approach. This might be more applicable for the space sector as technology development is for example highly politically influenced.

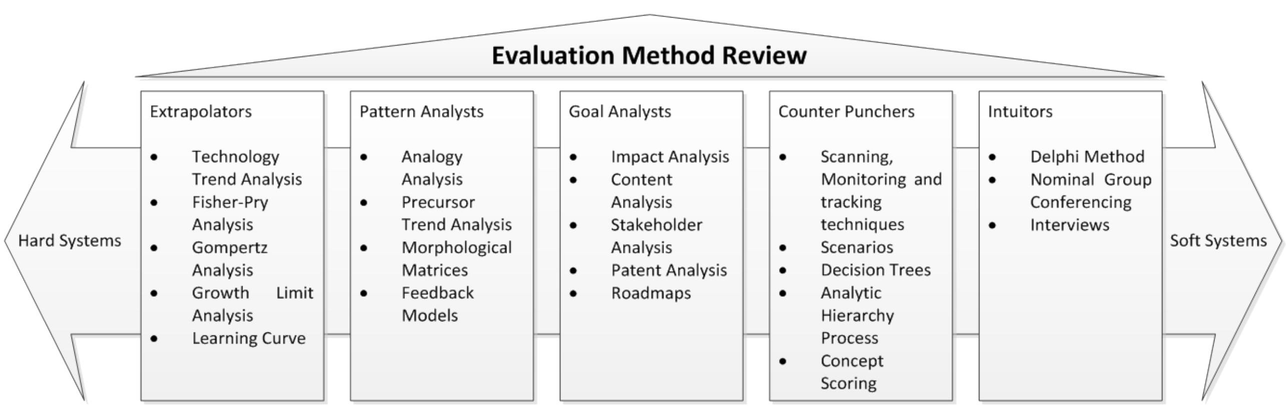

Figure 2-2: Five Views of the Future strategic analysis framework

In Figure 2-2, the axis of hard and soft system views is used to provide a categorization of evaluation methods. On the axis from hard to soft, the Extrapolators, Pattern Analysts, Goal Analysts, Counter Punchers and Intuitors are listed. These different categories contain several methods which are described and assessed on their advantages, disadvantages and applicability as evaluation methods for space technologies.

2.1 Extrapolators

Extrapolating methods are based on the view that the future state will be a logical extension of the past. Complex forces will drive the future in a predictable manner that can be used in creating forecasts based on analyzing trends from the past. Due to this fact, a forecast can be made by extrapolating the past according to mathematical principles. The methods that follow this hard view on systems are highly quantitative in nature. Examples of extrapolators are:

- Technology Trend Analysis
- Fisher-Pry Analysis
- Gompertz Analysis
- Growth Limit Analysis
- Learning Curve.

These forms of extrapolators are explained in the following subsections.

2.1.1 Technology Trend Analysis

Technology Trend Analysis is based on several observations of technologies advancing according to an exponential improvement process (for example Moore's law in number of transistors that can fit on an integrated circuit as seen in Figure 2-3).

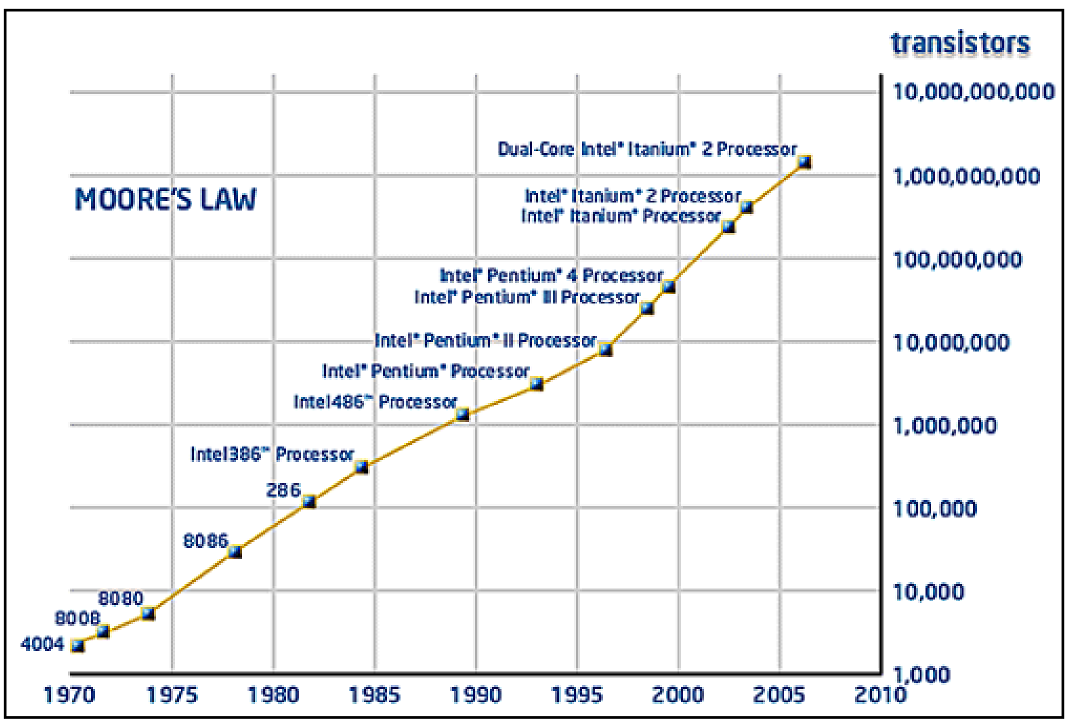

Figure 2-3: Trend of Moore's Law [RD 5]

The analysis relies on past data to determine the factor of improvement and extrapolate this to the future. This leads to a forecast of the future based on past rate improvements in the technology. The technique is highly quantitative and does not incorporate any physical, social or legal barriers. It is mostly used to forecast a level of performance (e.g. technical, costs, quality, efficiency) of single dimension competing technologies. Examples are processor manufactures competing on speed (transistor count), hard disk drives manufactures competing on area density and solar cells manufactures competing on efficiency.

2.1.2 Fisher-Pry Analysis

Fisher-Pry Analysis is a mathematical technique used to model the process of technology replacement in the form of radical innovations [RD 6]. Examples of past radical innovations that could be predicted by this technique are [RD 7]:

- Replacement of black and white TV by color TV (more recently CRT TV's by LCD and plasma TV's)
- Replacement of nylon tire cord by rayon tire cord
- Replacement of natural fiber by synthetic fiber
- Replacement of dial-up connections by broadband connections

The technique is based on the theory that the adoption of radical innovations normally follows a logistical curve for adoption also called the S-curve. The S-curve was first explained by Stafford Beer who stated that: *"Technological change can be categorized as a series of overlapping S-shaped curves"* [RD 8]. The formula for this S-curve depends on two parameters; the first one determines the starting point of the adoption while the second one determines the rate of adoption. These parameters can be determined by an analysis of the early adoption data, which for example is a percentage of customers using a certain technology. After this determination the analyzed early adoption data can be extrapolated to provide a forecast for a technology replacement process. Results produced by this technique are highly quantitative. The formula used for the Fisher-Pry Curve is

$$\frac{f}{1-f} = 2^{a(t-t(0))}$$

where:

f = fractional ratio of substitution at time t, a = the annual fractional growth in the early years and

$t(0)$ = take-over point where f = ½.

2.1.3 Gompertz Analysis

The Gompertz Analysis has a high similarity to the Fisher-Pry Analysis since they both use a mathematical technique to plot S-curves. The Gompertz Analysis differentiates itself by advanced modeling the intense competition between two technologies. The Gompertz model usually applies to important consumer adoptions or substitution processes that require a major change in expense behavior. An example of this could be the adoption of online services instead of local services. The Fisher-Pry model usually applies to business substitutions and adoptions, or to consumer substitutions that do not require major behavior changes or expense for example, online users who upgrade their modems. Like the Fisher-Pry Analysis, Gompertz Analysis predicts adoption by use of a two parameter mathematical model. In similar manner, early adoption is used to determine these parameters and the resulting adoption curve. The difference is mainly that the S-curves coming out of the Gompertz analysis are less 'steep'. The formula used for the Gompertz curve has the following standard form,

$$y = Le^{-be^{kt}}$$

where:

$y =$ the variable representing performance, $L =$ the upper limit, $e =$ the base of the natural logarithms, t = time and b & k = the coefficients obtained by fitting the curve to the data.

2.1.4 Growth Limit Analysis

Growth Limit Analysis is yet another form, which models technologies developments according to S-shaped curves. It differentiates itself from the former two by not predicting the adoption of a technology in the market, but rather the maximum performance of a technology. This analysis utilizes a logistical curve, which is called the Pearl Curve, to project the pattern in which dominant maturing technologies will approach their development limits. The formula used for the Pearl Curve has the following standard formula:

$$y = \frac{L}{1 + \alpha e^{-bt}}$$

where:

L = the upper limit to the growth of the variable y, e = the base of the natural logarithms,

t = time and a & b = the coefficients obtained by fitting the curve to the data

2.1.5 Conclusions for Extrapolators

Extrapolating methods cannot be used for forecasting DSTs because DSTs do not compete with dominant technologies on their primary performance dimension. This makes the extrapolation of a trend of the past in the performance of the primary performance dimension useless because one characteristic of DSTs is that they will not follow this trend.

Additionally, for extrapolation, a forecaster would need many accurate data points over a relatively long period in order to extrapolate the trend, which are usually not available in the space sector. This is caused by the irregular use of space technologies which makes identifying trends very complicated and rarely accurate (usage of space technology is highly dependent on missions).

Because of this, extrapolation methods inhibit the evaluation of technologies as no past data can be extrapolated.

On top of this, technologies often do not follow distinct patterns and often jump in performance after reaching a plateau for some time [RD 12]. Due to these reasons, it is not recommended to use extrapolator forecasting techniques for the evaluation of DSTs. Extrapolators have the following advantages and disadvantages:

Advantages

+ Forecasts based on extrapolation methods are backed up by historical data, which is usually highly accurate and relatively easy to obtain
+ Very accurate predictions can be made if it can be proved that technologies follow a certain rate of improvement over an extended amount of time
+ Predictions are usually made relatively quickly, as they do not rely on expert inputs
+ Using only quantitative data eliminates the factor of bias

Disadvantages

- Prediction of performance gain only works for technologies focusing on one performance dimension
- Methods do not take physical restrictions into account like size or complexity
- Methods do not take market factors into account like market restriction and regulations
- Changes in driving forces (e.g. customer demand, development in adjacent technologies, development of new materials) might change the development of a technology

2.2 *Pattern Analysts*

Pattern analysts assume that future technology adoption will reflect the process of past technology adoptions. This view of reality has led to a method of identifying and analyzing analogous situations of the subject technology and applying the found patterns to predict the future development of the technology. The adoption of color television, for example, closely followed that of black-and-white television and that, in turn, followed the pattern of radio adoption. Thus, one might reasonably forecast the pattern for future adoption of high-definition television by examining the pattern of past adoption of color television. However, it is quite possible to choose an invalid analogy and, in any case, future developments never exactly replicate past analogies. This field differentiates itself from extrapolators in a way that it is broader, i.e. focusing on more than a single performance dimension or technology replacement. The following paragraph describes the pattern analysis methods:

- Analogy Analysis
- Precursor Trend Analysis
- Morphological Matrices
- Feedback Models

2.2.1 Analogy Analysis

Analogy analysis is based on the view that patterns of diffusion of technological innovations are often analogical to that of similar technologies in the past. Analysis forecasters identify appropriate analogies and analyze similarities and differences. Generally, having more examples minimizes the probability of selecting false or inappropriate analogies. An example of this method is illustrated in Figure 2-4. In this, a foreign system is compared to a current system, in order to create a prediction on the occurrence of events. Occurrences D and E are forecasted based on the pattern observed in the past. The result of the analogy analysis usually does not predict one future but rather a range of futures. As a result this method is semi-quantitative in nature.

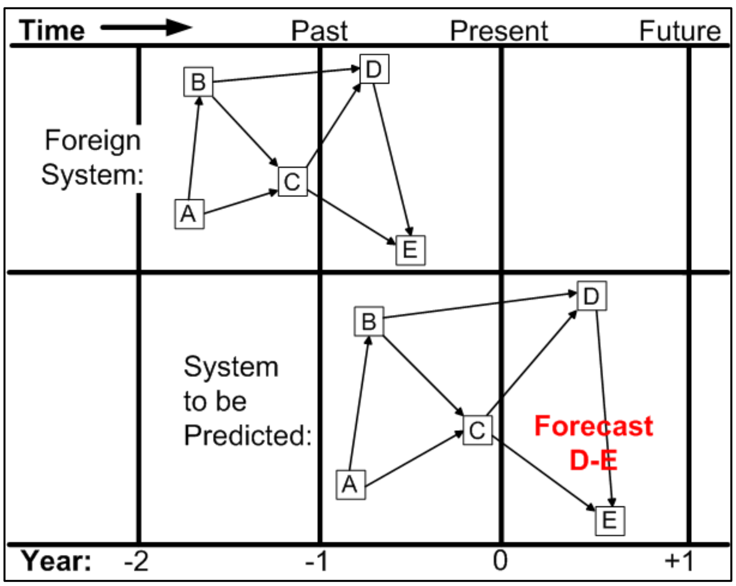

Figure 2-4: Example of the use of an analogy method [RD 13]

2.2.2 Precursor Trend Analysis

Precursor trend analysis makes a forecast based on the fact of recurrence of a time lag between technology developments in different fields. It projects the timeframe future developments in a new technology by correlating them with previous developments in a related leading technology. For example, the first application of technical advances in passenger cars (e.g. anti-lock brake system, traction control, four-wheel drive) typically occurred approximately four years after their application in race cars. Similarly, the applications of new technologies in commercial products tend to follow laboratory demonstrations by a relatively constant period. This has been researched by Agarwal and Bayus [RD 14] who state that there is a general relation between invention, commercialization, firm takeoff (the point where a firm get investors and starts to grow) and sales takeoff (where the product becomes economically viable). This relation has been illustrated in Table 2-3.

Using this analysis the future of technology lag can be determined by analyzing the precursor technology and the past similar technology replacements. Results of this technique are highly quantitative and rely on the selection of the right past similar technology replacements and precursors for its accuracy.

Table 2-3: Product Innovations and their development [RD 14]

Product	"Invention" year	"Commercialization" year	Firm takeoff year	Sales takec year
Sewing machine	1830	1849	1853	1859
Automobile	1771	1890	1899	1909
Phonograph record	1877	1897	1917	1919
Vacuum cleaner	1907	1911	1928	1934
Outboard engine	1905	1913	1916	1936
Electric blanket	1914	1915	1923	1952
Dishwasher	1898	1915	1951	1955
Radio	1912	1919	1922	1923
Clothes washer	1901	1921	1923	1933
Freon compressor	1930	1935	1938	1964
Cathode ray tube	1897	1935	1943	1949
Clothes dryer	1930	1935	1946	1950
Electric razor	1928	1937	1938	1943
Styrene	1831	1938	1943	1946
Piezoelectric crystals	1880	1941	1944	1973
Home freezer	1924	1946	1947	1950
Antibiotics	1928	1948	1950	1956
Turbojet engine	1934	1948	1949	1951
Ballpoint pen	1888	1948	1957	1958
Garbage disposer	1929	1949	1953	1955
Magnetic recording tape	1928	1952	1953	1968
Heat pump	1851	1954	1960	1976
Computer printer	1944	1960	1971	1979
Home microwave oven	1947	1970	1974	1976
Monitor	1927	1971	1975	1981
Microcomputer	1962	1974	1977	1982
Home VCR	1951	1974	1975	1980
Compact disc player	1979	1983	1984	1985
Cellular telephone	1970	1983	1985	1986
Optical disc drive	1979	1984	1987	1993

The results from Table 2-3 are summarized in Figure 2-5. As can be seen, there is a general trend between Invention, Commercialization, firm takeoff and sales takeoff.

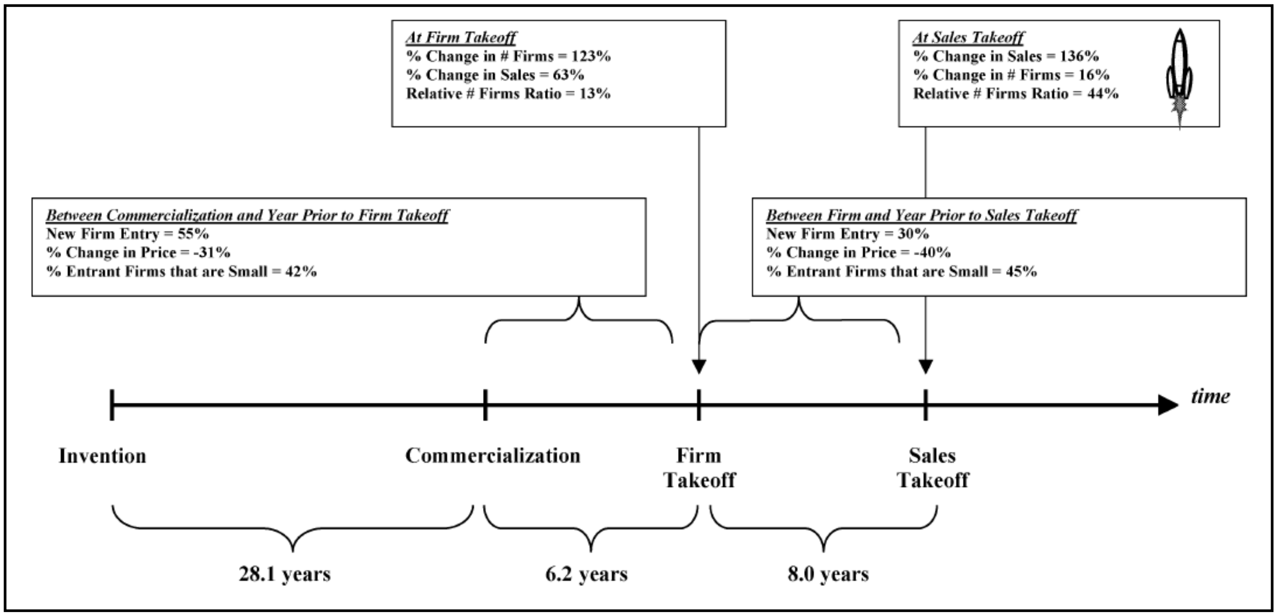

Figure 2-5: Descriptive statistics for the market evolution of product innovations [RD 14]

2.2.3 Feedback Models

Feedback models are techniques which allow the modeling on interactions of technical, market, societal, and economic factors as the future unfolds. It utilizes a computer model which mathematically specifies relationships between each of the relevant factors. For example, advances in science may result in higher performing technology that could result in increased sales and more funds for science. These models are part of the system dynamics approach. This technique is highly quantitative, however it is often used to examine qualitative consequences of trends, events, or decisions.

2.2.4 Conclusion Pattern Analysts

Pattern Analysis is reasonably applicable to Disruptive Space Technologies. Especially Precursor Analysis might be applicable in determining the timeframe of the dominant technology's disruption by the Disruptive Space Technology. This is probably hard to determine due to the low frequency in which space technologies are used. For the same reason Analogy Analysis is not applicable because of the inaccuracy of past data and the major differences between space technologies. Morphological matrices might be useful for one company to assess new fields of technology development but it is not applicable as an evaluation or forecasting method. It might, however, be applicable as a search method but this falls out of the scope of this research. Feedback models are unsuitable for an evaluation method for DSTs due to lack of data concerning the relationships between factors.

Advantages

+ The usage of repetitive patterns of the past can give accurate forecasts of the future
+ Because the forecast is based on past data it has a high validity
+ When the correct analogy is picked, a relative high accurate forecast can be made

Disadvantages

- Picking the wrong past event for analogy will lead to a false forecast
- It is very difficult to find an analogy that completely fits to the present situation
- The quantitative approach to qualitative problems might lead to one sided forecasts
- It is hard to take the complexity of markets into account using this technique, which may lead to choosing the wrong analogy

2.3 Goal Analysts

Goal analysts assume that the future is caused by the beliefs and actions of various individuals, organizations, and institutions. The future is therefore not determined and is susceptible to alteration by one or several of these entities. Because of this, a forecast can be made using the stated and implied goals of the various decision makers and trendsetters. In case of the space industry an example would be the European space policy and the included technology objectives which serve as a strategy for the technology development in Europe. Examples of goal analysts are:

- Impact analysis
- Content analysis
- Stakeholder analysis
- Patent analysis

2.3.1 Impact Analysis

Impact Analysis is a brainstorming technique used to assess the impact of an event (innovation) on its surroundings. It is a relatively simple formal method, which takes the fact into account that in a complex social system trends, innovations, and decisions often have consequences that are neither intended nor foreseen. Because of this, brainstorm practices are applied to identify the range of impacts an innovation might have. Brainstorm sessions force human brains to follow alternative thought processes and in this way allows for the detection of the unforeseen. The results of this technique are highly qualitative in nature.

2.3.2 Content Analysis

Content Analysis is a technique for weighting the relative importance of social, political, commercial, and economical events through measuring the amount of media attention the event receives. If a trend can be found involving the media attention of column-inches in newspapers, time allocated on television, and, more recently, number of items on the internet forecasters can extrapolate this and in doing so make a forecast of future events. In the area of technological innovations, this technique can be used to project advances in new technologies through measuring the attention a possible new technology receives. Although this is a qualitative technique, the results are often displayed in quantitative format. Recently many of these content analysis techniques have begun surfacing. Most notable tools are Google Trends [RD 16] (results shown in Figure 2-6, where A-F are news items and Search Volume Index is the relation between keyword searches and average searches over a period of time), Recorded Future, Shaping Tomorrow, World Future Society and the Web Bot Project. Google Trends analyses the number of new items and the number of searches for a certain query. This tool could be used to get a fast view on the attention a technology receives. Unfortunately, it does not work for specialized searches yet; only for frequently entered search items.

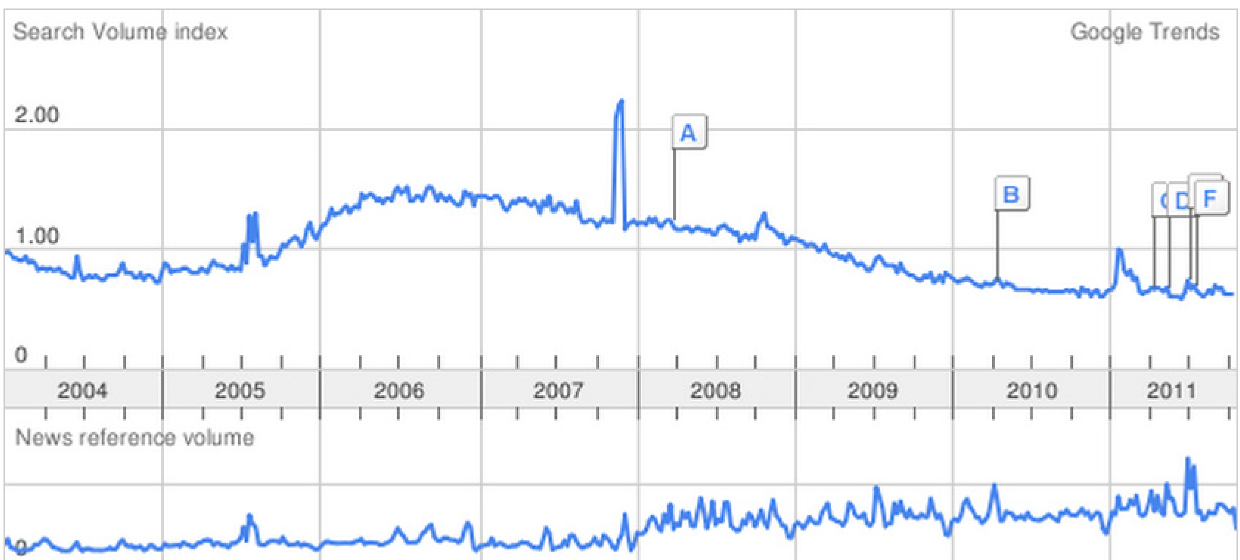

Figure 2-6: Google trends graph for the search term space [RD 16]

2.3.3 Stakeholder Analysis

Stakeholder Analysis is a formal method that measures the influence that individuals and institutions have on future developments. This technique analyzes the importance that each individual or group assign to these issues and the relative influence that they might have on events. The resulting analysis is partially quantitative and is often used to test the validity of forecasts that might be impacted by unexpected opposition or support. An example of this method is illustrated in Figure 2-7, where the interests and decision power of various stakeholders is analyzed.

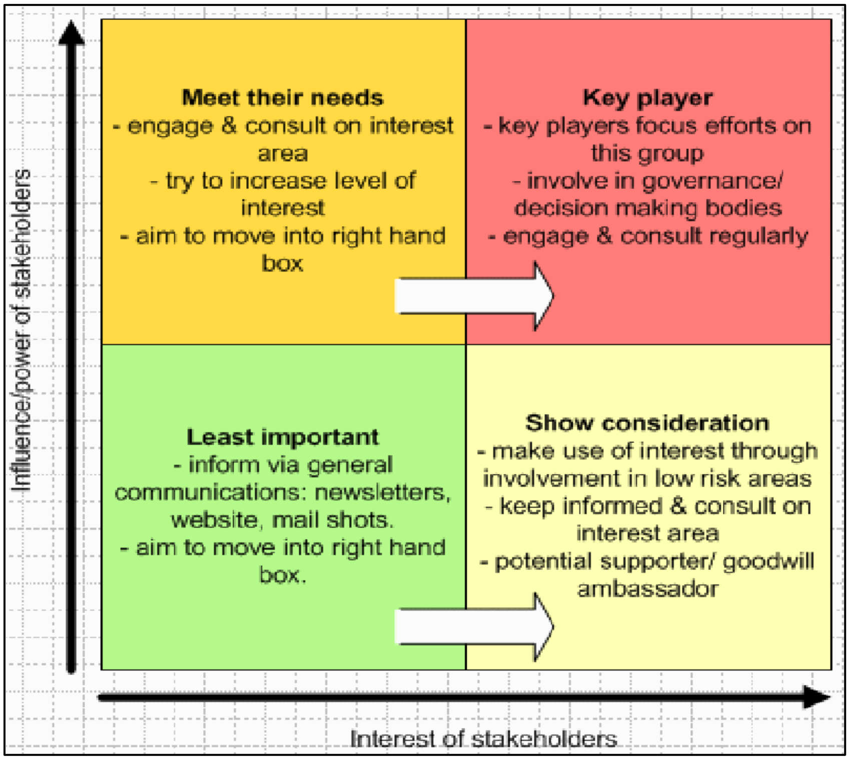

Figure 2-7: Stakeholder map [RD 17]

2.3.4 Patent Analysis

An analysis of the filed patents can indicate the interest companies and researchers have of a certain technology. It is based on the assumption that an increasing number of filed patents are early indicators for the success of a technology. When analyzing these trends, maybe in combination with an analysis of analogous technologies, a forecast for the future can be made. The results of this analysis are presented in a quantified manner but their use in decision making is based on a qualitative evaluation. An example of a patent analysis of power storage is illustrated in Figure 2-8. The figure shows the real data of patents that were submitted concerning Nickel Cadmium, Lead Acid, Nickel Metal, Lithium, and Fuel cell power storage. As can be seen, the area of fuel cells has been getting increased attention over the last few years while patents in lithium batteries have always been high.

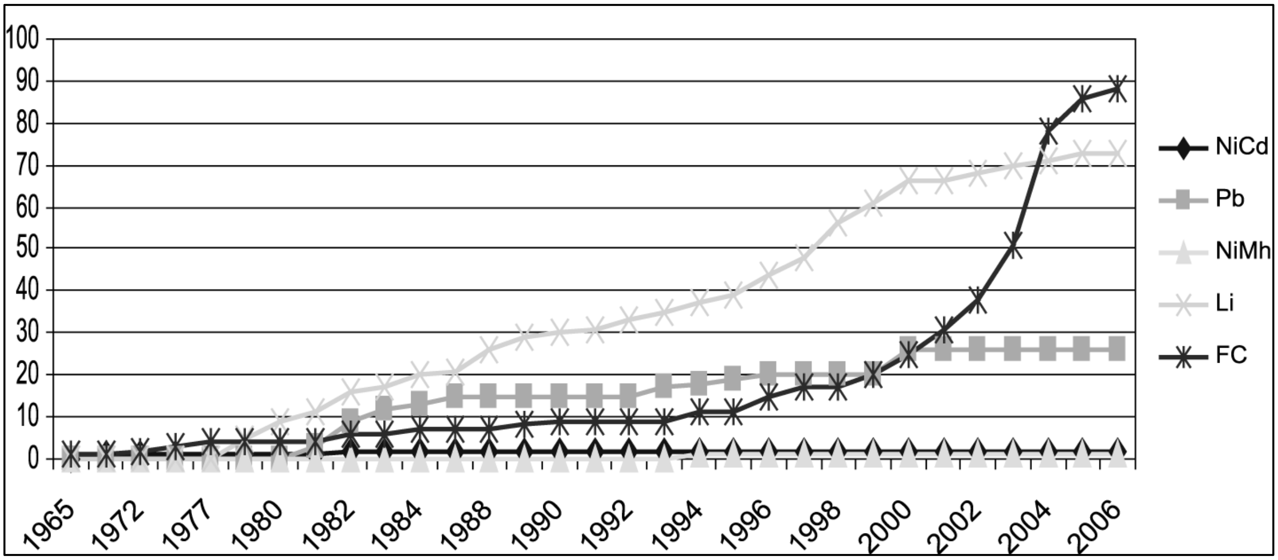

Figure 2-8: Number of patent applications of different power sources [RD 18]

2.3.5 Conclusion for Goal Analysts

In general, goal analysts are well applicable for forecasting Disruptive Space Technologies because they analyze markets instead of focusing on the technology.

Impact analysis, however, has little predictive value as it merely describes the impact of an innovation if it would be successful. Because of this, it is not usable for predicting Disruptive Space Technologies.

Content Analysis might be very helpful in the future as these techniques develop but is not useable yet, because it cannot follow trends of specific technologies.

Stakeholder Analysis is usable as the stakeholders for technology development in the European space sector are both pushers and pullers (for more information on technology development push or pull, examine TN01). This tool might, however, be more of a tool that helps with the development rather than for evaluation.

Patent Analysis is also applicable for predicting the success of innovations as it determines the interest of academia and the amount of research being done on it. However, this might not be a strong indicator for Disruptive Space Technologies as they are sometimes unexpected by the main market and therefore a level of interest might merely be an indication of a sustaining innovation.

Advantages

+ The success of an innovation is determined by the market adoption, therefore an extensive evaluation of the market (through stakeholders, content, and patent analysis) can be an accurate forecasting method

+ Content Analysis will potentially prove to be a very accurate technique in the future as this provides a quick real time indication of interest in a certain technology

+ Stakeholders Analysis goes to the core of decision makers concerning technologies
+ Patent Analysis is a clear indication of the academic interest in a certain technology

Disadvantages

- An indication of interest by the development parties alone has no direct influence of the success of a technology
- Merely an increase in content concerning the technology is not a direct indicator for the success of a technology

2.4 Counter Punchers

Counter Punchers assume that forces shaping the future are highly complex and therefore future events are essentially unpredictable. They propose that the best way of handling the future is by identifying a wide range of possible trends and events by monitoring changes in technical and market environments. The way to cope with changes from an unpredictable future is by maintaining a high degree of flexibility in the technology planning process. The methods discussed in this section are:

- Scanning, Monitoring, and Tracking techniques
- Alternate Scenarios
- Decision Analysis

2.4.1 Scanning, Monitoring and Tracking Techniques

Scanning, Monitoring and Tracking techniques are based on the principle that for most new technologies a considerable amount of time is required from invention to innovation. When considering this, an alert organization can take advantages of this lag-time through the techniques discussed before. While all techniques involve the scanning of the environment, they do differ in purpose, methodology, and degree of focus.

Scanning techniques involve a broad scan of the environment in order to detect promising technologies and different trends. Monitoring follows the trend in broad fields and markets. Finally, tracking involves the continuous observation of developments in a specified area (specific technologies, market developments etc.). Results of these techniques can be highly quantitative to basically qualitative, depending on the technique used. These techniques require a high amount of effort over a continuous period but provide a real-time protection against disruptive effects within a market.

2.4.2 Alternate Scenarios

The Alternate Scenarios technique is a structured method in which a number of individual forecasts are combined into a series of comprehensive, feasible narratives about how the future might develop. A good example of this is the OECD report *Space 2030* [RD 19], which analyzes three scenarios for the future of the space sector: 'Smooth sailing', 'Back to the future' and 'Stormy weather'. They explained their decision to use this method with the following quote:

"Because of the long timeframe adopted here, a scenario-based approach was adopted for an analysis of the demand side. Indeed, when exploring inherently unpredictable futures – as is the case for the future of the space sector – the building of a range of scenarios offers a superior alternative for decision analysis, contingency planning or mere exploration of the future, since uncertainty is an essential feature of scenarios."

This Alternate Scenarios technique can be used as an assistance tool for complex decisions such as technology investment decisions. Although this can also be done by using a Single Scenario technique, an Alternate Scenarios technique adopts a view that not one certain future can be forecasted but rather a range of opportunities for forecasts.

2.4.3 Decision Analysis

Decision Analysis techniques involve the detailed analysis of a decision using multiple criteria and weights originating from the operations research field. These methods can use a combination of quantitative and qualitative inputs to deliver a quantitative result. These methods can be used for a variety of decisions but for the field of innovation and technology development they are mostly used as investment decision methods. Below several different techniques are elaborated:

2.4.3.1 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a method for multi-criteria decision analysis [RD 20]. It involves the reduction of complex decisions to a series of pair-wise comparisons, then synthesizing the results, decision-makers arrive at the best decision with a clear rationale for that decision. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations. This makes the technique semi-qualitative. An example of the AHP is shown in Figure 2-9.

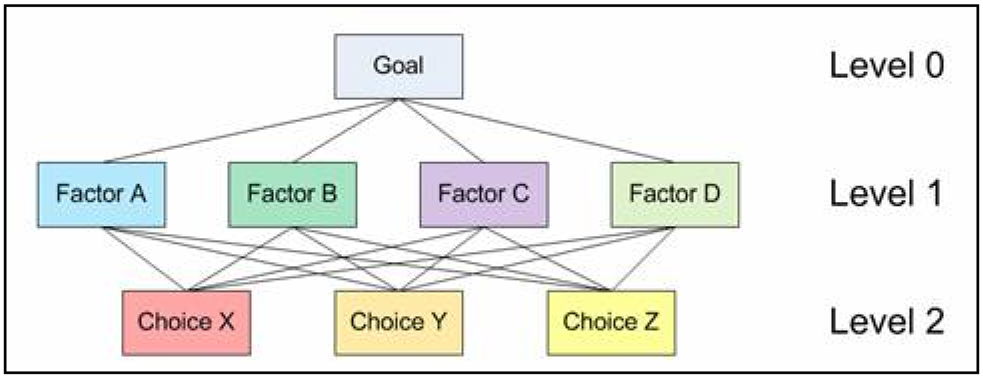

Figure 2-9: Example of AHP [RD 21]

2.4.3.2 Concept Scoring

The concept scoring matrix incorporates a ranking of concepts through a structured method [RD 22]. It involves the selection of a concept for investment by taking the following steps:

1. Prepare a selection matrix
2. Rate concepts
3. Rank concepts
4. Combine and improve concepts
5. Select one or more concepts
6. Reflect on the results of the process

An example of the matrix used in this method is illustrated in Figure 2-10. It shows a scoring of different cup holder concepts for boats. The method uses a weighted factor to adjust the level importance of the selected criteria. The allocation of the weighted factor per criteria will differ with every evaluated concept and will have to be determined by the evaluator. Most criteria will result in numbers, which can be compared with each other.

Selection Criteria	Weight	Concept A Rating	Concept A Weighted Score	Concept C Rating	Concept C Weighted Score	Concept F Rating	Concept F Weighted Score	Concept I Rating	Concept I Weighted Score	Concept J Rating	Concept J Weighted Score	Concept K Rating	Concept K Weighted Score	Concept O Rating	Concept O Weighted Score
Flexible Use	20														
Use in different locations	15	7	105	7	105	8	120	6	90	6	90	5	75	7	105
Holds different beverages	5	5	25	5	25	3	15	4	20	5	25	3	15	3	15
Maintains Drink Condition	15														
Retains temperature of drink	13	5	65	5	65	5	65	1	13	5	65	5	65	5	65
Prevents water from getting in	2	5	10	7	14	5	10	5	10	5	10	5	10	5	10
Survives Boating Environment	5														
Doesn't break when dropped	1	6	6	6	6	9	9	7	7	5	5	9	9	6	6
Resists corrosion from sea spray	2	7	14	7	14	8	16	8	16	5	10	9	18	7	14
Floats when it falls in water	2	5	10	6	12	8	16	4	8	5	10	8	16	7	14
Keeps Drink Container Stable	20														
Prevents spilling	7	3	21	4	28	3	21	5	35	5	35	3	21	3	21
Prevents bouncing in waves	6	7	42	8	48	7	42	5	30	5	30	7	42	7	42
Will not slide during pitch/roll	7	5	35	5	35	5	35	5	35	5	35	5	35	5	35
Requires Little Maintenance	5														
Easily stored when not in use	1	7	7	6	6	8	8	9	9	4	4	8	8	7	7
Easy to maintain a clean appearance	2	6	12	6	12	3	6	4	8	5	10	5	10	6	12
Allows liquid to drain out bottom	2	5	10	5	10	5	10	5	10	5	10	5	10	5	10
Easy to Use	15														
Usable with one hand	5	7	35	7	35	7	35	6	30	5	25	7	35	7	35
Easy/comfortable to grip	5	8	40	8	40	6	30	5	25	5	25	6	30	8	40
Easy to exchange beverage containers	2	5	10	5	10	5	10	8	16	5	10	5	10	5	10
Works reliably	3	3	9	3	9	3	9	3	9	4	12	4	12	3	9
Attractive in Environment	10														
Doesn't damage boat surface	5	8	40	8	40	8	40	8	40	8	40	6	30	8	40
Attractive to look at	5	7	35	8	40	3	15	4	20	5	25	5	25	8	40
Manufacturing Ease	10														
Low-cost materials	4	5	20	4	16	7	28	8	32	4	16	8	32	6	24
Low complexity of parts	3	4	12	3	9	7	21	4	12	3	9	8	24	5	15
Low number of assembly steps	3	5	15	5	15	8	24	3	9	3	9	8	24	6	18
Total Score			578		594		585		484		510		556		587
Rank			4		1		3		7		6		5		2

Figure 2-10: Scoring matrix [RD 22]

2.4.4 Conclusion for Counter Punchers

Out of the Counter Punchers, some techniques are more applicable to forecasting Disruptive Space Technologies than others.

Scanning, Monitoring and Tracking techniques are well applicable to organizations wishing to follow particular technology developments over time. Although the authors agree that this technique might lead to good results, they are however concerned with the amount of effort it takes to continually track the development of all technologies within the space sector. Therefore, it is concluded that an evaluation at a single point in time might be more efficient.

The Alternative Scenarios technique is not applicable to forecasting Disruptive Space Technologies as an investment decision maker has no use of different scenarios in the case of a technology disruption. More applicable is a single scenario technique, however, this has the disadvantage of providing a definitive view on the future and thus closing an investment decision maker's mind to alternative scenarios.

Decision Analysis techniques are very applicable to evaluation of Disruptive Space Technologies because their aim can be seen as evaluation for investment decisions. The AHP, for example, can be used to rate technology concepts on different criteria and weigh them according to expert opinions. The Concept Scoring method in turn can be used to provide a scoring matrix for ratings on different criteria and compensate them with weights.

Advantages

- \+ Applicable for long term forecasts
- \+ Allows for the continuously tracking for trends decreasing response time to innovations
- \+ Allows a range of several events instead of one fixed event, which forces decision makers to deal with uncertainty
- \+ Decision Analysis allows for an evaluation on several criteria and can therefore encompass a range of other methods and measure them together

Disadvantages

- \- Mostly applicable to long term forecasts
- \- A wide range of trends or alternative scenarios are not applicable to specific cases

2.5 Intuitors

Intuitors are a group of futurists that believe that the future will be realized through a complex mixture of trends, random occurrences and the actions of individuals and institutions. Because of this complexity they believe that no technique can provide an accurate forecast of the future. Therefore, they usually rely on the subconscious information processing capability of the human brain and use this to provide useful insights about the future. They do this by feeding the brain with information and allow intuition and experience (tacit knowledge) of experts to make judgments on the likelihood of a future. Methods included in this section are:

- The Delphi Method
- Nominal Group Conferencing
- Structured and Unstructured Interviews

2.5.1 The Delphi Method

The Delphi Method is a widely used and accepted technique for achieving convergence of opinion and gathering data from respondents within their domain of expertise [RD 23]. Its far-reaching field of application includes two particular uses that represent the main goals of Delphi surveys and their benefits: The first is to provide judgmental data in areas, where hard data is either unavailable or too costly to obtain and can be used as input data in studies. The use of the Delphi technique excels in the process of supplying decision makers with reliable expert opinions [RD 50]. In addition, it is often used as forecasting tools or as part of technology forecasting methods [RD 54].

The Delphi Method has its origins in US American defense research. Sponsored by the United States Air Force and developed by the RAND Corporation in the mid-1950s mainly by Norman Dalkey and Olaf Helmer, it had the purpose of estimating the effects of a massive atomic attack on the United

States [RD 50]. Even if all factors could have been assessed, which is considered unlikely, a statistical analysis of this scale would not have been possible with the computers of that time. Thus, taking into account the opinion of experts was the only feasible solution for a prediction of that kind and delivered the original justification for the first Delphi study [RD 53].

Since its invention, the Delphi Method has come a long way. While used mainly as a technology forecasting tool in the mid-1960s, it has evolved to arguably one of the most popular incentive evaluation methods today with the number of studies being conducted rising in only a decade from a three digit count in the late 1960s to a four digit number in the 1970s [RD 53]. Since then, the field of application has been extensively diversified and its characteristics have been expanded in practice and in literature [RD 49].

A general description of the Delphi Method given by Wechsler reads as follows: "*It is a survey which is steered by a monitor group, comprises several rounds of a group of experts, who are anonymous among each other and for whose subjective-intuitive prognoses a consensus is aimed at. After each survey round, a standard feedback about the statistical group judgment calculated from median and quartiles of single prognoses is given and if possible, the arguments and counterarguments of the extreme answers are fed back* [...]" [RD 56].

There are two basic forms of the Delphi process [RD 53]. The first is the "paper-and-pencil version" where a small monitor team develops a questionnaire, which is then sent to the participants of the survey. Upon return of the questionnaire, a new questionnaire is created based on the answers on the original one. The next iteration round informs the participants of the results of the first round and gives them the opportunity to re-evaluate their opinions taking into consideration the knowledge of the entire group. This form is called the "conventional Delphi".

The second form called "Delphi Conference" replaces the monitor team with a computer programmed to carry out the compilation of the group results. This approach has the advantage that the delay between the iteration rounds is eliminated and the process is concluded much faster. It requires however, that the characteristics of the communication are well defined before the Delphi is undertaken since they cannot be later adjusted according to the group responses [RD 53].

One of the main advantages of the Delphi method is that is constitutes a process of gaining consensus from a group of experts while maintaining their anonymity to decrease bias. Bias can come from communication that occurs in a group process and deals with individual interests rather than focusing on solving the problem [RD 47]. Furthermore, it can come from the effect that dominant individuals have over others in terms of opinion forming.

Another big advantage of this method is the minimal cost for maximum output as illustrated by Jillson in the example of a policy Delphi on drug abuse, a special form of the Delphi method [RD 52], [RD 55]. The ability to conduct a Delphi with respondents spread over a wide geographic area is another big advantage of the Delphi method.

Time requirements can be seen as one of the biggest concerns toward the Delphi method. The conclusion of each iteration round can only be conducted once all the participants have sent in their answers. As a consequence to this delay, a lot of participants will lose interest and drop out the study. Lindstone & Turoff regard the following as the most common reasons for a Delphi failure [RD 53]:

- Imposing monitor views and preconceptions of a problem upon the respondent group
- Assuming that Delphi can be a surrogate for all other human communications
- Poor techniques of summarizing and presenting the group response
- Ignoring and not exploring disagreements
- Underestimating the demanding nature of a Delphi and the fact that respondents should he recognized as consultants and properly compensated for their time

2.5.2 Nominal Group Conferencing

Nominal Group Conferencing is a formal technique used to structure expert opinions. The technique resembles mechanisms used in Brainstorming techniques but requires the active participation of all the participants. Just like in Brainstorming, it forces participants to think along different lines than usual. Examples of this include: To generate new ideas, to assess the ideas of others, to jointly examine the implications of new ideas, and to formally evaluate a series of options. The technique is often used to project future developments and the results are usually semi-quantitative.

2.5.3 Interviews

Structured and Unstructured Interviews are well known methods of gathering information from experts concerning their thoughts and opinions on how the future will unfold. Structured Interviews consist of methods such as surveys and opinion polls. It is provided that the interviewers know beforehand what they would like to know from the interviewees. In contrast, in Unstructured Interviews the subject is broadly set but the details are less defined. The results of the interview are determined by the interviewee’s answers to each question.

2.5.4 Conclusion Intuitors

In general, Intuitors are very applicable in forecasting Disruptive Space Technologies. Especially the Delphi technique is applicable since it involves a group of experts, which has to reach a consensus on a question. It depends, however, on the questions asked if the Delphi method can be useful since Disruptive Space Technologies are not easy to find; experts can be questioned according to disruptive indicators. Additionally, the Delphi method benefits from anonymity, which decreases bias and is applicable to long distance communication. Especially the communication point makes the Delphi technique very applicable for the space sector as experts are often located all over the world. This also makes the nominal group conferencing and interview techniques less applicable as traveling for interviews might be highly time-consuming. This problem can be solved through the usage of teleconference techniques although this might decreases the effectiveness of communication.

Advantages

- + Forecasts are made on data from reliable, experienced sources (experts)
- + Forecast results have a high validity
- + Using multiple rounds (Delphi method) may reduce bias factors
- + Uncertainty of the future and multi-objectivity can be incorporated

Disadvantages

- - Often the view of experts is one sided, which may lead from blind-sightedness to unexpected events
- - Bias factors are large and difficult to mitigate for intuitive forecasts

2.6 Conclusion of Evaluation Tools

In Table 2-4, the conclusions with respect to evaluation methods are summarized. This table contains the discussed methods along with the required information input, type of forecast, applicability in forecasting DSTs, work effort and pro's and con's. The most promising methods are used for the creation of the evaluation guidelines. The Scanning Monitoring and Tracking techniques (SMTs), Analytic Hierarchy Process (AHP) and Delphi Method are ranked highest on their applicability to DSTs.

SMTs are deemed impractical within the scope of the present research as they require an extensive time investment. It would, nonetheless, be advisable for ESA to implement SMTs in future DST searches, as they will mitigate chances of unexpected DSTs arising. In addition, they can be used to track other kind of innovations (e.g. incremental, radical, game-changing, cross-cutting). ESA can do this by expanding the technology database created in TN03 and implementing a technology tracking system. SMTs are also used by NASA in their External Governmental Technologies (EGT) database. Because of the obvious benefits they provide, SMTs will still be taken into consideration when selecting criteria for the evaluation guidelines. The other two methods, AHP and Delphi, are used for the creation of the evaluation guidelines.

The other two methods, AHP and Delphi, are used for the creation of the evaluation guidelines in Chapter 5. Additionally, within the selection of criteria in Chapter 3 and 4, these two methods will be taken into account.

Table 2-4: Conclusions of evaluation methods

Chapter	Method	Information input	Type of forecast	Pro's	Con's	Effort **	Applicability *
Extrapolators							
2.1.1	Technology Trend Analysis	Performance data	Technology performance trend	Accuracy of forecast / Free from Bias / Relative low time effort	Inability to cope with complex situations / Self-fulfilling prophecy /Measures only one performance dimension	3	2
2.1.2	Fisher-Pry Analysis	Adoption data	S-Curve graph			4	2
2.1.3	Gompertz Analysis	Adoption data	S-Curve graph			4	2
2.1.4	Growth Limit Analysis	Performance data	S-Curve graph			3	2
2.1.5	Learning Curve	Cost data/performance data	Cost graph			3	3
Pattern Analysts							
2.2.1	Analogy Analysis	Technology analogy data	Adoption pattern	Accurate forecasts	Wrong analogy leads to wrong forecast / Difficult to find the right analogy	2	2
2.2.2	Precursor Trend Analysis	Adoption times	Adoption time			2	2
2.2.3	Feedback Models	Environment factors	Relationship factors			2	1
Goal Analysts							
2.3.1	Impact Analysis	Brainstorm session	Unforeseen events	Takes market factors into account / low time effort	Merely measure the interest which is only one factor determining the succes of a technology	3	2
2.3.2	Content Analysis	Trends in media attention	Future interest			5	3
2.3.3	Stakeholder Analysis	Stakeholder information	Influence by stakeholders			4	3
2.3.4	Patent Analysis	Patent trends	Future scientific interest			3	3
Counter Punchers							
2.4.1	Scanning, Monitoring, and Tracking techniques	Performance data	Continuous forecast	Allows for performance tracking over time / Allows for a measuring of	Tracking is highly time consuming	1	5
2.4.2	Alternate Scenarios	Various sources	Scenarios Forecast			2	2
2.4.3	Analytic Hierarchy Process	Expert opinions	AHP model			2	5
2.4.4	Concept scoring	Expert opinions	Potential rating			4	4
Intuitors							
2.5.1	The Delphi Survey technique	Expert opinions	Expert ratings	Reliable data source / Good for complex situations	Bias factors	2	5
2.5.2	Nominal Group Conferencing	Brainstorming data	Expert ratings			2	3
2.5.3	Structured and Unstructured Interviews	Interviews	Expert ratings			3	3

* 1, Not applicable 2,Slightly applicable 3, Reasonably applicable 4, Applicable 5, Very applicable ** 1, Heavy 2, Substantial 3, Reasonable 4, Light 5, Very little

3 Evaluation Criteria Review

After selecting a range of methods which are applicable for evaluating space technologies, the criteria will be determined. Criteria relate to factors that determine if a technology will be disruptive or not. Besides the perceived performance mix, which was determined in TN01 as a viable framework for performance criteria, several other factors might be applicable as criteria in the evaluation guidelines. Business management literature has already produced several papers and books on evaluating, forecasting, and predicting disruptive technologies. This chapter analyzes these sources and their corresponding methods in order to determine if their view on DTs fits with the theory of DSTs, what their evaluation methodology is and whether or not the methodology is applicable for evaluating DSTs. In the conclusion, the different criteria from several sets of literature will be evaluated for their use on DSTs. The most promising criteria will be used in the evaluation guidelines for DSTs. The different research groups and their DT prediction methods reviewed in this chapter are:

1. Seeing What's Next Methodology [RD 2]
2. SAILS Methodology [RD 25]
3. Linear Reservation Space Methodology [RD 26]
4. Value Trajectory Methodology [RD 27]
5. Scenario Planning Methodology [RD 28]
6. Measuring Disruptiveness Methodology [RD 29]
7. Propositional Framework Methodology [RD 30]

3.1 Seeing What's Next Methodology

Since this methodology was created by the creator of the theory Christensen, it also has a `classical´ view of Disruptive Technologies [RD 2]. This theory has been renamed to disruptive innovations in order to broaden the theory to encompass all types of innovations. Besides the theory already discussed in the previous books, this book adds to the theory by clarifying that disruption is a process and not an event. It does, however, still focus on the fact that disruption is affecting technology dynamics as well as competitive dynamics. This means that in order for a technology to be disruptive, it should be promoted by a new entrant and disrupts the business of an incumbent. It also states that Disruptive Technologies are a relative phenomenon. In other words, what is a disruptive innovation to one company may be a sustaining innovation to another.

This book provides a supplementary viewpoint on DTs, as evident by the statement of Christensen, Anthony & Roth [RD 2]: *"While the two previous books were aimed at managers inside firms who wanted to defend against or attack with a disruption, Seeing What's Next is written for those who watch industries from the outside, and who must make important decisions based on what they see. It will help executives, analysts, investors, and others who have a stake in a specific industry to evaluate the impact of innovations, the outcomes of competitive battles, and the moves made by individual firms — and to make smarter business decisions, forecasts, and stock recommendations based on those evaluations. The goal here [in Seeing What's Next] is to dramatically increase the odds of getting things right in the arena where wrong decisions could be devastating."*

The methodology described by Christensen, Anthony & Roth [RD 2] can be used by decision makers and business analysts to predict a DT by predicting industrial change according to a three-part process:

1. Identify signals of change
2. Evaluate competitive, head-to-head battles between companies loosely classified as "attackers" and "incumbents"
3. Formulate appropriate strategic choices that can influence the outcome of competitive battles

These different steps are interlinked according to the model depicted in Figure 3-1:

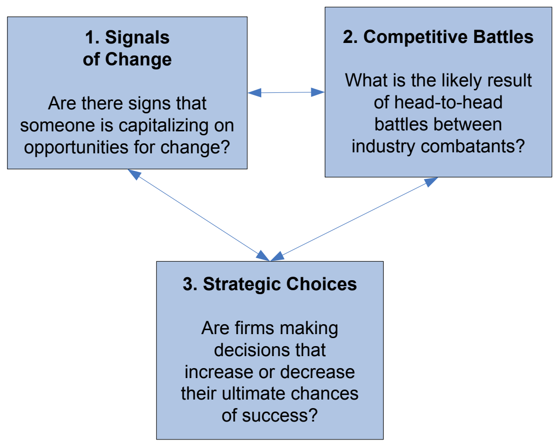

Figure 3-1: Overall method to predict an industry change (disruption) [RD 2]

The first step of the methodology is to watch for signals of change. This includes the analysis of customers of a certain dominant technology. Since DTs often emerge from a niche market, before disrupting a dominant market, the analysis of undershot (technical performance is not as high as demanded), overshot (technical performance is higher as demanded), or noncustomers is imperative. In addition nonmarket context should be analyzed; these are signs that nonmarket players are taking action to increase or decrease specific barriers to innovation. These signs are often regulatory or political in nature. These signals of change are also depicted in Figure 3-2.

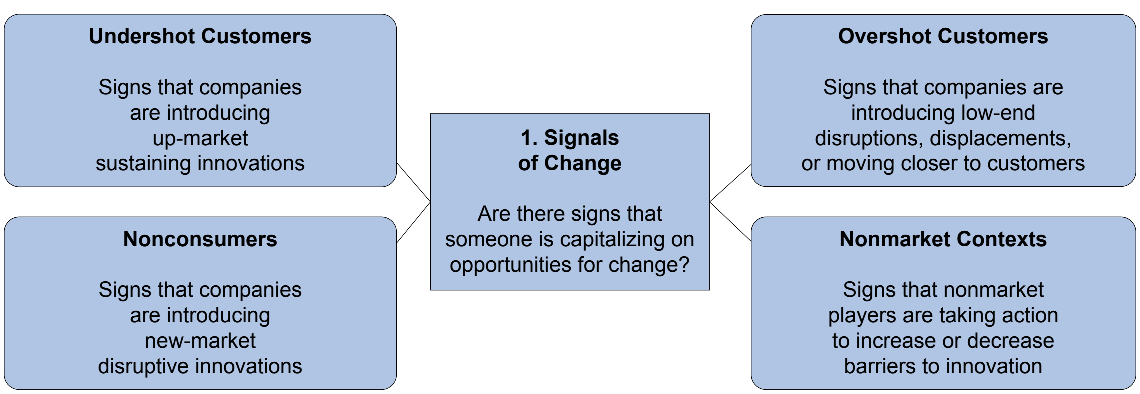

Figure 3-2: Signals of Change [RD 2]

The second step of the methodology includes the evaluation of competitive battles between newcomers and incumbents. This step resembles a Strength, Weaknesses, Opportunities and Threats

(SWOT) analysis of the entire industry. It aims on finding new entrants, which are capable of producing a DT, while analyzing the incumbents in their strength and weaknesses to defend themselves. This is also depicted in Figure 3-3.

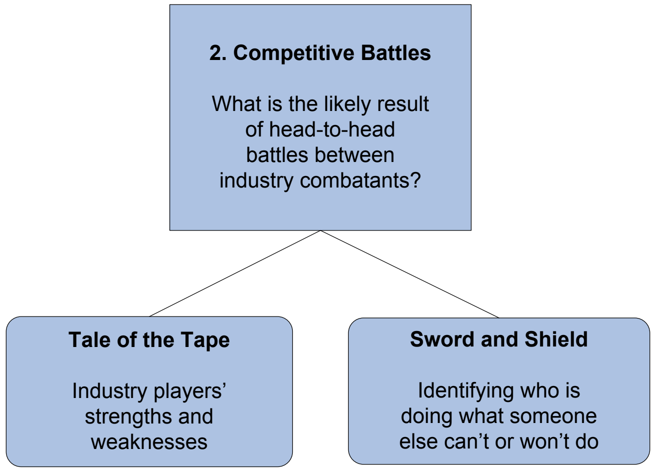

Figure 3-3: Competitive battles [RD 2]

The third part of the methodology focuses on the strategic choices companies make. The strategic choices focus both on the entrants and the incumbents. The incumbents are measured by their experience in dealing with DTs in the past, while entrants are measured on their preparation of gaining a foothold in the market and their value networks. This is also depicted in Figure 3-4.

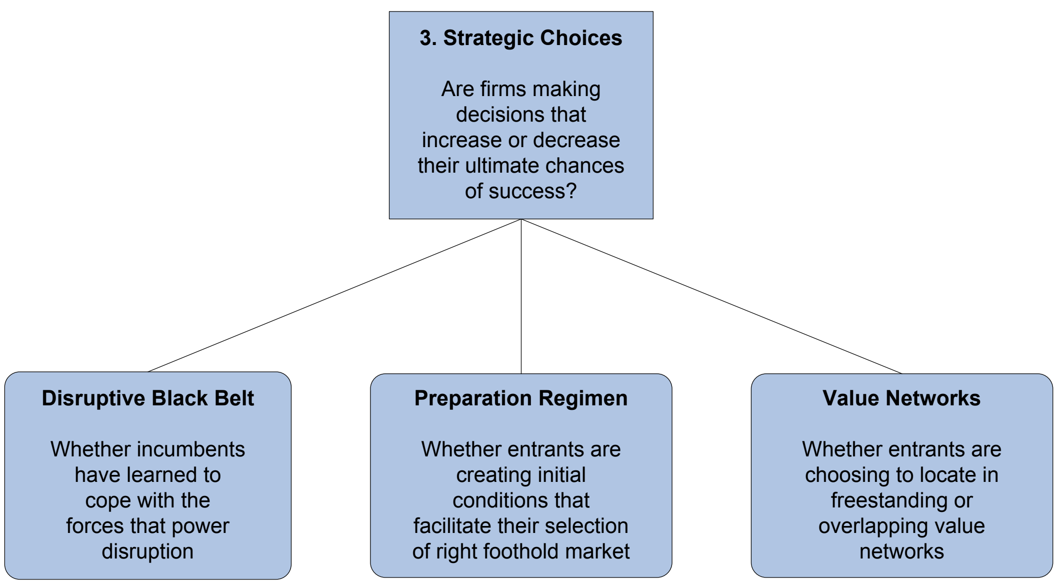

Figure 3-4: Strategic choices [RD 2]

The methodology of Seeing What's Next is only partially applicable to the space sector. Especially the signal of change step is promising as it analyses customers rather than businesses. This is applicable to Disruptive Space Technologies because this also focusses on customer demands instead of competitive battle between companies. For this reason the competitive battles and the strategic choices are not applicable with respect to the DST theory.

3.2 *SAILS Methodology*

The view of the Standards, Architectures, Integration, Linkages and Substitutions (SAILS) methodology on DTs is rather rudimentary. In the first section, Vojak & Chambers [RD 25] distinguish DTs as being equal to radical, discontinuous, and emergent improvements. This is deviant from almost all other scholars who perform research on DTs. However, since the DST theory deviated from the normal DTs as well, criteria or factors influencing disruption might still be applicable to the theory.

The SAILS methodology is based on five components, which are recurring contributors to disruption at the subsystem level of the value chain. These five components are explained in Figure 3-5.

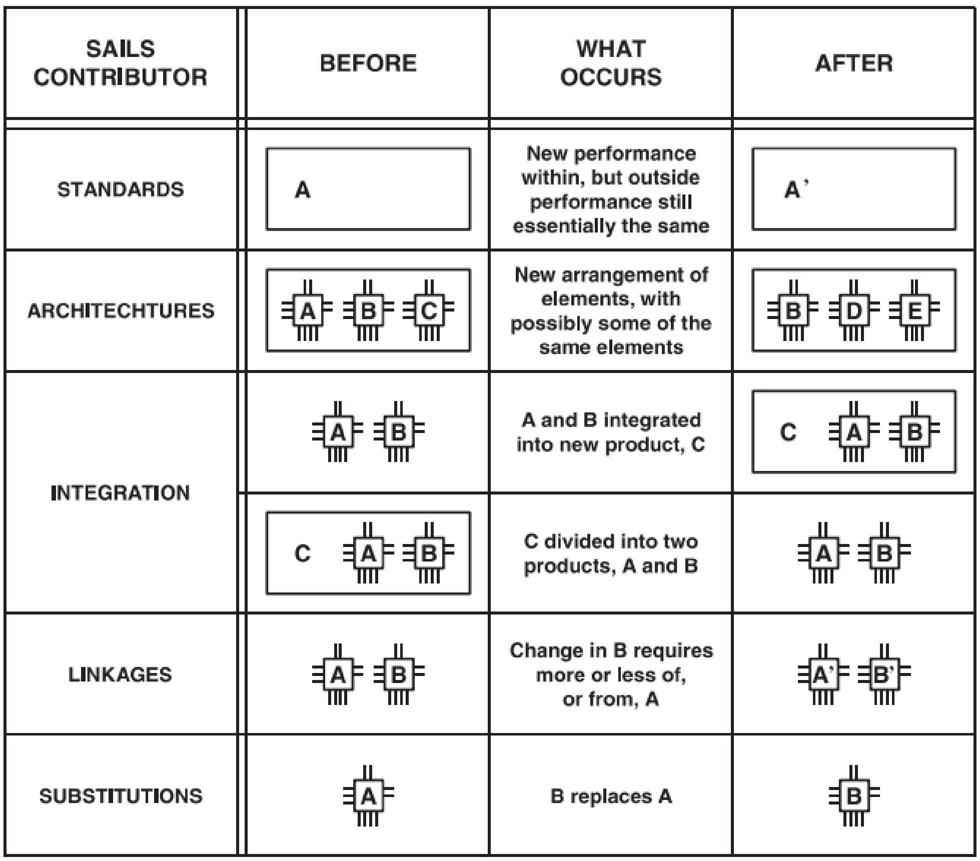

Figure 3-5: Summary of the five components of the SAILS methodology [RD 25]

The methodology involves a design engineer taking a bill of materials and applying the five perspective of the SAILS methodology. The applicable methodology of the components can be described as follows [RD 25]:

Standards

The process begins with the designer seeking to understand what the trends are for industry standardization at various levels of the value-added chain and how they impact product performance characteristics. Standards are common in every industry and determine levels of performance, compatibility, technology interactions etc. Participation in the standards process is an excellent way to gain oversight in various standardizations.

Architecture

The designer moves to brainstorming of various architecture options available at each value-added level within the super system. These first two steps set the stage for the rest of the analysis.

Integration

The burden on the designer is to develop options for forward integration, backward integration, and lateral integration into the rest of the super system. It also involves putting oneself in the position of the designer of other portions of the super system and determining to what extent your product (or some portion of the function of your product) could be a potential target of disruption. This part of the analysis must be repeated for each standard and architecture option under consideration. In addition, various sequences and combinations of disintegration and reintegration must necessarily be considered. Often a blank paper approach to meeting the system or subsystem requirements is helpful.

Linkages

One of the most difficult (and most rewarding) task is the identification of linkages between the functional performances of all portions of the product with the performance of all other elements of the supersystem. This part of the analysis also must be repeated for each standard and architecture option under consideration.

Substitutions

This step is challenging since it requires the designer to seek out what he or she may currently not be aware of, competitive threats to a component of your product or some portion of the product that may radically replace that element. As much as with the other elements of the methodology, this requires a proactive scanning of the technical literature to know what is out there as well as to evaluate the level of threat or opportunity it provides. The net must be cast very widely as the most disruptive substitutions can occur quickly through the adoption of a component or subsystem that has already been developed for a very different application.

The SAILS methodology is not really applicable for DSTs as an evaluation method as it merely provides a layout for analyzing potential breakthrough innovations on a sub-system level. This makes it hard to use for evaluating technologies for their future success but rather in the selection of technologies for sub-system design purposes. It does however provide an interesting methodology for space systems designers to identify and apply breakthrough technologies.

3.3 Linear Reservation Space Methodology

Schmidt & Dreuhl give a modified definition of the Disruptive Technology theory [RD 26]. They claim that the theory of DTs should relax the constraint that DTs should be introduced by new entrants. This is especially true for the space sector as technology development is mostly the product of institutes and research groups, while being built by industry, thus excluding any possibility of disrupting incumbents. Additionally, it categorizes the market in which DTs can diffuse according to the position of the market. This means that disruption can occur in fringe-markets, detached-markets and intermediate scenarios. The theory is well applicable to the space sector as spin-off and spin-in of technologies is essential for the future of the space sector [RD 29]. Table 3-1 lists the type of diffusion, the disruption, and examples of different types of innovations.

Table 3-1: Mapping the Type of Innovation to the Type of Diffusion [RD 26]

Type of Innovation	Type of Diffusion to which It Maps	Description	Example
Sustaining Innovation	High-end encroachment	The new product first encroaches on the high end of the existing market and then diffuses downward.	Pentium IV relative to Pentium III
Disruptive Innovation	Low-end encroachment	The new product first encroaches on the low end of the existing market and then diffuses upward.	
New-Market Disruption	Fringe-market low-end encroachment	Before encroachment begins, the new product opens up a fringe market (where customer needs are incrementally different[a] from those of current low-end customers).	5.25 inch disk drive relative to 8 inch drive
	Detached-market low-end encroachment	Before encroachment begins, the new product opens up a detached market (where customer needs are dramatically different[a] from those of current low-end customers).	Cell phone relative to land line
Low-End Disruption	Immediate low-end encroachment	Low-end encroachment begins immediately upon introduction of the new product.	Discount relative to department stores

[a] The distinctions between fringe and detached markets and between incrementally and dramatically different preferences are illustrated in the disk-drive examples provided herein.

The framework introduces a three-step approach based on the linear reservation space model [RD 26]. These steps and their descriptions are:

Step 1: Identify market segments and primary attributes of the product

This step involves the identification of the dominant technology's market segment and its primary performance attributes. In addition, it must consider the new market segments and assess along which other performance attributes they might compete.

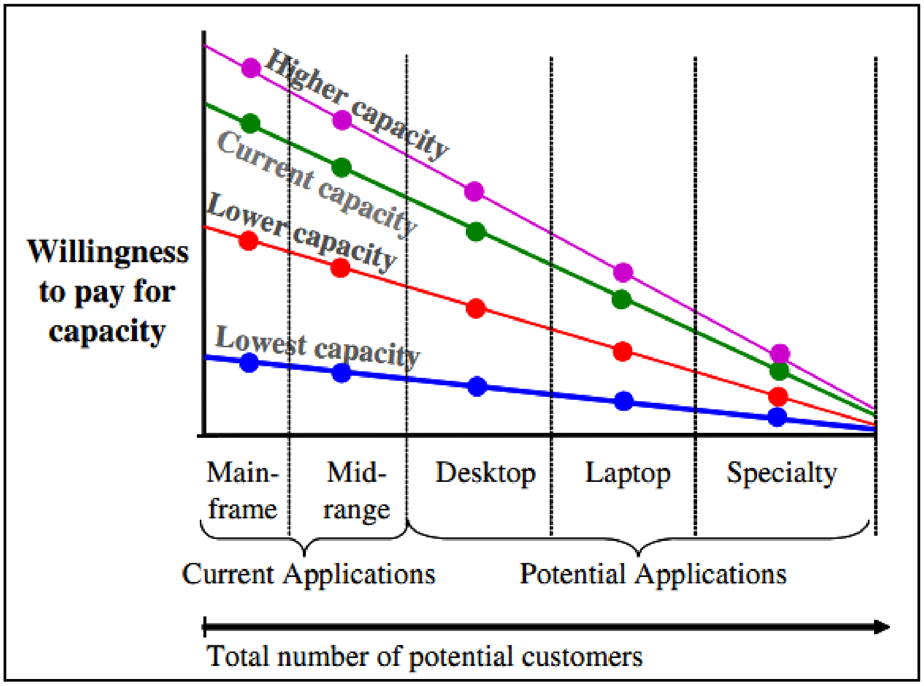

Figure 3-6: Willingness to pay for Capacity as a function of market segment [RD 26]

Step 2: Assess each market segment's willingness to pay for each attribute

This step involves the assessment of the willingness to pay for each market segment. It does this by plotting the willingness to pay against the market segments as illustrated in Figure 3-6. As can be seen, every market segment has a different willingness to pay for either the current, higher, lower, or lowest capacity (capacity is measured in bits). In general the mainframe segment is willing to pay much more for higher performance in capacity than laptop and specialty markets are willing to do.

Step 3: Assess which segments will buy a given new product over time

The third and most complicated step will involve the forecasting of how the sales of the new technology will increase at the cost of the sales of the dominant technology. This is done by introducing a new reservation price line for every market segment. This step is also the most complicated as no explicit method of how to do this is given by the authors. An illustration of this method is given in Figure 3-7, where sales of an old technology (in this case hard disk drives), is overtaken by a new technology.

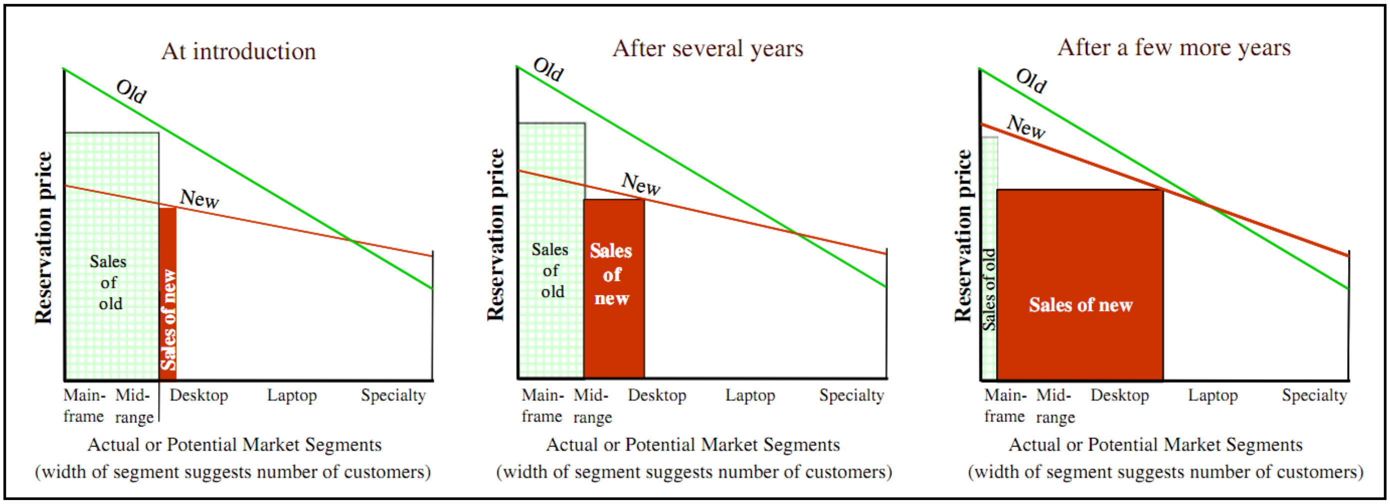

Figure 3-7: Example of a Low-End Encroachment [RD 26]

The three step process fits very well to the theory of DSTs. Especially the first step, which involves the identification of different market segments and the identification of performance attributes, is applicable for evaluating DSTs. The second and third step are less applicable, however, because they are very hard to determine for the space sector. In general, the willingness to pay for performance per market segment and the prediction of low-end encroachment requires information, which is not possible to get for the space sector. This is caused by the complexity of space technologies, which causes it to compete on multiple performance attributes. In addition, determining the sales over time in competition with the dominant technology is impossible as too many factors are influencing this to give any accurate form of prediction.

3.4 Value Trajectory Methodology

Adner [RD 27] views DTs as innovations that are over performing upon an alternate performance dimension. He states that: *"DTs are technologies that introduce a different performance package from mainstream technologies and are inferior to mainstream technologies along the dimensions of performance that are most important to mainstream customers."* This view coincides with the DST theory, stating that a DST is a technology over performing a dominant technology upon an alternate perceived performance mix. Additionally, Adner [RD 27] mentions nothing on the competitive battles between incumbents, a condition which is also relaxed for DSTs.

When a technology emerges, the technology is valued by the customers mainly on its most critical performance value [RD 27]. Over time however, when the initial basic functionality or functional threshold is reached, the perceived performance package (mix) of the technology starts to change. This is because, even though customers still appreciate a performance gain on the critical performance value, they do not want to make concessions to other performance attributes like e.g. cost, flexibility, and simplicity. Therefore, customers do not want to make concessions for performance they do not need; the mainstream market divides itself into different market niches that value different aspects of performance. Adner explains this by taking an example out of the microprocessor industry and compares the Pentium processors to the Celeron processors [RD 27]. He states that even though the Celerons are technological inferior to the Pentiums, the Celeron was and still is very successful because it targets a market segment that values low cost more than high technical performance. Each performance attribute is valued differently according to the customers in the corresponding market niche. This process is illustrated in Figure 3-8 by the value trajectory, which is a two-dimensional representation of the perceived performance mix. The graph shows the value trajectory of a market segment that passes through several indifference curves. The indifference curve is a level of performance needed of a functional attribute by a customer. It has three levels; low-, medium-, and high-end market segments.

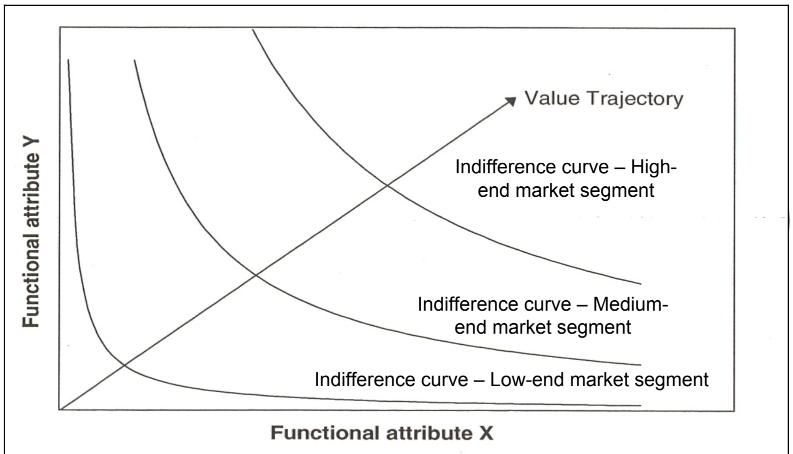

Figure 3-8: Indifference curves and value trajectory [RD 27]

Figure 3-9 shows an example of the value trajectory of a personal computer (PC) and a personal digital assistant (PDA). As can be seen, customers of a PDA technology are quickly satisfied with a low storage capacity while the portability attribute is valued much higher. The customers of the PC technology have an alternate perceived performance mix and value storage capacity higher than portability.

Other examples that have a value trajectory and indifference curves in this graph are netbooks, laptops, and tablet PCs. The phenomenon of changing value trajectories or changing perceived performance can also occur within one technology domain. For example, automobiles were first primarily valued on speed, after which aesthetics, functionality, and safety became more important attributes creating an indifference of most customers to maximum speed.

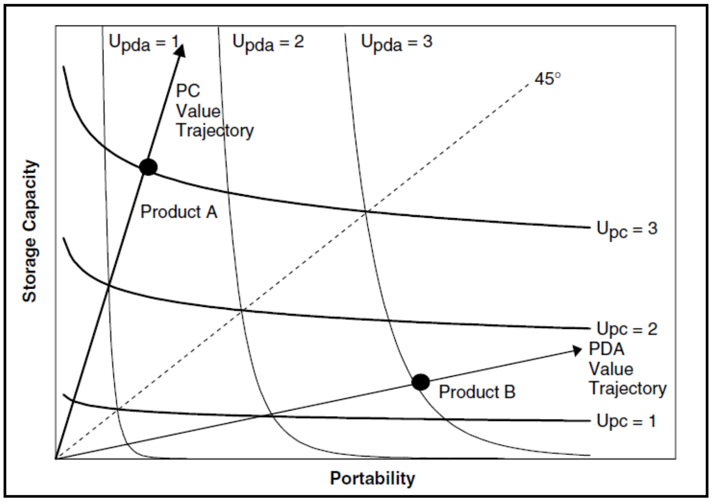

Figure 3-9: Value trajectories [RD 27]

The view of Adner coincides with the view of DST on technology disruption [RD 27]. Although the method of measuring a DST using value trajectories and indifference curves might be good tool for explaining technology disruption, it is too complicated to be used as an evaluation tool. Because the data for the modeling is already hard to determine on hindsight, this is even harder to predict. In addition, the value trajectory allows for a measurement of three performance dimensions (2 technical and one cost) which might not be enough for space technologies.

3.5 Scenario Planning Methodology

Through referring to multiple sources Drew begins with his analysis by pointing out that there are many, sometimes contradictory, studies on how to identify Disruptive Technologies [RD 28]. Because of this, Drew focuses on how to distinguish DTs but on the requirements for an environment which needs to be established to enable the identification of Disruptive Technologies. The main part of the paper thereafter describes on how to create this environment through use of 'scenario planning'.

As a result of his literature review, Drew summarizes five "core capabilities" required to develop strategies to cope with disruptive technologies:

1. Foresight into possible future paths of technology and innovation and their accompanying uncertainties
2. Capacity to absorb and manage new knowledge and to make sense of signals of impending change from the periphery
3. Creative thinking and strategic analysis skills in management teams
4. Flexibility and agility in decision making and planning for future action
5. Leadership that can build a culture of openness and commitment to change

To foster these capabilities, Drew suggests to use the so-called 'scenario planning' methodology [RD 28]. After originating as methodology to develop military strategies, Shell was the first civil company to employ scenario planning in the 1970s to prepare for "oil price shocks and major geopolitical events". Scenario planning was afterwards adjusted to also cover the field of technology innovation and Drew recapitulates its current "essence" as:

- Analysis of multiple views and different perspectives on the future
- Combination of traditional research with expert opinion and judgment
- Organizational learning and systems thinking
- A comprehensive and open approach to understanding competition and the business environment
- Consideration of multiple stakeholders and their interests
- Critical and creative approaches to strategic thinking
- Use of storytelling and strategic conversation

Adapted to the specifics of disruptive technologies, Drew then derives seven basic steps (cf. Figure 3-10). Through all steps, the most important element is to involve multiple disciplines to be able to cover all aspects of an analysis and to establish a consistent understanding of the situation.

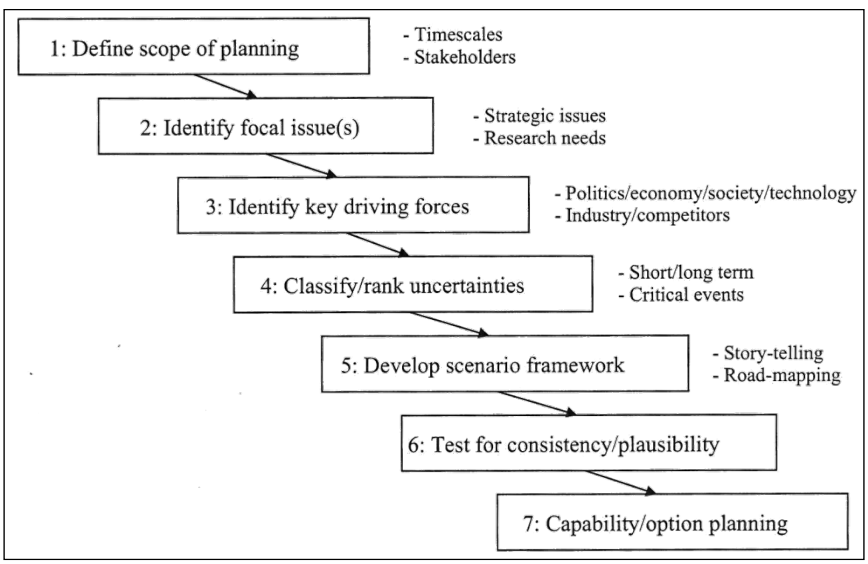

Figure 3-10: Steps of Scenario Planning [RD 28]

The first step is to *define* the global *scope* (time frame, involved parties, resources) after which the *focal issue(s)*, meaning the specific ideas or problems that are going to be investigated, is/are identified. Step three clarifies why the topic/technology needs to be considered by *identifying key driving forces*. As most analyses cannot cover all involved aspects, it is important to pinpoint unknowns and *rank* their importance with respect to each other as well as the overall goal (step four). In step five, up to four *scenarios* need to be envisioned, i.e. "how a new technology could be adopted" or "how uncertainties could affect the development", to establish a so-called *framework* covering a wide range of views on possible future outcomes. These views are afterwards validated through the *test for consistency/plausibility* in step six to form the baseline for the final decision process (step seven, *capability/option planning*) on whether or not a technology has the potential become disruptive.

The methodology of Drew [RD 28] focusses mostly on scenario planning for DTs. In the summary, he states that one of the aspects within his approach is *"identifying technologies that are potentially disruptive"*. However, the method in actually provides no tools of how to do this. The whole method rather focusses on creating three to four scenarios of things that might happen in the future. Because of this, the method is very hard to apply to DST evaluation because it focusses on general future scenarios rather than practical technology level evaluation.

3.6 Measuring Disruptiveness Methodology

Govindarajan and Kopalle [RD 29] classify Disruptive Technologies into two classes: low- and high-end. To be able to cover both types in their current evaluation, the authors defined a conceptualization of disruptiveness of innovations:

"A Disruptive Technology introduces a different set of features, performance and price attributes relative to the existing product, an unattractive combination for mainstream customers at the time of product introduction because of inferior performance on attributes these customers value. A different customer segment may however, value the new attributes. Subsequent developments over time, however, raise the new product's attributes to a level sufficient to satisfy mainstream customers, thus attracting more of the mainstream market."

After having conducted studies on how to assess the disruptiveness of innovations the authors identified five characteristics of disruptive innovations [RD 29]:

1. The innovation underperforms on the attributes mainstream customers value
2. The new features offered by the innovation are not valued by the mainstream customers
3. The innovation typically is more simple and cheaper and is offered at a lower price than existing products
4. At the time of its introduction, the innovation appeals to a low-end, price-sensitive customer segment, thus limiting the profit potential for incumbents
5. Over time, further developments improve the innovation's performance on the attributes mainstream customers value to a level where the innovation begins to attract more of these customers

However, in their current evaluation, the authors point out, that these characteristics only apply to so-called low-end disruptions [RD 29]. These low-end disruptions, in contrast to radical disruptions, improve upon existing products instead of being based on new technologies.

A second remark regarding the previously studied approach is that it can only be applied *ex post*, i.e. once the technology already entered the market. The authors propose to utilize the experience from these ex post analyses to make ex ante predictions [RD 29]. As the distinct disruptive innovations are subjects to the companies' field of expertise, the authors concentrate on evaluating the "*type of company better able to develop such innovations.*" To be able to measure this organizational ability, two variables were identified:

- Customer orientation
- Technology opportunism

They derive these two variables from their previous work, stating, that the most important requirements for disruptive innovation are a clear understanding of the customer's need as well as the ability to discover and utilize new technologies [RD 29].

There is no clear method proposed, rather characteristics which a disruptive technology should have. Even though the characteristics fit to the theory of DSTs, a lack of a described method makes it hard to be applied. It might be that the method developed in TN01 for measuring performance (perceived performance mix) is applicable to measuring these characteristics. Because of this, the theory might still be useful.

3.7 Propositional Framework Methodology

The definition of Disruptive Technologies of Sainio & Puumalainen [RD 30] is based on the view of Christensen but includes some additions: "*the technology enables changes in product characteristics, added value and product-market positions, destroys the existing competences of a firm, and drives or enables changes in the value network*". According to the researchers, for this method "*the technology must be strategically important and relevant to the company*" to be a Disruptive Technology [RD 30]. This method is very corporate-oriented and therefore selected parts are less applicable to DSTs.

The evaluation method combines the determination of the disruptiveness potential of a technology and the effect of the technology on the company. The principle of the evaluation method uses a propositional framework to examine the properties of a technology and to evaluate the potential of disruptiveness. Therefore, two variables are created: the technology's disruptiveness potential and its strategic importance to the firm. These variables become affected by five propositions. The sixth proposition is an analysis tool for the results of the variables. The propositions, together with the sub-questions how the proposition can be answered, are listed below.

Proposition 1: If the technology enables changes in product characteristics and added value, it is potentially disruptive.

- Is the value proposition different from other applications in the market?
- Does it change the added value to customers?
- Does it respond to new customer needs? Does it require the customer to change his or her behavior?
- Is the new knowledge demanded of customers?

Proposition 2: If the amount of uncertainty related to markets and technology is high, the technology is potentially disruptive.

- What is the associated amount of uncertainty related to the technology?
- What kinds of factors affect technological uncertainty?
- What is the associated amount of uncertainty related to the markets of the technology applications?
- What application-related factors make markets uncertain?

Proposition 3: If the technology enables or drives changes in product-market positions, the technology is potentially disruptive and of strategic importance to the firm.

- Does the technology change the focus of the mission?
- Does it create new markets or customer groups?
- Does it cannibalize existing services?
- Does it enable new forms of earnings logic?
- Is it a product or process innovation? In which product groups?

Proposition 4: If the technology is competence-destroying, it is potentially disruptive and of strategic importance to the firm.

- Is the technology competence-destroying or –enhancing? In which competences or resources?
- Is it expertise- or knowledge-destroying?
- How does it contribute to the knowledge base of the company? Is it a logical continuation of existing knowledge or does it require new knowledge?
- Do commitments to existing technologies limit the use of the technology?

Proposition 5: If the technology drives or enables changes in the position of players in the value network, it is of strategic importance to the firm.

- Does the technology increase or decrease co-dependency in the value network?
- Does it change the power positions of the actors in the value network?
- Does it require new actors in the network?

Proposition 6: The greater the disruptiveness potential and the greater the strategic importance of the technology, the more radical the changes in the firm's business model will be.

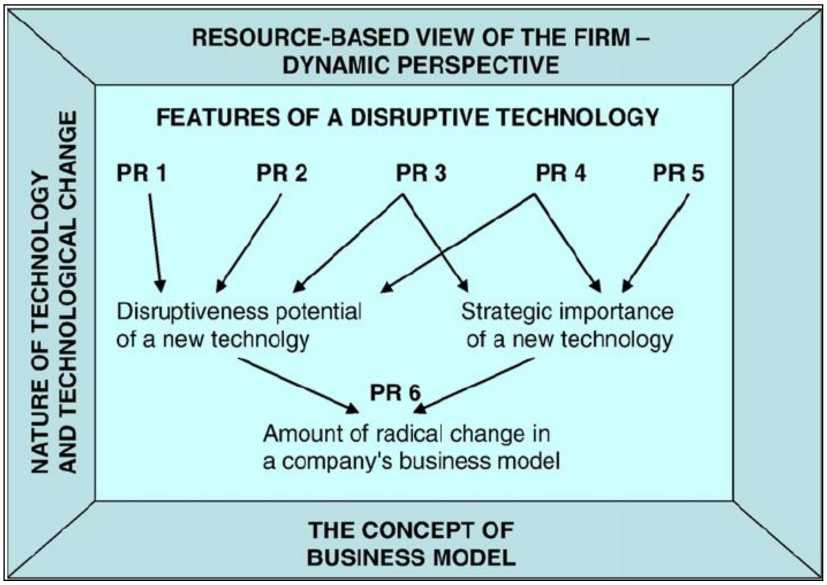

Figure 3-11: Propositional framework [RD 30]

Figure 3-11 shows the structure of the evaluation method; how each proposition (PR) interacts with the two variables and how these affect the business model of the firm.

Also the second proposition might be applicable to DSTs, although not as much as the first one. This proposition deals with the uncertainty in the market which might be an indicator for disruptiveness. Propositions 3, 4 and 5 are too much company oriented to be applicable to DSTs. This is also shown in Figure 3-11, where it shows that propositions 1, 2 contribute to the disruptive potential, while 3, 4 and 5 contribute to the strategic importance to firms.

3.8 Conclusions

In the present chapter, the analysis with the most promising literature with respect to evaluating and predicting DTs is described. The methods haven been reviewed on their view of Disruptive Technologies, methodology used and their fit to evaluating potential DSTs is. So far none of these methods are empirically proven on their accuracy, thus theoretically any of these methods might lead to finding DTs. A common factor within all methods is using criteria for evaluating potential technologies or market factors. In Table 3-2, the different methods, criteria, applicability to DST and correlating view to the theory of DST is shown. As can be seen, several methods show promising criteria for evaluating DTs. The most promising criteria are used in the evaluation guidelines for DSTs.

Table 3-2: Conclusion criteria for potential DTs

Method / Criteria	Applicability to DST *
Seeing What's Next Methodology	
Signals of Change	5
Competitive Battles	1
Strategic Choices	1
SAILS Methodology	
Standards	2
Architecture	1
Integration	1
Linkages	1
Substitutions	2
Linear Reservation Space Methodology	
Assess performance attributes	4
Willingness to pay for attribute	2
Assess buy of new product over time	1
Value Trajectory Methodology	
Indifference curves	3
Value trajectory	2
Scenario Planning Methodology	
Define scope of planning	1
Identify focal issues	2
Identify key driving forces	3
Classify/rank uncertainties	3
Develop scenario framework	2
Test for consistency/plausibility	2
Capability/option planning	1
Measuring Disruptiveness Methodology	
Underperforms on the attributes mainstream customers value	5
The new features offered by the innovation are not valued by the mainstream customers	4
Innovation is simple and cheaper	4
At the time of its introduction, the innovation appeals to a low-end, price-sensitive customer segment	3
Over time, further developments improve the innovation's performance on the attributes mainstream customers value to a level where the innovation begins to attract more of these customers	2
Propositional Framework Methodology	
If the technology enables changes in product characteristics and added value, it is potentially disruptive.	5
If the amount of uncertainty related to markets and technology is high, the technology is potentially disruptive.	4
If the technology enables or drives changes in product-market positions, the technology is potentially disruptive and of strategic importance to the firm.	2
If the technology is competence-destroying, it is potentially disruptive and of strategic importance to the firm.	3
If the technology drives or enables changes in the positions of players in the value network, it is of strategic importance to the firm.	2
The greater the disruptiveness potential and the greater the strategic importance of the technology, the more radical the changes in the firm's business model will be.	2

* 1, Not applicable 2,Slightly applicable 3, Reasonably applicable 4, Applicable 5, Very applicable

These criteria or a variation on them will be used for the Evaluation Guidelines for DSTs. In the next chapter a range of criteria (including the ones identified as applicable to DSTs within this chapter) will be presented which might indicate a potential for disruptiveness within space technology concepts.

4 Criteria Definition

This chapter describes the evaluation criteria that measure the disruptiveness of space technology concepts. Sources of these criteria are the theory of DSTs elaborated in TN01 and the criteria from different DT prediction methodologies (cf. Chapter 3). The different criteria from these sources are sorted into the four categories of the macro-environmental domains of the STEP analysis [RD 62]:

- Social Domain
- Technological Domain
- Economic Domain
- Political Domain

The goal of this chapter is to gather the criteria that indicate a potential for disruptiveness within space technologies. Only the ones with the highest potential to measure disruptiveness are used in the DST evaluation guidelines and therefore not all criteria are used. Some of them aim at measuring the disruptiveness of a DST candidate while others have more of a classification purpose. Additionally, some criteria require a higher workload than others or need to be applied for an extended period of time in order to act as an indicator for the measurement of disruptiveness. Nevertheless, the identified criteria can also be used as a general guideline handbook for evaluating DST candidates. This can be helpful in regard to later technology evaluation activities within ESA.

In the conclusion of this chapter, the criteria are assessed with respect to the strength of their disruption indication and the required workload to measure it. Additionally, they are ordered according to the most promising methods for evaluating DSTs (cf. Chapter 2).

4.1 Social Domain

The factors within the social domain influence technology diffusion within the space sector by influencing the demand of the technology. This means that if the public perception of a technology changes, the investment decision makers will be influenced in their technology development decision. The social domain is fairly weak compared to the other domains but might nonetheless provide an indicator to disruptiveness. The social domain can be measured according to a range of criteria, which are be explained and elaborated below.

Criterion 1.1: What is the amount of media attention the DST candidate receives and is there an increasing trend?

One of the indicators of disruptiveness could be the attention a DST candidate receives, because an increased attention indicates the extent to which people perceive a technology as useful or valuable. One way to measure this attention would be to see how much media attention a DST candidate receives. This criterion counts to the so called soft factors and was derived from the Goal Analysts method of Section 2.3. This factor should be observed time-dependently since the change over time can shed light on certain trends (e.g. increasing, stagnating or decreasing trend).

Criterion 1.2: How many research publications exist on the DST candidate and is there an increasing trend?

This criterion is derived from the Goal Analysts (Section 2.3). Although media attention is a fairly strong indicator, they are usually behind the scientific community in describing space technology concepts. Because of this, it might also be good to check the number of research publications on conference proceeding or in journals to check the scientific attention a DST candidate receives. This factor should also be observed time-dependently since the change over time gives information about certain development trends.

Criterion 1.3: How many patents were filed on a DST candidate or a similar field and is there an increasing trend?

Similar to criterion 1.1 and 1.2, patents can give some indication on the activity within a certain technology area. The patent factor however, focuses more on the commercial attention a space technology receives. This criterion is also described in Section 2.3. This patent analysis can be done by analyzing patent databases. A measure over time can lead to an insight in trends and thus indicate the potential for disruptiveness of a space technology concept.

Criterion 1.4: How active is the research field of a DST candidate? (e.g. amount of active research groups)

Another indicator for measuring disruptiveness (or the potential for disruption) is the observation of the activity level within the candidate's research field. How many research groups are active in the research field of interest? Are there new groups pulling in or out? Are the different R&D budgets increasing or decreasing over time? Those kinds of questions can give information on the general activity level of the research field. Although this criterion has some similarities with criterion 1.2, which measures the research attention through publications, it is listed here since it describes attention within a broader context.

Criterion 1.5: Does the DST candidate pose an ethical dilemma/ problem? And if so, how severe is it?

If the usage of the technology creates any ethical dilemmas, public perception might turn and decrease the potential for disruptiveness. The ethical dilemma focusses on the severity of the risk versus the potential benefits. For example, sending a nuclear reactor into space might radically improve performance but a launch failure might contaminate an area with radioactive waste for hundreds of years.

Criterion 1.6: Does the use of the DST candidate lead to advantages /disadvantages with respect to the environment?

Using a technology might lead to advantages or disadvantages to the Earth's environment. Examples of this would be toxic chemicals in boosters (disadvantages) or space based solar power, decreasing dependency on fossil fuels (advantages). Society's opinion on the benefits of space technologies is partially governed by these benefits or drawbacks.

Criterion 1.7: Does the use or development of the DST candidate promote global cooperation?

International cooperation in space can lead to cooperation in a number of other areas as well. Because of this, space technologies can contribute in creating international understanding and peace. A technology's contribution to global cooperation benefits to a technology's potential for disruptiveness.

Criterion 1.8: Does the DST candidate contribute to the solution of other social problems? (E.g. depletion of non-renewable resources, healthcare, malnutrition)

Today, our society faces many different problems (e.g. depletion of non-renewable resources, healthcare, and malnutrition). If a technology can help solve problems, it will be viewed as more valuable by society and therefore have a higher potential for disruptiveness.

4.2 Technical Domain

The technical domain measures factors like performance and impacts on other systems. The technical domain is the most important evaluation segment because an over performing technology (in several different performance attributes or metrics) is essential to disruption. Because of this, the technical performance of a technology concept versus the state-of-the-art has to be determined. It is important that the technology does not need to be obviously better than the state-of-the-art (as this would merely identify a sustaining innovation) rather that a group of customers of the technology finds the performance more suited to their needs than the state-of-the-art. It is necessary to make a clear distinction between performance requirements of a technology and performance attributes. Performance requirements are factors, specific to the space environment, that have to be fulfilled in order to function. Performance attributes are performance metrics, which differentiate technologies from each other and cause disruption (e.g. efficiency, thrust, lifetime, mass).

Criterion 2.1: Does the technology fulfill or could it fulfill the technology requirements with respect to the space environment?

In order to evaluate the possibility of a technology candidate to become a space technology, one evaluation factor is to assess, if a general suitability for the harsh space environment exists or if the technology can be adopted in this direction. Here are some environment requirements that most space technologies have to fulfill:

- Function despite high energy radiation (both ionizing and electromagnetic)
- Resistance against extreme temperatures
- Function under large and frequent temperature variation
- Resistance against micrometeoroid and orbital debris impacts
- Function within a vacuum
- Cope with shocks and (de)acceleration (during launch and reentry)
- Cope with limited opportunities for repair or adjustments after launch

Table 4-1: Primairy and secondary performance attributes of selected domains

Primairy performance attributes		
Mass		Lifetime
Volume		
Secondary performance attributes		
Spacecraft Electrical Power		***Materials & Processes***
Power output max		Plasticity
Reliability		Flexural strength
Durability		Conductivity
Radiation risk (RTGs and Nuclear)		Corrosion resistance
Temperature insensitivity (Solar Cells)		Specific mass
Efficiency (Solar Cells)		Compressive strength
Radiation resistance (Solar Cells)		Hardness
Cell voltage (Batteries)		Thermal conductivity
Charge cycles (Batteries)		***Propulsion***
Energy density (Batteries)		Specific Impulse
Storage capacity (Batteries)		Thrust
Cycle times (Batteries)		Reignitability (Chemical)
On-Board Data Systems		Environmental impact (Chemical)
Power consumption		Throttle ability
Processing power		Reusability (Chemical)
Memory		Propellant toxicity (Chemical)
Data storage		Power consumption (Electric)
Precision		
Failure resistance		

Criterion 2.2: Does the technology over perform the state-of-the-art on the perceived performance mix?

Technologies within the space sector are very diverse and their performance attributes or dimensions are different for every technology domain. By example of the first step in the methodology from Schmidt & Dreuhl (Section 3.3), these attributes will have to be found in order to compare the technology to the state-of-the-art [RD 26]. This is also confirmed within the first proposition of Section 3.6, which states: "*If the technology enables changes in product characteristics and added value, it is potentially disruptive*" [RD 29]. The attributes can be divided into primary and secondary attributes; the primary attributes are shared by all technologies and the secondary attributes are technology domain specific. The primary attributes and some of the secondary attributes of the major domains selected in the search scope in Section 3.3 of TN01 are illustrated in Table 4-1.

Each technology has its own set of secondary attributes, depending entirely on the technology domain and the potential application. It is essential to assess the importance of these attributes according to different market segments and assess the performance of a potential DST on the attributes in comparison with the state of the art. In WP2000, such a method was developed. It is called the perceived performance mix and it measures the performance of a technology as perceived by a representative group of customers or market segment (e.g. universities, governmental space agencies, telecommunication satellite providers, research institutes). The perceived performance mix takes the form of a radar chart illustrated in Figure 4-1.

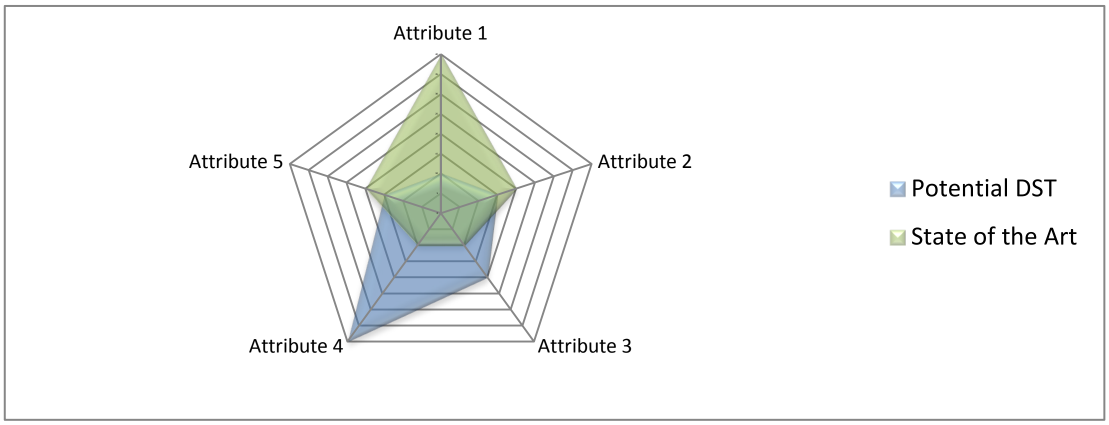

Figure 4-1: Example of the potential DST's and the state of the art's performance per attribute

If technology has a potential to be disruptive, it has to over perform the state-of-the-art on the perceived performance mix. In general a technology with a larger surface in a perceived performance mix, when compared to the state of the art, has a potential to become disruptive.

Criterion 2.3: On which aggregate level does the DST candidate act (material, component, subsystem, spacecraft, mission, or architecture)?

It might be good to assess the impact of the technology candidate on the space system. Technologies can influence different aggregate levels, depending on their field of application. For example, a technology can affect the material (M), component (C), subsystem (S/S), spacecraft (S/C), mission (MI), or architecture level. The higher the level of aggregation, the higher the impact of a technology or a technology concept is. Because of this, it is prudent to assess the aggregate level of the technology. This categorization has been more extensively elaborated in Chapter 3 of TN01.

Criterion 2.4: What is the level of complexity of the DST candidate?

The complexity level can give information about technical challenges a new technology has to face. The higher the complexity level, the higher are the technical challenges for the development team. These technical challenges are standing in direct relation to increasing development costs. A categorization under the economical domain of the STEP framework could also be done. Nevertheless since the development costs are already covered, a pure focus on the technical complexity seems advisable.

Criterion 2.5: Does the potential DST enable a new technology or an increased development rate of another technology?

Technologies can be enablers or catalysts for other developments. For example, carbon nanotubes have the potential to increase the development rate of technologies within the material science and electronics domain and potentially enable new technologies like the space elevator. Because of this, if a technology is an enabling or catalyst technology, it might increase its disruptive potential. These types of disruption have also been identified as indicators for disruptiveness within Subsection 2.5.5 of TN01.

Criterion 2.6: What is the technology's rate of performance improvement?

An important measure for disruption is the performance improvement of a technology over time. This will give an indication when, if at all, the potential DST will over perform the state-of-the-art. Although the signal strength of this criterion is high, it requires a work effort over several years in order to be effective.

The criterion is based on the theory of S-Curve extrapolation methods in Section 2.1 and the value trajectory in Section 3.4. With an SMT method approach (compare 2.4.1) from the *Counter Punchers* a continuous monitoring of a technology is executed and the performance values are plotted over time. An example of the performance of a technology plotted and extrapolated is illustrated in Figure 4-2.

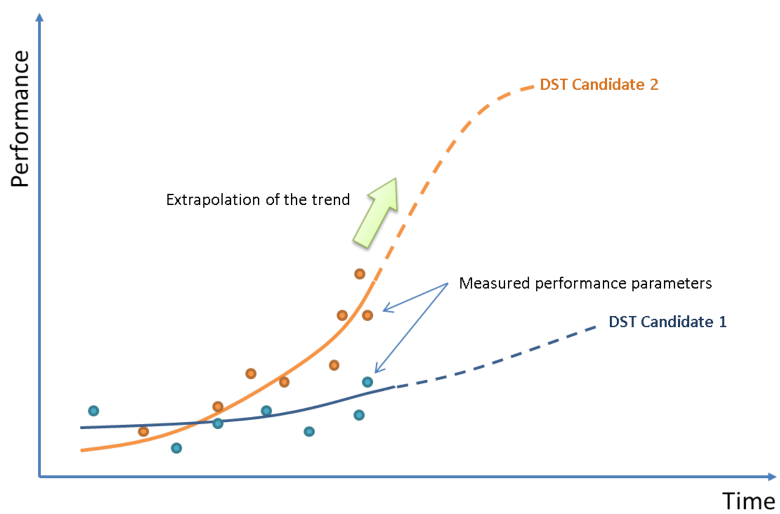

Figure 4-2: S-Curves of two DST candidate plotted and extrapolated

Criterion 2.7: What is the maturity of the DST concept?

This criterion examines the maturity of a DST candidate, which correspond with the key findings of the Precursor Trend Analysis (compare Subsection 2.2.2). In order to evaluate different DST candidates is necessary to know at which point in time of the life cycle phase the DST candidate is. This maturity index is not comparable with the TRL procedure within the space sector, as it measures the state of a technology before it enters a typically space system development. Indicators for this criterion could be the level of detail in which the DST candidate is described and how much research effort was already applied.

Criterion 2.8: What kinds of factors affect technological uncertainty? And what is the associated amount of uncertainty related to the DST candidate?

This criterion is derived from proposition 2 of the theory of Govindarajan and Kopalle, which was investigated in Section 3.6 [RD29]. In order to attain a clear view on this issue, one has to consider a multi factor analysis, which considers all influencing factors that contribute to the uncertainty. Within this analysis also aspects from the social-, political-, and economic domain need to be considered. Nevertheless, criterion 2.7 is listed in the technical domain, since technical uncertainties might be evaluated more easily than the other domains, especially at an early stage of the technology development. A *Best Engineering Estimate* (BEE) approach seems to be one time efficient solution for avoiding an increased work load.

Criterion 2.9: Does the DST candidate have a positive feedback on one or more bottleneck areas within the space sector? (e.g. space transportation, power conversion and in-space propulsion)

Bottleneck areas within the space sector are limiting the overall performance level of a space system and so limiting the overall performance of the space architecture. Some examples of bottleneck areas are space transportation, power conversion and in-space propulsion. Does the implementation of the DST candidate have positive feedbacks upon the space system or space architecture (even when it is not a technology specific to one of the bottleneck areas)?

4.3 Economic Domain

The economic factor measures the monetary aspects of space technologies. DSTs are defined as technologies that make operations simpler, cheaper, more flexible, and/or more responsive compared to the dominant technology. Economic aspects are of high importance in identifying space technologies. A rating on economic factors should encompass whether or not the technology concept provides significant economic benefits to its users.

The following criteria package deals with the different market types in which a disruptive technology can occur. As stated in Section 2.2 of TN01, missions are either in the civilian field or in a military market. These markets are, however, segmented in submarkets, which are again segmented in even more submarkets. If a technology is potentially disruptive then it should have an application within a set of missions in one of these markets. Building upon the theory of market encroachment [RD 26], the signal of change criteria [RD 2], and the specifics of the space sector, the following criteria are derived:

Criterion 3.1a: Can the DST candidate be transferred from a niche set of applications to a broader range of applications?

Criterion 3.1b: Does the DST candidate have the potential to be applied to a set of missions that require a lower performance than the state-of-the-art but are price sensitive?

Criterion 3.1c: Does the DST candidate have the potential to be applied to a set of missions that require a higher performance than the state of the art?

Criterion 3.1d: Is the potential DST originally a terrestrial application which has not previously been applied to the space sector?

The amount of economic benefits is determined by the perceived value of customers (e.g. universities, governmental space agencies, telecommunication satellite providers, research institutes). This discrepancy within the perceived value, allows the market to be segmented. The segmentation of the market leads to different methods of market encroachment for DSTs to be identified, as shown within the evaluation criteria review (Section 3.3) the following types of criteria, related to different market encroachments shall be used [RD 26]:

1. Niche-market encroachment (part of the market with different requirements, for example, small satellites)
2. Low-end encroachment (encroachment in a part of the market, where customers have a lower willingness to pay for performance, for example, the emergence of commercially available off-the shelf (COTS) parts)
3. High-end encroachment (encroachment in a part of the market where customers have a higher willingness to pay for performance, for example, Lithium-Ion batteries that are more expensive than NiH_2 batteries but their higher performance makes them more attractive)
4. Fringe encroachment (encroachment in a market that is similar to the mainstream market; for the space sector, these markets are potential sources for spin-in).

In order to be potentially disruptive, a technology has to fit within one of these markets. Several researchers have devised methods in order to identify customers of potential DTs and thus identify the possible market disruption. Christensen, for example, proposes to search for [RD 2]:

1. Undershot (technical performance is not as high as demanded)
2. Overshot (technical performance higher as demanded)
3. Noncustomers (customers whose needs are not being served yet)

The demand of customers of space technologies is, however, not the same as the consumer demand of products that most DT theory focusses on. As with consumers, the space technologies demand comes from a need for a solution to a certain problem or challenge. For space technologies, the needs and challenges are derived from a range of missions.

Criterion 3.2: What is the size of the potential market for the DST candidate?

A factor determining the success of a technology development is the potential market size (or the number of potential applications) of a technology. If this is high, then the technology development costs can be shared over a wide range of areas. If it is small then it could be that the technology might be too expensive to develop.

Criterion 3.3: What are the costs related to the material required for the technology and how high are the costs related to the handling of the technology after deployment?

The material characteristics of technology determine the cost of a technology and factors that lower cost are an indicator for disruptiveness. Because of this, the cost of the material can be essential when assessing the potential of a DST candidate. In addition the handling cost of a technology can determine the potential for disruptiveness. For example: green propellants have a lower performance compared to hydrazine but the handling costs are much lower.

Criterion 3.4: How high are the costs related to the development of the DST candidate?

Development costs are an essential indicator for evaluating technologies. Although the pure development costs are too complex to be an indicator for measuring the level of disruptiveness of a DST candidate, it can give additional information with respect to the adaption probability towards a space technology. The precision or accuracy of the development cost estimate is rather rough, especially when the uncertainty within the DST candidate's environment is high. Nevertheless, a Rough order of Magnitude (RoM) estimate in this category is helpful for the overall evaluation.

Criterion 3.5: How many potential applications with respect to space sector does the DST candidate inhabit? Does the technology provide a new value compared to the state-of-the-art?

This criterion is an adopted disruptive indicator of proposition 3 from Section 3.6. The criterion deals with the number of possible additional applications or features of a DST candidate when implemented in the space sector. By space sector several different aggregated levels can be meant, which are described in criterion 2.3 (the material- (M), component- (C), subsystem- (S/S), spacecraft- (SC), mission- (MI) or architecture (A) level). For example a DST candidate could act on component level (e.g. a new electric power storage system), but furthermore the technology could be implemented (in a modified manner) within a component of the structure subsystem (e.g. a deployable boom). Even jumps between the aggregated levels might be thinkable, like from SC to MI, or rather common from M to C. So, this criterion measures the added value of the DST candidate with respect to additional features that the technology could inhabit.

Criterion 3.6: Does the DST candidate have adjoining or partnering technology areas and what is the size and growth rate of this area(s)?

This criterion investigates the surrounding research environment of the DST candidate. An adjoining or partnering technology area could have similar research goals and similar development objectives than the DST candidate (compare Figure 4-3).

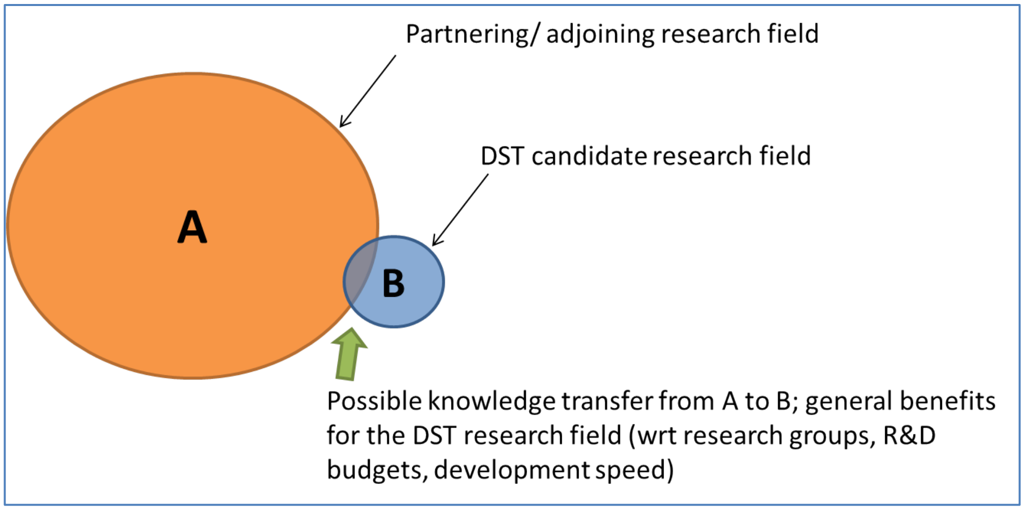

Figure 4-3: Example of a beneficial relationship of partnering research fields with respect to a DST candidate.

The DST candidate can benefit from research results within the partnering research domain. Here, it is necessary not only to identify the partnering research areas, but also to evaluate the size (and so the research output) and the time dependent growth rate (if present). For example could be a new innovative satellite fuel cell technology benefit from the research results of the automobile industry, which has a rather big research budget dedicated to fuel cell research within cars.

4.4 Political Domain

Section 2.2 of TN01 concludes that technology development is highly influenced by governments and thus political decisions. Because of this, the political domain is a fairly strong influence on the development of technologies.

Criterion 4.1: Does the DST candidate fit within the European space policy?

This political influence within the European space sector is documented within the European space policy. This policy is influenced by the representatives of participating nations and can be viewed as the overall strategy of the European space sector. It has identified that Europe must be able to respond to global challenges and to play a global role. This overall strategy results in the following objectives:

- To develop and exploit space applications serving Europe's public policy objectives and the needs of European enterprises and citizens, including in the field of environment, development and global climate change
- To meet Europe's security and defense needs as it regards space
- To ensure a strong and competitive space industry, which fosters innovation, growth and the development and delivery of sustainable, high quality, cost-effective services
- To contribute to the knowledge-based society by investing strongly in space-based science and playing a significant role in the international exploration endeavor
- To secure unrestricted access to new and critical technologies, systems, and capabilities in order to ensure independent European space applications

Criterion 4.2: Does the DST candidate fit within the technology objectives from ESA?

These objectives translated into a technology development strategy will result in the following:

"Technology development is an enabling activity. The objectives are to prepare future programs, strengthen European competitiveness, avoid dependence, balance innovation and product development / improvement, and benefit from spin-in" [RD 32]

Supporting this quote are ESA's technology objectives derived from the ESA Technology Strategy and Long-Term Plan [RD 32]:

1 Prepare and enable future space programs

2 Foster innovation in architectures of space systems, identification of disruptive technologies, and development of new concepts

3 Support competitiveness of industry in the European institutional and in the global commercial markets

4 Ensure European technology non-dependence / ensure the availability of European sources for critical technologies

5 Leverage technological processes and innovations outside the space sector to use and adapt them to design new space systems (spin-in); foster technology transfer for space to non-space applications (spin-off)

New technologies developments (and thus also DST candidates) have to fit within these policies in order to have a chance of being developed. Because of this, fitting in the European space policy can be seen as an important indicator for a potential DST. While the European space policy determines the direction and the strategy of the European space sector, the technology objectives state a very clear line along which technologies have to be developed. If a concept has a high potential for disruptiveness, it should fit in the policy stated by the governing bodies as well as the technology objectives.

	T1		T2		T3		T4	T5	T6	T7
External Impacts	Space race, Success of CERN, IGY		Success of Intelsat		Post-Apollo invitation, Failure of Europa		Spacelab problem	Invitation to ISS	End of Cold War	Further Commer-cialization
Org.	ESRO	ELDO	ESRO	ELDO	ESRO	ELDO	ESA	ESA	ESA	ESA
Leadership	Scientists	GB+F	GB vs. F	GB vs. F	F vs. GB	F vs. D	F+D	F+D	F vs. D	GB(?) or EU(?)
France	S, T	M, A, C	T, C, S	A, T, C	C, T, S	A, T/C	A, C, T	A, T	A, C, T	C, F, A
Germany	S, T	T	T/S	T	C, T/S	F*	T, A, C	T, A, S	F	C, F
Britain	S	F	T, S, F	F	C, T, S	F	C, T	C, F	C, F	C, F
Others	S/T	T	S/T	T, A	T/S, C	T, A	T, A/C	T, A	T, A, F	T, F, C
Europe	S	Fragile	T/S, C	Fragile	C/T, S	Fragile	A, C, T	A, T	Fragile	C, F vs. T
Institutional change	Creation of ESRO/ ELDO, protection of national logics		*Juste retour* (ESRO), 'go it alone' Creation of ESC		*À la carte* participation, package deal, Creation of ESA		European-ization of national programs	Re-emergence of Ministerial Council	Increasing importance of Ministerial Council	Reform of *juste retour*, Union of Centres, 'ESS'

S= Logic of Science, T= Logic of Technology, A= Logic of Autonomy, C= Logic of Commerce, M= Logic of Military, F= Logic of Finance, Tn is shown in the subsections. GB= Great Britain, F= France, D= Germany.

* German policy logic for ELDO in T3 was based on the logic of finance because the German government wanted to switch their funding to Spacelab, which was driven by the logic of technology and science.

Figure 4-4: Historical changes of Major Policy Logics and Institution by Suzuki (2003)

Criterion 4.3: What is the technology's robustness against policy changes?

Technology concepts only become disruptive after a significant period of time. Due to this long development time, the chance of changing policies is high. Because of this, a short summary will be given of Suzuki's research results documented in: Policy Logics and Institutions of European Space Collaboration [RD 34]. This research has traced the evolution of European space collaboration from the early 1960s. Together with the European space sector, the leadership and consequently policy making changed. Suzuki identified six different types of ruling policy logics, which influence decision making:

Logic of Science, Space technology should support the science community and be a platform for new discoveries.

Logic of Technology, Space technology should support European citizens and companies through spin off.

Logic of Autonomy, The European space sector should be independent from other space faring agencies.

Logic of Commerce, European space sector should be competitive in the commercial space sector.

Logic of Military, Space technology should support military goals.

Logic of Finance, Space technology should be developed according to budgets stated by the national agencies. And investments of national agencies should be returned to the nations industry according to the concept of 'juste retour'.

As can be seen in Figure 4-41, in 2003 the Logic of Commerce, Finance and Autonomy were dominant in the European space sector. This logic seems to have perceived today with an increase leadership of EU within the European Space Sector. Based in the history of policies in the European space sector, the logic will almost certainly change again in the future. Therefore, when evaluating a technology, not only current policies should be considered but also possible future changes in policies.

Criterion 4.4: Are there any significant investments (monetary or human capital) in the dominant technology, which prevent decision makers from investing in the DST candidate?

Govindarajan and Kopalle identified that commitments to existing technologies might limit the use of the potential disruptive technology [RD 29]. Within the space sector this factor is especially strong as technologies require an extensive investment in human capital and equipment. This initial investment and the common resistance to cannibalize existing technology development is an inhibiting factor against technology development [RD 63].

4.5 Conclusion

In the present chapter, the analysis of a range of criteria is described, which could be used for measuring the potential of technology concepts for disruptiveness. The criteria are arranged according to the four domains of the STEP analysis (Social, Technology, Economic and Political). All the different criteria are analyzed and a summary of this analysis is illustrated in

Table 4-2. This table shows the different criteria and their applicability to measure the potential for disruptiveness of space technology concepts. This applicability is measured on a 10 point scale and represents the strength of the indicator or factor that the criteria measures. As can be seen, there are several strong indicators and several weaker ones. The aim is to use the strongest and most applicable criteria in the Evaluation Guidelines.

The results of the criteria analysis is illustrated in the graph in Figure 4-5. This graph lists the different criteria on a measuring strength versus work effort axis.

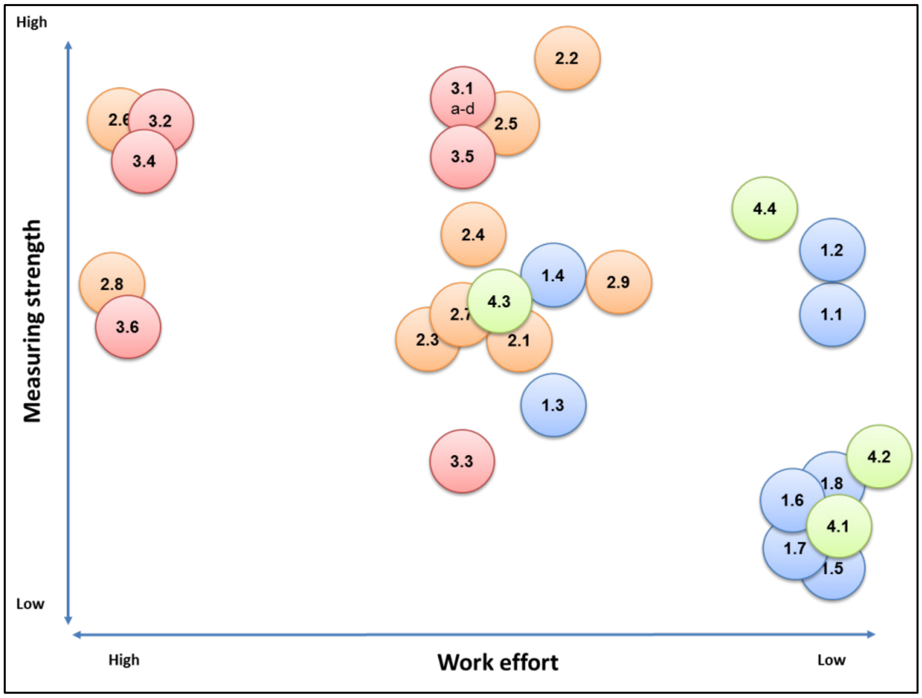

Figure 4-5: Graph indicating the strength and work effort of every criterion

Chapter 2 shows the selection of the Delphi Method, Analytic Hierarchy Process (AHP) and the Scanning, Monitoring and Tracking technique (SMT) as the most promising methods to evaluate DSTs.

Table 4-2 shows the methods and the criteria that are most suitable for them. In addition to the selected methods, a desk research method was added, which will provide some background information concerning the DST during the Delphi method process. The SMT will not be implemented within this research as it is an effort over a longer period of time, which does not fall within the scope of this research. It is nonetheless recommendable that ESA implements an SMT system to monitor DSTs development over a longer period of time.

Table 4-2: Conclusion table of criteria selection

#	Factors and Criteria	Strength*	Work effort	Delphi	SMT	Desk research
	Social**					
1.1	What is the amount of media attention the DST candidate receives and is there an increasing trend?	5	low		x	(x)
1.2	How many research publications exist on the DST candidate and is there an increasing	6	low		x	(x)
1.3	How many patents were filed on a DST candidate or a similar field and is there an increasing trend?	4	medium		x	(x)
1.4	How active is the research field of a DST candidate? (e.g. amount of active research	5	medium		x	(x)
1.5	Does the DST candidate pose an ethical dilemma/ problem? And if so, how severe is it?	2	low	x		
1.6	Does the use of the DST candidate lead to advantages /disadvantages with respect to the environment?	4	low	x	x	
1.7	Does the use or development of the DST candidate promote global cooperation?	2	low	x		
1.8	Does the DST candidate contribute to the solution of other social problems? (E.g. depletion of non-renewable resources, healthcare, malnutrition)	3	low	x		
	Technical**					
2.1	Does the technology fulfill or could it fulfill the technology requirements with respect to the space environment?	4	medium	x		x
2.2	Does the technology over perform the state-of-the-art on the perceived performance	10	medium	x		x
2.3	On which aggregate level does the DST candidate act (material, component, subsystem, spacecraft, mission, or architecture)?	4	medium			x
2.4	What is the level of complexity of the DST candidate?	6	medium	x		x
2.5	Does the potential DST enable a new technology or an increased development rate of another technology?	7	medium	x		
2.6	What is the technology's rate of performance improvement?	9	high		x	
2.7	What is the maturity of the DST concept?	5	medium			x
2.8	What kinds of factors affect technological uncertainty? And what is the associated amount of uncertainty related to the DST candidate?	6	high	x		
2.9	Does the DST candidate have a positive feedback on one or more bottleneck areas within the space sector? (e.g. space transportation, power conversion and in-space propulsion)	6	low/ medium	x		
	Economical**					
3.1a	Can the DST candidate be transferred from a niche set of applications to a broader range of applications?	8	medium			x
3.1b	Does the DST candidate have the potential to be applied to a set of missions that require a lower performance than the state-of-the-art but are price sensitive?	8	medium			x
3.1c	Does the DST candidate have the potential to be applied to a set of missions that require a higher performance than the state of the art?	8	medium			x
3.1d	Is the potential DST originally a terrestrial application which has not previously been applied to the space sector?	8	medium			x
3.2	What is the size of the potential market for the DST candidate?	7	high	x		x
3.3	What are the costs related to the material required for the technology and how high are the costs related to the handling of the technology after deployment?	3	medium			x
3.4	How high are the costs related to the development of the DST candidate?	7	high			x
3.5	How many potential applications with respect to space sector does the DST candidate inhabit? Does the technology provide a new value compared to the state-of-the-art?	7	medium		x	x
3.6	Does the DST candidate have adjoining or partnering technology areas and what is the size and growth rate of this area(s)?	5	high			x
	Political**					
4.1	Does the DST candidate fit within the European space policy?	3	low	x		x
4.2	Does the DST candidate fit within the technology objectives from ESA?	4	low	x		x
4.3	What is the technology's robustness against policy changes?	4	medium		x	
4.4	Are there any significant investments (monetary or human capital) in the dominant technology, which prevent decision makers from investing in the DST candidate?	6	low	x		

* Signal strength with respect to measuring the potential disruptiveness of a DST candidate; 10 Point scale: 1-3 low, 4-6 medium, 7-10 high signal strength

**Preselection domains of the AHP technique

5 Evaluation Guidelines

In this chapter, the evaluation guidelines used to assess space technology concepts for their disruptiveness are described. These guidelines are created using the methods and criteria researched and elaborated on in previous chapters. All of these methods and criteria have been appraised on their applicability to DST concepts and the most promising methods and criteria are combined within the evaluation guidelines.

The evaluation process starts with a database of potential DSTs, the steps involved in creating this database are described in TN03. On the technologies from this database, an AHP will be used in order to pre-select the most promising technologies (cf. Sub-subsection 2.4.3.1). The result of the AHP will be a ranking of the technologies on technology domains.

From each technology domain set in the search scope of TN01 (Spacecraft Electrical Power, Materials & Processes, Propulsion and On-Board Data Systems), the top 5 potential DSTs are selected and used as input for the Delphi method. Experts from each domain are identified and their participation in the method is requested. The Delphi involves several iterative rounds, whose aim it is to achieve a consensus among the experts. The iterative rounds are supported by desk research, which is providing background information on the technologies. In general, all methods are structured around the STEP framework elaborated in Chapter 4. The results of these three methods (AHP, Delphi and desk research) form the basis for ESA's candidate selection for the roadmap process (cf. TN05). The overall logic of the evaluation guidelines is illustrated in Figure 5-1.

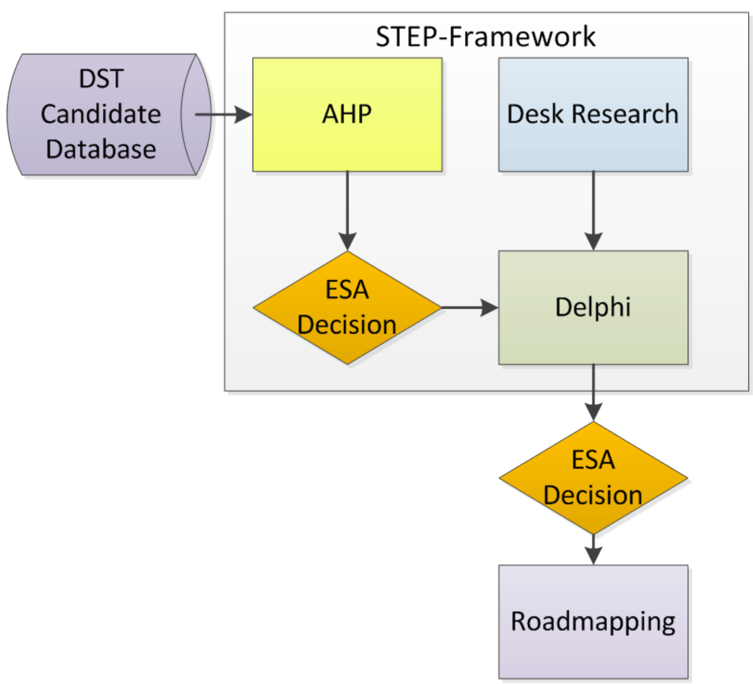

Figure 5-1: Overview of Evaluation Guideline

5.1 *Pre-Selection of Potential DSTs (Analytic Hierarchy Process)*

This potential DST database will be evaluated using the Analytic Hierarchy Process (AHP), which was identified in Chapter 2 as an evaluation method with high potential for space technologies. As described before, AHP is a method for multi-criteria decision analysis [RD 20]. It involves the reduction of complex decisions to a series of pair-wise comparisons, when synthesizing the results, decision-makers arrive at the best decision with a clear rationale for it. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehendible sub-problems, each of which can be analyzed independently. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing two elements to each other. In making the comparisons, the decision makers can use concrete data concerning the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations. The selection panel in this case will be the decision makers, which for this research will be the DST project members and a selection of internal DLR experts. This process will serve as the pre-selection of DST candidates for the Delphi process. Like explained in Chapter 4, the overall factors of the STEP analysis will be used as evaluation criteria for AHP evaluation. The process and the factors will shortly be explained to the participants as described in Annex 1. An overview of the AHP method is illustrated below.

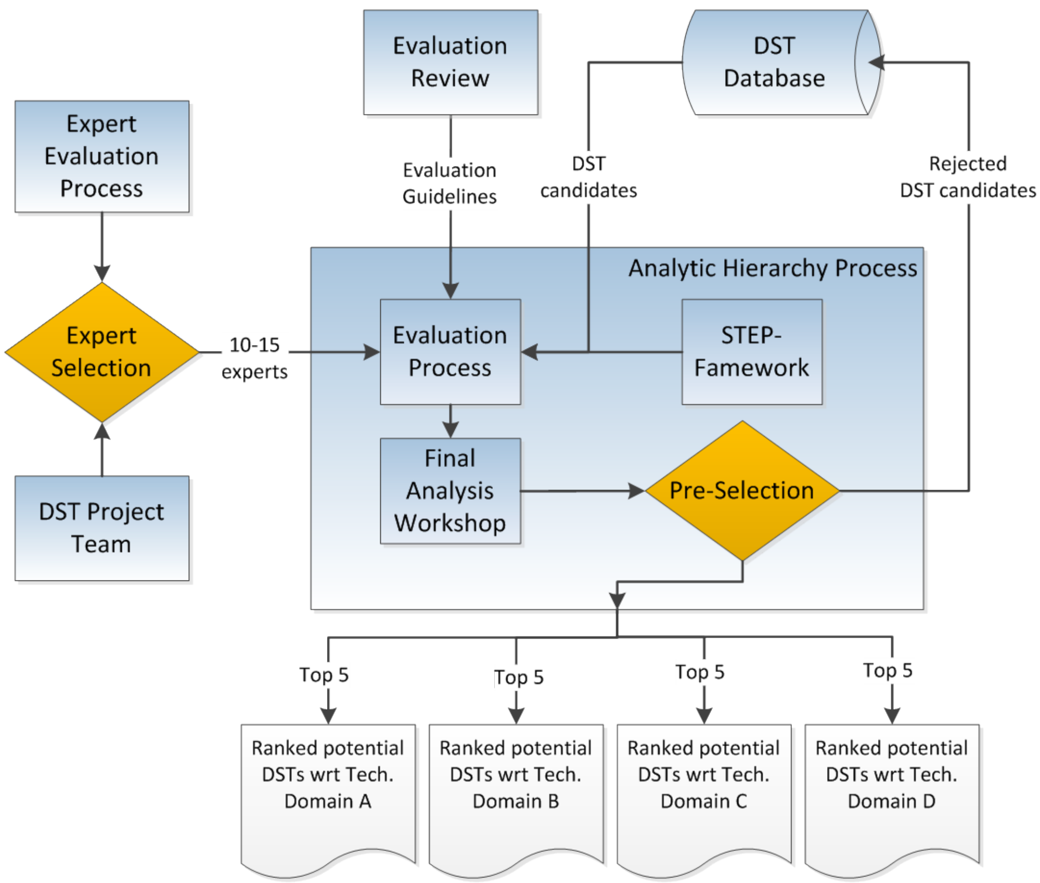

Figure 5-2: AHP overview

5.1.1 AHP Weighting Factors

After formulating the domains, they have to be weighted according to their importance following a method called pairwise comparison. These evaluations are then transformed into so called priorities, i.e. weight factors that will be used for calculation of the weighted score for each technology. These factors are checked on their consistency [RD 46].

Table 5-1: Pairwise comparison of the AHP criteria

Social	1	Technical	9	Technical factors are much more important than social factors because they determine if a DST is better than the state of the art. Weight: 9
Social	1	Economic	5	Economic factors are more important than Social factors because a decrease in any form of costs makes the technology more interesting for development. Weight: 5
Social	1	Political	4	Since political factors are highly important within the space sector, it has a moderate increased performance over social factors. Weight: 4
Technical	4	Economic	1	Technical factors are more important than economic factors because a DST might also be a high-end encroachment. Weight: 4
Technical	6	Political	1	Technical factors are strongly more important than political factors because they determine the value of a technology. Weight: 6
Economic	3	Political	1	Economic factors are slightly more important than Political factors because an important factor for political decisions are economic factors Weight: 3

As a first step, the criteria are pairwise compared to receive relative weights to each other, but only in pairs. For the mentioned criteria of this AHP application, Table 5-2 shows the comparisons and the respective scores. The values are derived from the table illustrated in Table 5-2.

Table 5-2: The fundamental scale for pairwise comparisons

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment moderately favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

With these scores a comparison matrix can be set up, which is then used to calculate the priorities, i.e. actual weights, for the AHP process (compare Figure 2-9). The matrix corresponding to Table 5-2 is given in Figure 5-3.

	Technical	Political	Economic	Social
Technical	1	6	4	9
Political	1/6	1	1/3	4
Economic	1/4	3	1	5
Social	1/9	1/4	1/5	1

Figure 5-3: Priorities Matrix for the AHP

The priorities for the individual criteria are then calculated via the eigenvalues and eigenvectors. They are the components of the normalized eigenvector of the priorities matrix. As a first step the following equation is solved:

$$(\overline{\mathbf{A}}\mathrm{x} - \lambda\overline{\mathbf{E}}) = 0,$$

where ***A*** denotes the Priorities Matrix, ***E*** the Unity-Matrix and *x* the solution vector, whereas λ signifies the eigenvalue. With the above given matrix, the equation becomes:

$$\begin{pmatrix} 1-\lambda & 6 & 4 & 9 \\ 1/6 & 1-\lambda & 1/3 & 4 \\ 1/4 & 3 & 1-\lambda & 5 \\ 1/9 & 1/4 & 1/5 & 1-\lambda \end{pmatrix} = 0$$

From this, the characteristic polynom can be formulated and the solutions, λ be determined as eigenvalues. This matrix's real eigenvalues can be calculated to -0.16972 and 4.18071, of these two only the positive eigenvalue bears real importance. Consequently only one eigenvector exists, which is $(0.92488 \quad 016721 \quad 0.33497 \quad 0.06651)^T$. As the priorities, i.e. weights, need to have a sum of exactly 1 (i.e. 100%), this vector is then normalized with its sum (here: 1.49357) to gain a vector with a sum of 1. Therefore the priorities are then:

- Social: 0.04454
- Technical: 0.61924
- Economic: 0.22427
- Political: 0.11195

As the previous scores for each criterion has been selected more or less arbitrarily on the evaluators' discretion, the result needs to be checked on its consistency, which is achieved by comparison with a random matrix [RD 46], i.e. a Random Consistency Index (RI). For this first of all a consistency index CI for the given matrix is calculated via the formula:

$$CI = \frac{k-n}{n-1},$$

where *n* is the number of dimensions of the comparison matrix (here 4) and *k* the eigenvalue (here: 4.18071). Consequently for the above matrix, CI = 0.06024. For a four-dimensional matrix RI becomes 0.9 [RD 46] and therefore the consistency ratio (CR) can be calculated to:

$$CR = \frac{CI}{RI} = \frac{0.06024}{0.9} = 0.06693 < 10\%$$

CR is smaller than 10% and therefore the criteria can be considered to have been weighted in a consistent way [RD 46].

5.1.2 Measuring of AHP

In the subsections above, the different factors that measure the disruptiveness of a concept are outlined and the calculation of their priorities is shown. The overall AHP hierarchy is depicted in Figure 5-4 along with the priorities as determined in the previous subsection.

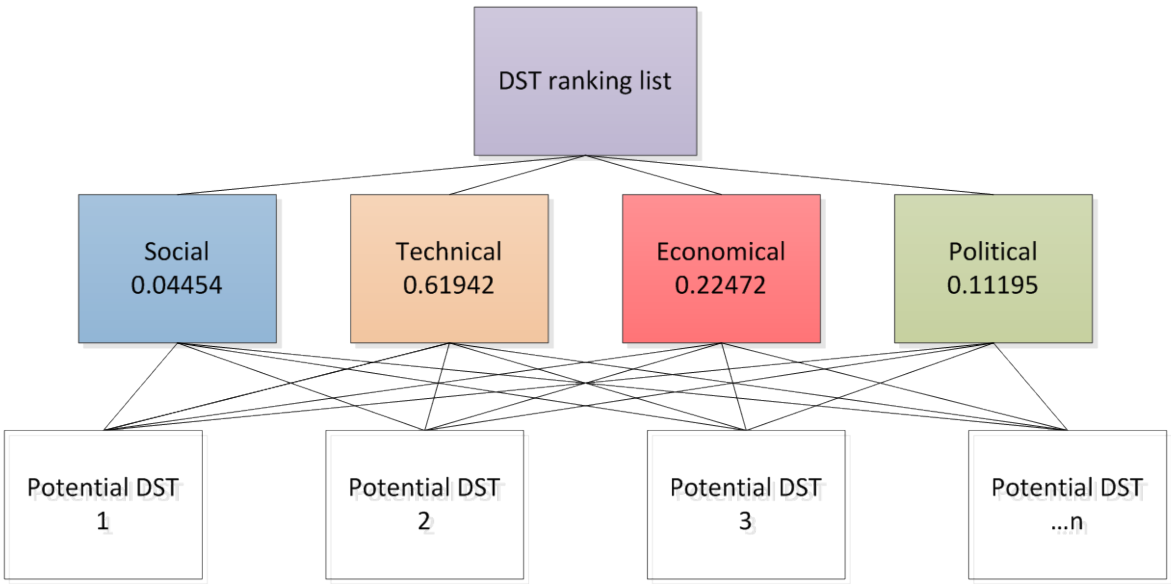

Figure 5-4: AHP hierarchy of DST Guidelines

The factors will be weighted upon by decision makers, which in this case will be a panel of DST experts who are working on the DST project, combined with other internal more experienced space technology experts. They will provide a rating on a 10 point scale, ranging from zero to ten that will lead to a rating per potential DST adjusted by the weights of the different criteria.

The ratings of the different panel members will be averaged. After this, a final ranking of the potential DSTs will be done showing the concepts with the highest potential of becoming disruptive. The top five of the technology concepts for each technology domain will then be analyzed according to a customized Delphi method. This method is described in the next section.

5.2 Delphi Method

The Delphi method as part of the evaluation guidelines enables, by expert opinions, the analysis of twenty of the highest potential DSTs in different domains through several iterations. Several steps have been identified within the Delphi process and are derived below. This process is more extensively described in TN04, as experience while doing the method leads to additional insights which at the writing of this TN has not been gained yet. An overview of the Delphi method is illustrated below.

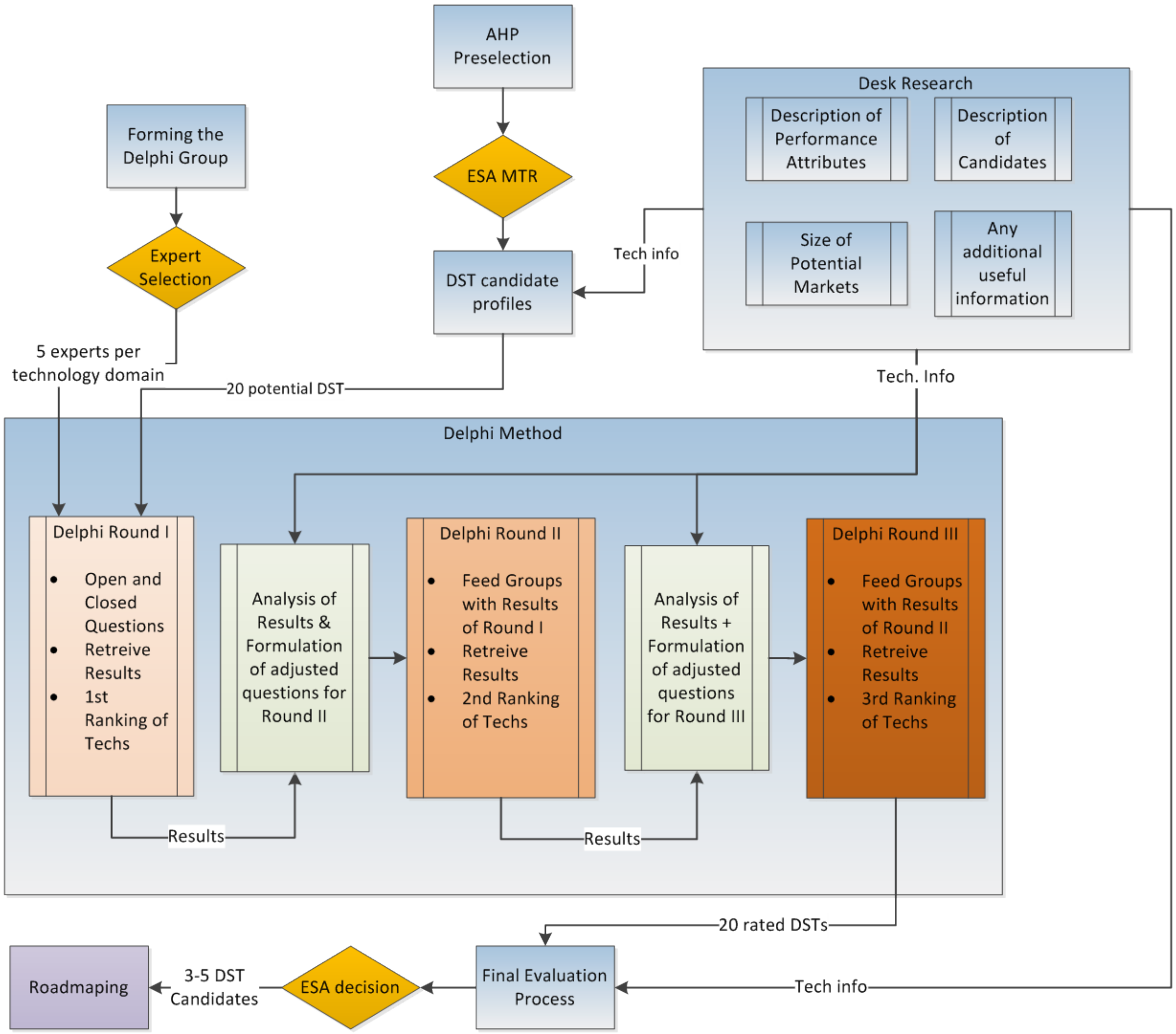

Figure 5-5: Delphi overview

5.2.1 Step One: Selection of Experts

The aim is to get five experts per technology domain to rate potential DSTs on the criteria elaborated before, which will determine the disruptiveness of a technology concept. Every technology domain will be subject to its own Delphi Method session. The technology experts who are asked in the technology survey, if they would be willing to participate in further studies, will potentially be selected as experts for their respective domain. In selecting the experts, several bias factors have to be taken into account. Although the Delphi method eliminates social bias through anonymity, there is still the issue of individual bias, which has to be dealt with. The individual bias is caused by the individual characteristics of experts who provide ratings for the Delphi method. In this subsection an elaboration will be given on how to mitigate different forms of bias in the selection of experts for the method.

To make sure the forecast offered by this research is as accurate as possible, individual biases will have to be mitigated as much as possible. This means that, when selecting a team of experts to participate in the Delphi method, attention must be given to personal, age, cultural and linguistic bias. These biases and the method to mitigate them are elaborated next.

Personal bias

It could be that experts have a personal interest in the outcome of the evaluation and are therefore tend to answer in favor of this personal interest. Therefore mitigating this bias will involve the selection of experts without any personal gain the selection of any of the technology concepts.

Age bias

Young people are more future-oriented than people from an older generation [RD 57] [RD 58]. This age bias could lead to a forecasting error as the older generation has a more conservative view than the youth on the possible future. Younger people are more accurate in predicting the long-term future, while older people with more experience see patterns more easily and are better in predicting the near-future [RD 58]. Supporting this is the first-law of Clarke:

"When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong."[RD 59]

This research adopts the view that just because the forecast is biased, it does not always mean that it is incorrect. Therefore one of the approaches to use the age bias in forecasting to our advantage is to consider the time horizon of the forecast and assign the appropriate generation to forecast them. For example long term forecast should be done by a younger generation while short term forecasts should be done by the more experienced older generation. In light of the medium term forecast in this research, a mixed aged team of experts is preferred.

Cultural Bias

Another form of individual bias is cultural bias as this has an influence on forecasting [RD 60]. This bias is related to considerable differences in values, beliefs, norms and worldviews in societies around the world. These differences could lead to alternate views on what the future holds. When selecting the forecasting participants, special attention has to be paid to their cultural influences. It would be wise to use as internationally orientated participants as possible as to reduce the cultural bias. Because of the context of this research, all technologies will be implemented within the European space sector. Therefore the selection of the experts might be better to focus on European candidates when there is a choice.

5.2.1 Step Two: Design of Delphi Method

The creation of the Delphi method involves the generation of datasheets, writing an expert manual and providing background technology information. The data sheets require input from the criteria identified in Chapter 4 as being most applicable to the Delphi method.

The most important indicator for disruptiveness is the measuring of the perceived performance of a potential DST. Before the Delphi method starts, the secondary performance attributes of a technology need to be determined through desk research. To make sure the chosen performance attributes for the technology are correct, a validation will be done by the experts. They will be asked if the chosen attributes are the ones that they value as most important when determining the value of a technology. In addition the experts have the possibility to add options in order to make sure all relevant attributes are covered.

Following, a ranking with respect to the performance attributes is performed. The method to do this is by allowing the experts to distribute 100 points among all attributes, giving the highest points to the most important attributes. From this, a ranking of the attributes can be generated and a radar chart can be created with the performance attributes. An example of this is listed below:

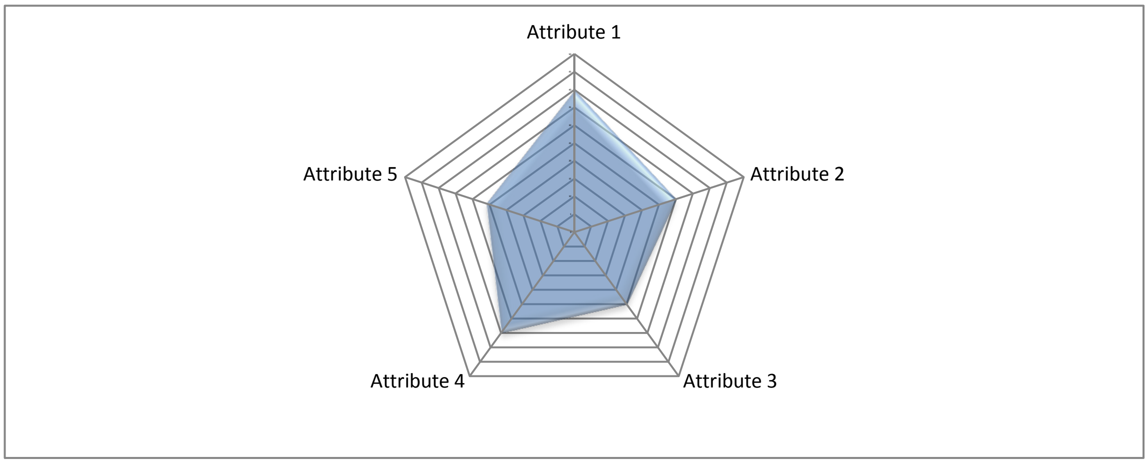

Figure 5-6: Example of values of a performance attributes

In addition to the perceived performance, also other criteria, identified in Chapter 4 will be used. These focus the different domains from the STEP analysis.

5.2.2 Step Three: Expert Rating Rounds

After the selection of experts and the creating of the evaluation matrix, the first round of expert ratings can be initiated. The scoring matrix, detailed information about the technologies and a scoring guide will be send to the participants. This will be the first round in the Delphi process. After the first round of the Delphi Method session the results will be processed. The average of all answers will be calculated and compared to the individual results of each participant. Extreme deviants will be sent back to the participants in asking of clarification for their deviation. This will give them the option of revising their answers or explain why they think their original opinion was correct. This will be the second round and this process will be repeated until either a consensus is reached or experts agree to disagree. The number of revision rounds depends on the amount of discrepancies between the ratings of the experts. Each round will aim at further clarifying the overall opinion of the experts. After the iteration rounds, the results of the Delphi Method will be summarized and sent to the participants. The results of the end rating of the Delphi method will be put forward to ESA, which then has to decide which technologies they want to see within the Roadmapping process.

5.2.3 Desk research

Desk research is the summary, collation and/or synthesis of existing research. Desk research provides the initial technology profile in addition to technology information, to the experts participating in Delphi method. Purpose of this research is to provide more background information on a DST candidate. Within the criteria definition in Chapter 4, several criteria are defined as being applicable to evaluating DST candidates. The criteria identified here are more of the categorization kind and often have a relative low strength of measurement, but can nonetheless provide extra information concerning the technology to experts. This information could take the form of:

- Trends in media, journal, patent publications
- Background information on the technology (e.g. performance, complexity, maturity)
- Market information (e.g. market size and potential, encroachment type, cost)
- Mapping of political issues influencing the technology

Information on these topics will be provided on an arbitrary basis, as not to cause an information overload to the experts. When information is relevant and indicates a disruption, it shall be delivered to the experts. For example if experts disagree on the scoring of a criteria, an additional piece of information or an analysis might be send in order to facilitate the reaching of a consensus.

5.2.4 Step Four: Measuring of Delphi Results

The final step involves the ranking of the concept's performance on the chosen attributes. In this, the ratings of the participants on a 10 point scale per attribute are measured in a matrix. The measuring of the expert opinions on the criteria elaborated in Chapter 4 is based on the concept scoring method [RD 22]. Chapter 2 identified this method as a high potential evaluation method and is used as a framework for measuring the final expert opinions with the Delphi method. The concept scoring method is chosen because of its simplicity and its capability to rank concepts according to expert opinions. An example of the final scoring method is illustrated in Figure 5-8.

The matrix has several fixed-, and several technology domain specific criteria. These technology domain specific criteria are illustrated by in the perceived performance mix. The matrix will use a weighted factor to adjust the level importance of these criteria. These weighted factors will be determined in WP 5000 using the same method as the weighting of the AHP.

The purpose of the matrix is to rank concepts and to do this all answers have to be quantified. All criteria can be compared to the current state-of-the-art and scored on a basis of over or under performance. Over performing the current state-of-the-art will result in a score of 50 or more. A score of above 50 will indicate a potential for disruptiveness of a technology concept, with the higher the score, the higher the potential. The scoring of the criteria will be according to the rating scale illustrated in Figure 5-7.

Rating	Relative performance
0	Much worse than the state-of-the-art
3	Worse than the state-of-the-art
5	Same as the state-of-the-art
8	Better than the state-of-the-art
10	Much better than the state-of-the-art

Figure 5-7: Scoring Matrix

The scoring matrix relies on the end results of the expert rounds and calculates a total score through weighted criteria and weighted scores. The resulting score is on a 10 point rating scale. Any score above 5 will indicate a DST candidate is better than the state-of-the-art. When multiple technology concepts out of a technology domain are analyzed, the highest score has the highest potential to become disruptive.

#	Technology Domain		Technology type					
			Technology 1		Technology 2		Technology 3	
#	Evaluation criteria	Weight	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
1	**Social**	**6%**						
1.1	Does the DST candidate pose an ethical dilemma/ problem? And if so, how severe is it?	TBD						
1.2	Does the use of the DST candidate lead to advantages /disadvantages with respect to the environment?	TBD						
1.3	Does the use or development of the DST candidate promote global cooperation?	TBD						
1.4	Does the DST candidate contribute to the solution of other social problems? (E.g. depletion of non-renewable resources, healthcare,	TBD						
	*** To be completed ***							
	Subtotal	**0%**		**0,00**		**0,00**		**0,00**
2	**Technical**	**60%**						
2.1	Does the technology fulfill or could it fulfill the technology requirements with respect to the space environment?	TBD						
2.2	Does the technology over perform the state-of-the-art on the perceived performance mix?	TBD						
2.2.1	Attribute 1	TBD						
2.2.2	Attribute 2	TBD						
2.2.3	Attribute n	TBD						
2.3	What is the level of complexity of the DST candidate?	TBD						
2.4	Does the potential DST enable a new technology or an increased development rate of another technology?	TBD						
2.5	What kinds of factors affect technological uncertainty? And what is the associated amount of uncertainty related to the DST candidate?	TBD						
2.6	Does the DST candidate have a positive feedback on one or more bottleneck areas within the space sector? (e.g. space transportation, power conversion and in-space propulsion)	TBD						
	*** To be completed ***							
	Subtotal	**0%**		**0,00**		**0,00**		**0,00**
3	**Economic**	**22%**						
3.1	What is the size of the potential market for the DST candidate?	TBD						
	*** To be completed ***							
	Subtotal	**0%**		**0,00**		**0,00**		**0,00**
4	**Political**	**11%**						
4.1	Does the DST candidate fit within the European space policy?	TBD						
4.2	Does the DST candidate fit within the technology objectives from ESA?	TBD						
4.3	Are there any significant investments (monetary or human capital) in the dominant technology, which prevent decision makers from investing in the DST candidate?	TBD						
	*** To be completed ***							
	Subtotal	**0%**		**0,00**		**0,00**		**0,00**
	Total			**0,00**		**0,00**		**0,00**

Figure 5-8: Rating table for the Delphi method (TBD: To Be Defined)

5.3 Summary

In this chapter, the evaluation guidelines for identifying the potential for disruptiveness of space technology concepts are described. These guidelines are created using the criteria and methods researched and described in respectively Chapters 2 and 4. These criteria are categorized according to the STEP-Framework, which is used throughout the evaluation guidelines. The overall process of technology search and selection is illustrated in Figure 5-9, using multiple methods, which funnel the amount of concepts and selects the most promising DSTs.

In general, AHP and Delphi are used as building blocks for the guidelines. These two methods combined, with support from desk research, form the Evaluation guidelines for DSTs. The evaluation process starts with a database of potential DSTs, the steps involved in creating this database are elaborated in WP 4100. From this database, an AHP will be used in order to pre-select the most promising technologies (cf. Section 5.1). This is done, because evaluating a large set technologies might be too time consuming to perform with a more complex method like for example Delphi.

The result of the AHP will be a ranking of the technologies in their technology domain. From every domain set in the search scope of TN01 (Spacecraft Electrical Power, Materials & Processes, Propulsion and On-Board Data Systems), the top 5 are selected and used as input for the Delphi method.

The Delphi process starts with identifying and enlisting experts from every domain for the iterative evaluation rounds of the Delphi method (cf. Section 5.2). The iterative rounds will be supported by a desk research, which will provide background information about the technology. After the results of the Delphi method, the highest potential DSTs will be presented to ESA, which will have to decide what technologies they would like to see developed in the Roadmapping phase (cf. TN05).

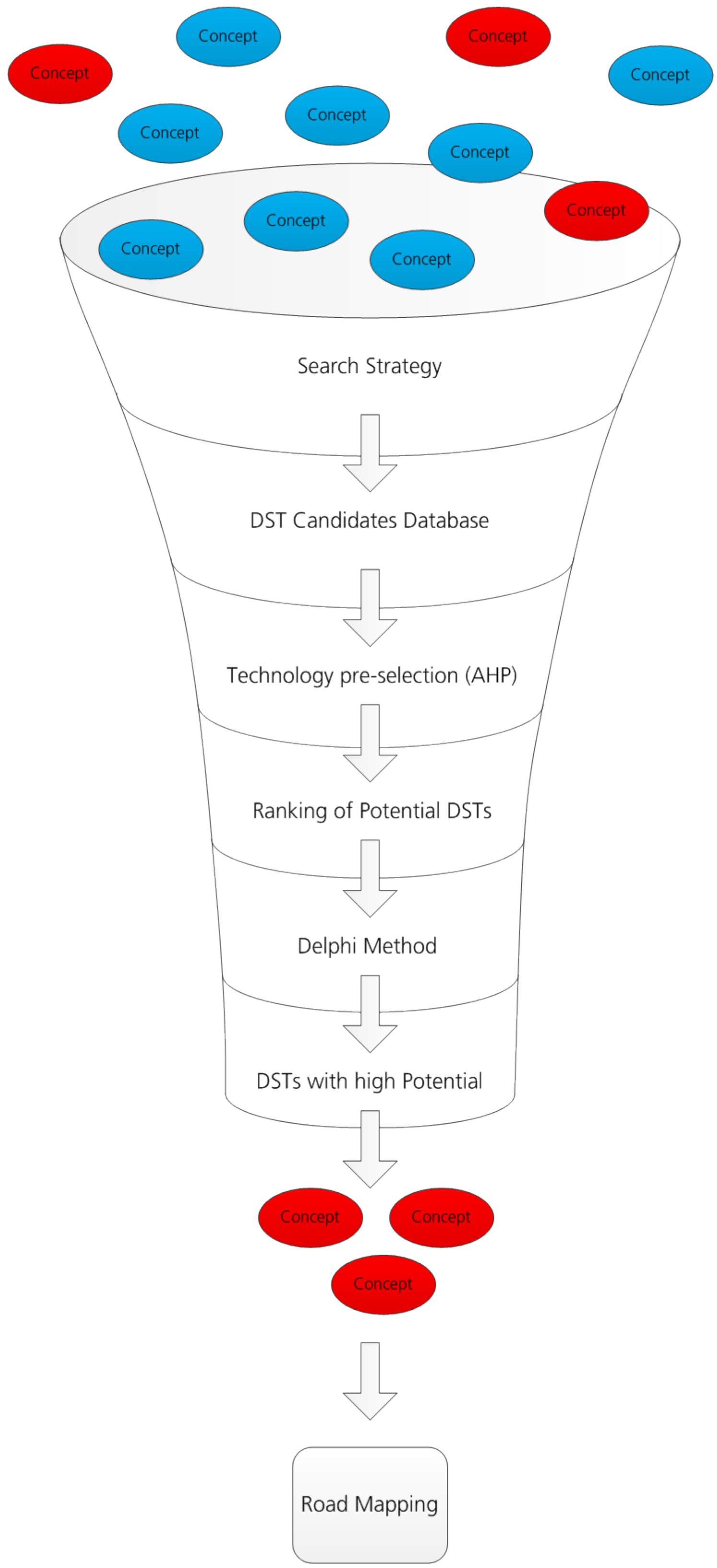

Figure 5-9: Overview of Search, Evaluation and Roadmapping (Red concepts are potential DSTs)

Annex 1: Evaluation Guide for AHP

When opening the Excel file, a list of technologies, with a description, advantage/disadvantages, disruption type, technology domain and maturity can be seen. In addition, there are four columns which represent the performance of a technology of several domains. These domains are:

- Social Domain
- Technological Domain
- Economic Domain
- Political Domain

These domains need to be answered according to the scoring scale illustrated below:

Rating	Relative performance
0	Much worse than the state-of-the-art
3	Worse than the state-of-the-art
5	Same as the state-of-the-art
8	Better than the state-of-the-art
10	Much better than the state-of-the-art

This scale allows for a measurement which compares the situation with the technologies which are being used today, or state-of-the-art, to the Disruptive Space Technology candidate. The aim here is to check if it over performs or under performs over the state-of-the-art. The description of the factors is listed below:

Social

The European space sector has to abide to certain social rules. Social factors influence technology diffusion within the space sector by influencing the demand of the technology in either a positive or negative way. A number of possible social factors are:

- Environment
- Depletion of energy sources
- Human wellbeing
- Healthcare
- Malnutrition
- Overpopulation
- Waste management
- Disaster mitigation

On the one hand, if a technology can help solve problems in this social context, it has a higher potential for disruptiveness. On the other hand if a technology contributes to one of these social problems, it will have a lower potential for disruptiveness. In this case, the technology should be compared to the current state-of-the-art (e.g. technologies in use today) within the evaluation. A lower than 5 score on this factor would mean that the technology will worsen social problems than the state of the art, while a higher than 5 score means it would (contribute to) solve social problems.

Technical

The technical factor is the most important factor, because an over performing technology (in several different performance indicators) is essential to disruption. Because of this, the technical performance of a technology concept versus the state-of-the-art will have to be determined. It is important that the technology does not need to be obviously better than the state-of-the-art rather that a group of customers of the technology would find the performance more suited to their needs than the state of the art. A lower than 5 score on this factor would mean that the technology underperforms upon the state of the art, while a higher than 5 score means it over performs.

Economic

Disruptive Space Technologies are defined as technologies that make operations simpler, cheaper, more flexible and/or more responsive compared to the incumbent technology. Because of this, economic aspects are of high importance in identifying space technologies. A rating on the economic factor should encompass whether or not the technology concept provides significant economic benefits to its users. A lower than 5 score on this factor would mean that the technology will cost the user more than the state of the art, while a higher than 5 score means it costs less.

Political

The development of technologies is highly influenced by governments and thus political decisions. This political influence is documented in the European space policy. The European space policy is influenced by the representatives of participating nations that are a part of the ESA. The ESA European space policy can be seen as the overall strategy of the European space sector. The European Space policy is defined as follows:

- *To develop and exploit space applications serving Europe's public policy objectives and the needs of European enterprises and citizens, including in the field of environment, development and global climate change*
- *To meet Europe's security and defense needs as it regards space*
- *To ensure a strong and competitive space industry, which fosters innovation, growth and the development and delivery of sustainable, high quality, cost-effective services*

- *To contribute to the knowledge-based society by investing strongly in space-based science and playing a significant role in the international exploration endeavor*
- *To secure unrestricted access to new and critical technologies, systems and capabilities in order to ensure independent European space applications*

For new technologies this means that they have to fit within these policies in order to have a chance of being developed. For a concept to have a high potential for disruptiveness, it should fit within the policy stated by the governing bodies. A lower than 5 score on this factor would mean that the technology will fit less with the policy than the state of the art, while a higher than 5 score means it fits better.