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Faculty of Technology, Policy and Management
M.Sc in Systems Engineering, Policy Analysis and Management

VOLKSWAGEN
AKTIENGESELLSCHAFT

Thesis

Upscaling the process for the collection, analysis, and delivery of information about emerging or existing technologies for enhanced decision making

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Summary

Background

The Volkswagen Group (Volkswagen) is the second largest automobile manufacturer in the world. For technology oriented organizations such as Volkswagen technological innovation is crucial for maintaining and increasing a competitive position. At Volkswagen, the 600 researchers of Group Research conduct cutting edge research in order to create and shape the cars of the future. However, researchers at Volkswagen find themselves confronted with an overload of information which they are unable to collect and interpret. Let alone base their decisions on this information.

Therefore, the department of Technological Foresight guides researchers and decision makers of Group Research through the vast and exponentially growing body of information and enables them to collect, filter and interpret relevant information in over 200 different technology domains. Thereby reducing the complex and uncertain environment of the organization and contributing to more informed decision making by researchers and decision makers. Hence: the department of Technological Foresight effectively equips researchers and decision makers with valid technological information so that they are in a position to make the best possible strategic decisions (Walde 2008). From a scientific perspective this is known as technology intelligence (TI) which is referred to as the *collection, analysis and delivery of relevant information about emerging or existing technologies, for enhancing decision making through the identification of new opportunities and threats as well as the assessment of current performance*.

The current conduct of TI

The main TI product is the *detailed technology intelligence product*. As the name implies the detailed TI product if fully customized to the issues and questions of the client. Each project is in fact *unique*. The conduct of TI is a lengthy and time intensive activity. This is mainly caused by the explorative nature of the process and the fact that every project is unique. Clients are often unable to express and specify their issues or questions, making the problem definition phase a cyclic, explorative, and inherently inefficient process. Every project involves a unique set of activities in which the analyst combines skills, methods, tools and resources to provide answers to the clients' questions: a unique problem solving procedure. Although no exact lead times are known, the average project lasts between 2 weeks and 2 months (Walde 2009)

Recently a demand has developed for projects that involve the assessment of *a large number of technology fields*. Such projects typically include over 50 disparate technology fields. This is problematic because the number of technology fields is directly related to the required capacity. Capacity growth is restricted by budget, whereas the demand for TI is expected to increase further.

Problem

The problem is that the current TI approach is *inadequate* for dealing with the upcoming of projects that involve a large number of technology fields. This is perceived problematic by management of a large engineering organization since these projects would allow them to get an overview of the developments in a significant part of the technologies in which they are active, rather than just a few. Therefore a new approach is required for dealing with this type of projects.

Proposed solution

A proposed solution involves standardization of particular elements of the TI process. The basic idea is that effective analyses of technology do not necessarily need to be labor intensive or time consuming. Every analysis does not need to be a custom solution; rather some flexibility can be sacrificed for increased familiarity, speed, validation and utilization (Porter and Cunningham 2005) (Porter and Cunningham 2006). To deal with the projects that involve

a larger number of technology fields a novel TI product is proposed in this thesis: the standardized technology intelligence product (STIP). *A STIP is a product that is generated through a set of standardized activities and procedures. The main benefit in comparison to other TI products is that it can be generated significantly faster.* The main characteristics of the STIP are:

- STIPs address a specific issue or set of questions faced by decision makers and technology managers
- The analytical procedure for solving the procedure is standardized (i.e. the process)
- The methods for extracting knowledge from information is standardized

The concept of using a STIP to solve demand for TI that involves a large number of technology fields will be referred to as *upscaling the technology intelligence process*. Table 1.1 highlights the major differences between the STIP and the detailed TI product.

Table 0.1.: Comparison of the traditional TI product and the STIP

	Detailed TI product	**STIP**
Issue identification	Issue is unique	Issue is fixed for each STIP
Analysis	Depends on issue, unique	Predetermined, standardized
Method execution	Manual, partially automated	Largely automated
Process	Cyclic, iterative, based on experience	Linear, based on procedure and routine
Outcomes	Presentation slides, report, diversity	One-pager, uniformity (standardization)
Level of interaction	High	Low
Information resources	Mainly patents and publications	Mainly patents and publications
Size of target group	$\sim$ 1-5	$\sim$ 20 - $\geq$ 200
Average duration	$\sim$ 2 weeks - 2 months	$\sim$ 1 day
Flexibility of product	High	Low

The ranking of research institutes in over 200 technology fields

Management of Group Research has expressed the desire to critically assess its' research partners in over 200 disparate technology fields. This will be done by deploying STIPs because the current approach to TI are inadequate for solving this project. This project is the first case in which the STIP will be used.

Problem exploration

Two aspects remain challenging. A first challenge is assuring sufficient quality of outcomes. TI products —including STIPs— are created through a process. Each process requires *input* from technology specialists to safeguard sufficient quality of outcomes. Furthermore the quality of output is determined by the quality of *input* provided. Within the context of this research project, high quality is achieved when the input or output is:

- Complete. The input or output includes all concepts.
- Authoritative. The input or output is perceived as authoritative by clients and other actors.
- Objective. The input or output is unbiased to any actor.
- Relevant. Apart from complete the input or output must also exclude irrelevant concepts.

In the present conduct of TI there is frequent interaction between analyst and specialist. This is a lengthy and cyclic process, but does safeguard the quality of outcomes. Since a STIP emphasizes speed this places limits on the extent to which analyst and specialist can interact and this may have an effect on the quality of input provided by technology specialists. In other words: a focus on the reduction of lead time may have an adverse effect on the quality of outcomes.

A second challenge involves successful coordination of technology specialists. Technology specialists are not always interested in cooperation for a variety of reasons. Nevertheless the quality of TI depends on these same specialists because they alone posses the knowledge to provide high quality input. The challenge is essentially to retrieve this knowledge from the technology specialists.

Research objective statement:
The research objective is *to design a process and model in order to create Standardized Technology Intelligence Products, that can be used to assess research performance of institutes in over 200 disparate technology fields, based on patent- and publication data. A second objective is to make recommendations towards the coordination of the key actors.*

Analyses
At present litarature offers no examples of a usable process and model for STIPs. Therefore the following approach is followed: First TI is decomposed into 4 key elements: (1) science and technology information, (2) certain questions that technology managers and decision makers have, (3) a systematic process and, (4) tools and techniques for retrieving useful knowledge from information. Based on these elements the implications on these elements as a result of upscaling TI are formulated. This results in a set of requirements for the design of a TI process and model.

The current conduct of TI at Volkswagen reveals a fifth element: a TI platform which can support the search query definition process by technology specialists. Analysis of the organizational and actor setting reveals that: (i) technology specialists are the most critical actors involved in the creation of STIP, since their technological expertise is required, (ii) technology specialists have diverse perceptions towards TI, (iii) the relation between TI analyst and technology specialist resembles a principal-agent relation, and (iv) this relation may challenge the quality of outcomes and the required time to complete the project.

Design
Two artifacts are designed: The first artifact is a TI process for creating STIPS. This process describes the analytical activities, the inputs and outputs of each activity and the control and support mechanisms. The primary components of this design are (a) activities that are carried out in order to produce the STIP, (b) procedures for the analyst to follow when carrying out the activities (i.e. search refinement, data cleaning and analyses), (c) supporting mechanisms such as the TI platform, scripts and macro's, software packages, (d) inputs to the system: data- and patent records and request for TI (external) and all flows between activities (internal), (e) actors: the technology analyst and the technology expert and (f) outputs of the system: the STIP in form of a one-pager and the search query.

The second artifact is a ranking model which is used for the assessment of research institutes. This ranking is based on bibliometric indicators for both patent and publication data. A model has been constructed to support this ranking. In addition to these artifact designs, recommendations are formulated to coordinate the involvement of technology specialists in the TI process more effectively.

Case study
A case study is carried out to test the TI process and model; to prove the concepts of STIPs; and to provide a hands-on and in-depth demonstration of both designs. The case study involves two different technology fields; 'augmented reality' and 'sulfur lithium cells'. The latter is also used in the construction of both designs. The main outcomes of the case study is (a) both the TI process design and model functioned as expected, (b) further improvements are needed to support specialists in formulating effective search queries. Based on these outcomes it can be concluded that it is possible to upscale the technology intelligence process. Further recommendations for improvements of the TI process and model are derived from the findings of this case study.

Conclusions
This research project has laid out the elements of TI, and has identified further elements by studying the conduct of TI at a large technology oriented organization. Furthermore requirements have been identified that are applicable for the design of processes and models that can be used for the production of standardized technology intelligence products. The focus is in particular on upscaling the process. A design of a TI process and model for the assessment of research institutes in over 200 technology fields has been presented. These designs are tested and further specified by means of a case study. This research has shown that the model is suitable for STIPs. The case study has

demonstrated that it is possible to set up a TI process and models in manner that can significantly reduce the lead time.
The overall outcome is positive, but additional measures must be taken to improve the quality of search queries defined by specialists. Based on the case study it can be concluded that it is possible for Volkswagen to deploy STIPs as a new product and use this to up scale the TI process. Secondly it is concluded that Volkswagen can use the design of the models and TI process for continuing the assessment of research institutes in the remaining technology fields.

Recommendations to the organization

The TI process
The TI process design is a generic description on how to develop standardized technology intelligence products. Improvements are necessary for achieving good results:

- Provide technology specialists with more knowledge on the use of Boolean operators (advanced search operators)
- Make changes to the TI platform so that it gives more accurate feedback on the search queries defined by technology specialists

The STIPs for ranking research performance
Although the ranking is based on well known and widely appplied (bibliometric) indicators, the question remains whether these indicators provide a complete picture of an institutes' research performance. The ranking values change significantly when different sets of indicators are used or when the relative importance of indicators is changed. Therefore it is recommended to:

- Take both the strengths and the weaknesses of the STIP into account
- Communicate assumptions and restricitions to clients

With regard to the STIP in general
The STIP for ranking research performance is only one of the many possible applications for the STIP. It is recommended to:

- Explore further applications for the STIP
- Follow both an issue driven (what questions do clients have) as well as a method drived approach (what questions can these methods answer) when identifying new applications for the STIP
- An issue driven approach seems most promising since this is expected to extent the degree to which STIPs are used by clients

STIPs in relation to other TI products at Volkswagen
It is recommended to:

- Use STIPs in addition to the detailed TI products, but only in case the issue can be properly resolved by the STIP
- Apply STIPs to increase the efficiency of the problem definition phase
- Use particular concepts from the STIP (e.g. standardized procedures and automated analysis) to improve efficiency of the detailed TI product and work towards more just–in–time technology analysis

With regard to the coordination of technology specialists
It is recommended to change the fund allocation model so that technology specialists are paid directly by the TI analyst instead of indirectly by the client. When the outcome of the transaction does not meet certain standards then the specialist is not rewarded for his effort. Based on agency theory this change is expected to have a positive impact on the quality of input provided by technology specialists. The client benefits in this new setting because risk is more evenly distributed between client and analyst.

- Change the fund allocation model so that technology specialists are rewarded directly by the TI analyst instead of indirectly by the client

Interpretation and utilization

In the current TI process design the interpretation and utilization of outcomes by clients is not considered because this goes beyond the scope of this research project. Nevertheless it is worthwhile to get feedback regarding utilization of results by clients since this may help to improve the STIP in the future.

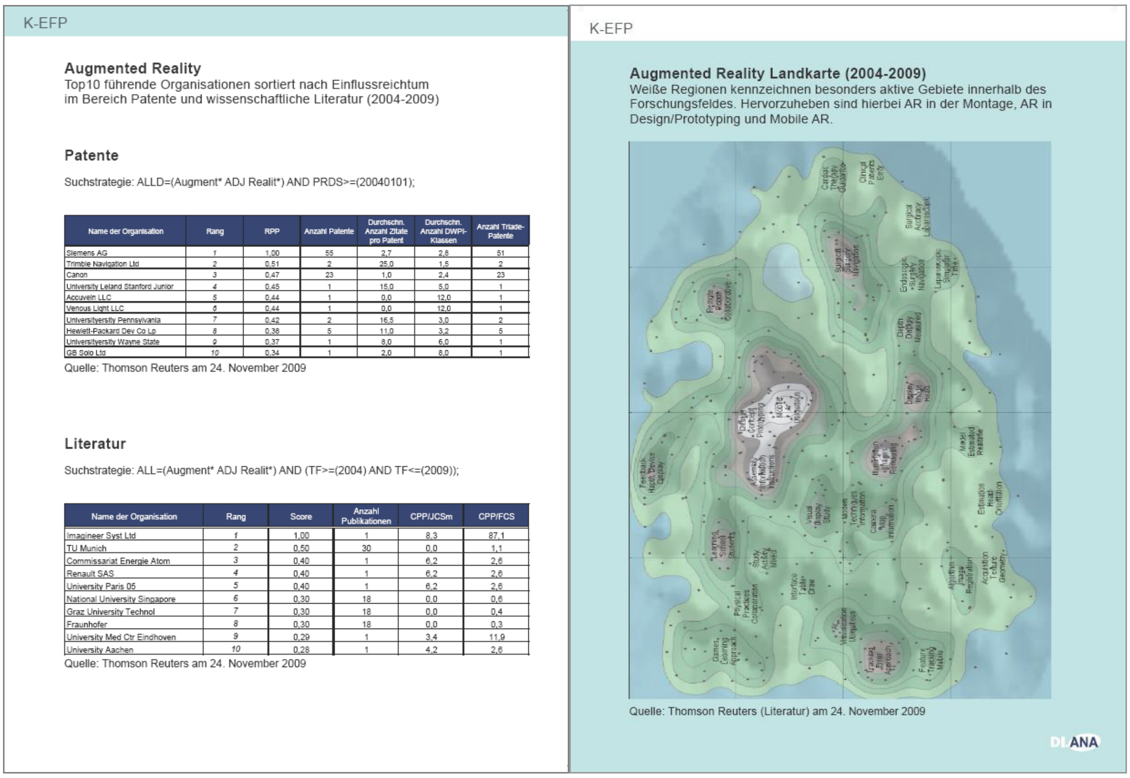
Recommendations for future research

Definition of search queries

Search queries are key to TI since these demarcate the technology field to be investigated. However the technology specialists' ability to formulate an effective search query leaves room for improvement. TI platforms can aid technology specialists in defining better search queries. Emperical research on such systems would increase the understanding of the mechanism that support this learning, and is therefore recommended.

Rankings based on (bibliometric) indicators

Literature on the measurement of science is extensive. However few practical guidelines are available on the selection of suitable (bibliometric) indicators for a given purpose. Ranking values are obviously sensitive to changes in the relative importance of indicators yet guidelines on how to assign weights to indicators are absent or kept hidden by those selling this information commercially. At the same time financial allocation systems are based on the same systems. Research on these issues would be greatly beneficial to those involved in the appraisal of research performance, or affected by these appraisals such as individual researchers, universities and research institutes.



K-EFP

Augmented Reality

Top10 führende Organisationen sortiert nach Einflussreichtum im Bereich Patente und wissenschaftliche Literatur (2004-2009)

Patente

Suchstrategie: ALLD=(Augment* ADJ Realit*) AND PRDS>=(20040101);

Name der Organisation	Rang	RPP	Anzahl Patente	Durchschn. Anzahl Zitate pro Patent	Durchschn. Anzahl DWPI-Klassen	Anzahl Triade-Patente
Siemens AG	1	1,00	55	2,7	2,8	51
Trimble Navigation Ltd	2	0,51	2	25,0	1,5	2
Canon	3	0,47	23	1,0	2,4	23
University Leland Stanford Junior	4	0,45	1	15,0	5,0	1
Accuvein LLC	5	0,44	1	0,0	12,0	1
Venous Light LLC	6	0,44	1	0,0	12,0	1
Universityersity Pennsylvania	7	0,42	2	16,5	3,0	2
Hewlett-Packard Dev Co Lp	8	0,38	5	11,0	3,2	5
Universityersity Wayne State	9	0,37	1	8,0	6,0	1
GB Solo Ltd	10	0,34	1	2,0	8,0	1

Quelle: Thomson Reuters am 24. November 2009

Literatur

Suchstrategie: ALL=(Augment* ADJ Realit*) AND (TF>=(2004) AND TF<=(2009));

Name der Organisation	Rang	Score	Anzahl Publikationen	CPP/JCSm	CPP/FCS
Imagineer Syst Ltd	1	1,00	1	8,3	87,1
TU Munich	2	0,50	30	0,0	1,1
Commissariat Energie Atom	3	0,40	1	6,2	2,6
Renault SAS	4	0,40	1	6,2	2,6
University Paris 05	5	0,40	1	6,2	2,6
National University Singapore	6	0,30	18	0,0	0,6
Graz University Technol	7	0,30	18	0,0	0,4
Fraunhofer	8	0,30	18	0,0	0,3
University Med Ctr Eindhoven	9	0,29	1	3,4	11,9
University Aachen	10	0,28	1	4,2	2,6

Quelle: Thomson Reuters am 24. November 2009

Figure 0.1.: Illustration of the STIP for *augmented reality*. Source: own work

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Part I.

Analysis

1. Introduction

1.1. Background

Volkswagen Group
The Volkswagen Group (Volkswagen) is the second largest automobile manufacturer in the world. Apart from the brand Volkswagen the group's brands include 9 other brands; Audi, Bentley, Bugatti, Lamborghini, Porsche, Scania, SEAT, Skoda and Volkswagen Nutzfahrzeuge. In 2009, over 6 million cars were sold, in 151 countries (Volkswagen Konzern 2009). Volkswagen is traditionally split into devisions, where every brand forms its' own devision. Several departments cover all devisions. One of these is Volkswagen *Group Research*. Group Research, as its' name implies, conducts cutting-edge research for the Volkswagen Group.

Group Research
Group Research stands at the leading edge of tomorrow's car, by gaining the knowledge to create and shape the technologies of the future. Research is an essential task for an organization whose success in terms of profit and growth depends on the constant renewal of products and processes. This is especially true in a time where the success of the car is strongly determined by dynamic economic, political and societal *factors*, and where non conformance to these factors may have radical consequences for the organization. Successful automotive manufacturers distinguish themselves by foreseeing and anticipating to these factors. Group Research is there to make sure Volkswagen has access to the required technologies and knowledge in carrying out its mission to become the world's leading automobile manufacturer.

Future Research and Technological Foresight
The mission statement of Future Research within Group Research is to 'provide foresight for successful automotive R&D and thus to stimulate innovations' (Internal document 2009). This is done through monitoring the relevant environment/external drivers and shaping forces for the automotive industry. The major domains are the societal, technological, environmental, economical and political domain. More concrete the actual conduct of future research is done through detection of weak signals, analyses of upcoming trends and issues, and interpretation of these factors for Volkswagen. Technological foresight deals mainly with the technology domain, although topics from other domains can analyzed as well (Internal document 2009).

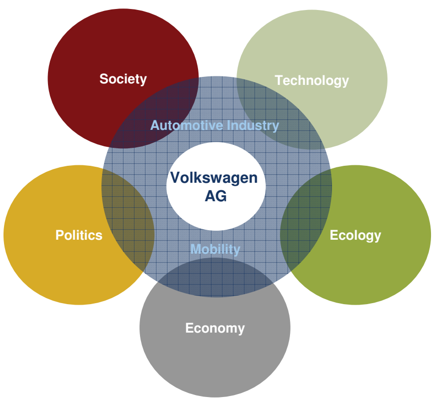


Figure 1.1.: Driving forces for Volkswagen Group Research. source: internal document

As part of Future Research the department of Technological Foresight guides researchers and decision makers of Group Research through the vast and exponentially growing body of information and enables them to collect, filter and interpret relevant information. Thereby reducing the complex and uncertain environment of the organization and contributing to more informed decision making. This is necessary since researchers find themselves confronted with an overload of information, and as a result they are unable to collect and interpret all information in their technology domains. Let alone make decisions based on this information. From a scientific perspective the conduct of Technological Foresight is known as *Technology Intelligence* (TI). The definition of TI used in this thesis is: *TI is the collection, analysis and delivery of relevant information about emerging or existing technologies, for enhancing decision making through the identification of new opportunities and threats as well as the assessment of current performance* (see appendix B)

1.2. An introduction to technology intelligence

This thesis deals with technology intelligence. A brief introduction to TI is given to introduce to important concepts. The users of TI —researchers and technology managers— are referred to as *clients*. Researchers are those whose primary task is to conduct research on a particular topic or technology. Technology managers can be (but are not necessarily) researchers and their main task is to manage technology in such a way to create competitive advantage: e.g. by managing the portfolio of technologies, technology mapping and technology strategy (Porter and Cunningham 2005).

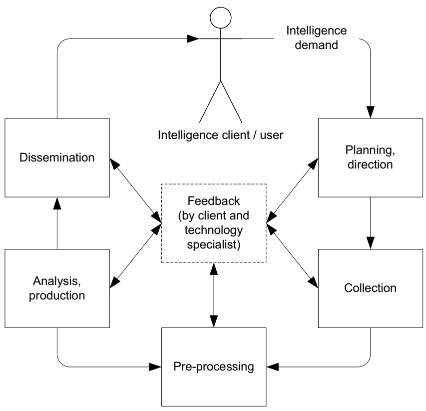


Figure 1.2.: The technology intelligence cycle. Adopted from Walde (2008)

From the perspective deployed in this research project, TI is created by *TI analysts* in a *process* involving a number of activities. An example of such a process is given in figure 1.2. The process is initiated by a client who has a *demand* for intelligence: a specific question or concern about particular technology characteristics. Intelligence demand may refer to one of the following issues (see e.g. Firat et al. (2008)):

- Prioritization and allocation of R&D expenditures by organizations.
- Managing the risks of innovation.
- The planning of new products
- Strategic decisions on mergers, alliances with other organization and the licensing, acquisition of technology and so forth.
- Research funding decisions from different sources: industry, government, education, nonprofit and cross na-

tional institutes.

These issues can be (re)-formulated into more specific *questions*. Question are often of the *what* and *who* type (Porter and Cunningham 2005). Examples of the what and who type questions are: 'what is going on in a particular field of technology?', and 'who is leading the research on Sulphur Lithium Cells?'. The analyst reinterprets this demand and develops a plan on how to resolve the issue. In a following step information is collected from science and technology databases (e.g. patent and publication databases), the information is pre-processed (made ready for analyses) and analyzed using specific *methods* and *tools*. The result of the analyses should be suitable for supporting decision making regarding the issue. As soon as results are obtained these are disseminated to the client(s) by means of presentations, workshops, spreadsheets or IT tools. Then new questions or issues may arise or particular aspects may need further exploration or clarification. When this is the case then the TI cycle is repeated.

An important element of TI is the interaction with clients and technology specialists (denoted in the middle of figure 1.2). Clients are the users of TI and therefore express their issues and give incremental feedback on intermediary results. Technology specialist possess the required expertise about a particular field of technology and have the knowledge to scope the problem (what items belong to a technology and what aspects do not), to safeguard quality (are items missing?) and to judge whether (intermediate) outcomes are plausible or not. The analyst therefore depends on the technology specialist because he does not possess this knowledge. The outcome of low quality or irrelevant input is that the output of the analysis has similar characteristics (i.e. garbage in – garbage out), which in turn is likely to negatively impact the quality of decision making.

1.3. Research problem

1.3.1. The current conduct of TI

A team within technological foresight, known as Di.Ana (i.e. Digital Analytics) works on quantitative foresight methods based mainly on scientific publications and patents. The majority of these methods can be classified as statistical and econometric methods. The main product of this team is the *detailed technology intelligence product.*

As the name implies the detailed TI product if fully customized to the issues and questions of the client. The conduct of TI is a lengthy and time intensive activity. This is mainly caused by explorative nature of the process and the fact that every project is *unique*. Clients are often unable to express and specify their issues or question, making the problem definition phase a cyclic, explorative, and inherently inefficient process. With regard to figure 1.2, the cycle is repeated several times. Every project involves a unique set of activities in which the analyst combines skills, methods, tools and resources to provide answers to the client's questions: a unique problem solving procedure. Although no exact lead times are known, the average project lasts between 2 weeks and 2 months (Walde 2009)

Recently a demand has developed for projects that involve the assessment of *a large number of technology fields*. Such projects typically include over 50 disparate technology fields. This is problematic because the number of technology fields is directly related to the required capacity. Capacity growth is restricted by budget, whereas the demand for TI is expected to increase further.

Problem
The problem is that the current approach of TI is *inadequate* for dealing with the upcoming of projects that involve a large number of technology fields. This is perceived problematic by management of a large engineering organization since these projects would allow them to get an overview of the developments in a significant part of the technologies in which they are active, rather than just a few. Therefore a new approach is required for dealing with this type of projects.

Proposed solution
A proposed solution involves standardization of particular elements of the TI process. The basic idea is that effective analyses of technology do not necessarily need to be labor intensive or time consuming. Every analysis does not need to be a custom solution; rather some flexibility can be sacrificed for increased familiarity, speed, validation and

utilization (Porter and Cunningham 2005) (Porter and Cunningham 2006). To deal with the projects that involve a larger number of technology fields a novel TI product is proposed: the standardized technology intelligence product (STIP). *A STIP is a product that is generated through a set of standardized activities and procedures. The main benefit in comparison to other TI products is that it can be generated significantly faster.* The main characteristics of the STIP are:

- STIPs address a specific issue or set of questions faced by decision makers and technology managers
- The analytical procedure for solving the procedure is standardized (i.e. the process)
- The methods for extracting knowledge from information is standardized

The concept of using a STIP to solve demand for TI that involves a large number of technology fields will be referred to as *upscaling the technology intelligence process*. Table 1.1 highlights the major differences between the STIP and the detailed TI product. UPSCALING TI

Table 1.1.: Comparison of the traditional TI product and the STIP

	Detailed TI product	**STIP**
Issue identification	Issue is unique	Issue is fixed for each STIP
Analysis	Depends on issue, unique	Predetermined, standardized
Method execution	Manual, partially automated	Largely automated
Process	Cyclic, iterative, based on experience	Linear, based on procedure and routine
Outcomes	Presentation slides, report, diversity	One-pager, uniformity (standardization)
Level of interaction	High	Low
Information resources	Mainly patents and publications	Mainly patents and publications
Size of target group	$\sim$ 1-5	$\sim$ 20 - $\geq$ 200
Average duration	$\sim$ 2 weeks - 2 months	$\sim$ 1 day
Flexibility of product	High	Low

1.3.2. Problem exploration

A first challenge is assuring sufficient quality of outcomes. TI products —including STIPs— are created through a process. Each process requires *input* from technology specialists to safeguard sufficient quality of outcomes. As a result, the quality of output is determined by the quality of *input* provided. Within the context of this research project, high quality is achieved when the input or output is:: QUALITY: COMPLETE, AUTHORITATIVE, OBJECTIVE AND RELEVANT

- Complete. The input or output includes all concepts.
- Authoritative. The input or output is perceived as authoritative by clients and other actors.
- Objective. The input or output is unbiased to any actor.
- Relevant. Apart from complete the input or output must also exclude irrelevant concepts.

In the present conduct of TI there is a frequent interaction between analyst and specialist. This is a lengthy and cyclic process, but does safeguard the quality of outcomes. Since a STIP emphasizes speed this places limits on the extent to which analyst and specialist can interact, this may have an effect on the quality of input provided by technology specialists. In other words: a focus on the reduction of lead time may have an adverse effect on the quality of outcomes.

A second challenge involves successful coordination of technology specialists. Technology specialists are not always interested in cooperation because they feel TI is not important. However the quality of TI depends on these same specialist because they alone posses the knowledge to provide high quality input. The challenge is to retrieve this knowledge from the technology specialists.

Further challenges not addressed by this thesis
The detailed technology analysis may be iterative and explorative, it does offer room for refinement of the problem definition and methods to best suit a clients' needs. In other words: TI outcomes have a good *fit* with the issues they aim to resolve. A good fit entails that clients are given the right blend of information to answer the questions that they have (Porter 2005). STIPs involve standardization of outcomes which may contribute to an inequality between the perceived problem and the proposed solution. Another challenge relates to the perceived authority of the TI analysis by technology specialists. Technology specialists may be skeptical towards TI, which is conducted by non-technology experts. This is caused by the fact that technology analysts often have little authority among users and therefore lack impact (de Bruijn and Porter 2004). Apart from this reason, individuals may doubt the credibility or validity of research conducted by anyone, especially when this research conflicts with their own thoughts and ideas. Actors that are not committed to the way the analysis was carried out; there is disagreement about the methods and tools used in the analysis (de Bruin and ten Heuvelhof 2002)

1.4. Research objective

Management of Group Research has expressed the desire to critically assess its' research partners in over 200 disparate technology fields.

Mergers and acquisitions as well as strategic alliances are well known as means for firms to enter new markets and achieving economics of scale and scope. In the environment of increasing competitive pressure, rising costs of R&D in combination with decreasing technology life cycles, strategic alliances between organizations have become an important means for managing to coping with technological change (de Man and Duysters 2005).

The assessment of research partners in over 200 technology fields will be done by deploying STIPs because the current approach to TI is inadequate for solving this project. This project is the first case in which the STIP will be used.

At present the *process* to create STIPs is unknown. What is clear is that standardization and partial automation of this process are key to reducing the cycle time of TI products. Therefore, this process needs to be developed.
Process
Secondly a *model* is needed that can be used to evaluate research performance of institutes based on several criteria. This model can be considered as the method for gaining insight into the performance of research partners. This
Model
model, as well as the criteria, need to be developed.

Demarcation
Because of the scope and complexity of this task the decision is made to produce a STIP for each technology field, which displays the performance Y_i of research institutes i in technology field t. Several choices are made to scope and bound the research problem. The choices are the result of discussions between the author and colleague TI analysts. These choices are the following: The output (the STIP) has the form of a *one-pager* and displays a top 10 rank of research institutes. Based on this rank, users are able to compare their current research partners to the top 10 in the field. The main data sources are patent- and publication data. Since the data source severely impacts the *TI process* and *model*, this is an important choice. The main methodology for the assessment of research performance is *bibliometrics.* Bibliometrics is "the field of science that deals with the development and application of quantitative measures and indicators for sciences and technology, based on (bibliographic) information" (van Leeuwen 2004).

Objective statement

A focus on the execution of the process, not use of TI products by technology managers.

Objective statement
To develop a *process* and *model* in order to create Standardized Technology Intelligence Products, that can be used to assess research performance of institutes in over 200 disparate technology fields, based on patent- and publication data. A second objective is to make recommendations towards the coordination of the key actors.

Two main evaluation criteria are considered for the STIP:

1. Quality of outcomes, largely determined by the *quality of input*
2. The required time to complete a STIP, the *lead time*

Scientific relevance
Intelligence products that involve standardization and automation have been discussed, but the literature on TI processes is scarce (Mortara et al. 2008) or lacks the right perspective. Furthermore while TI products involving standardization and automation have come within reach of many organizations, the questions of applying this on a large scale remains. The social relevance lies in the great advantages that can be achieved by incorporating TI into daily decision making. This research projects works towards making TI available to more decision makers than previous. The second social relance of this thesis is that it provides insight into the assumptions that underly the ranking of research performance and which have great effects on the allocation of research funds by governments to universities, by universities to researchers and large investment decisions by government agencies.

1.5. Research questions and methods

The main research question that corresponds to to the research objective is: *What does a process and what does a model look like, by which standardized technology intelligence products can be created that support decision making with respect to the appraisal of current and new research partners in over 200 disparate technology fields, based on patent- and publication data?*

1. What is a suitable definition of technology intelligence?
   Method: Literature study on the notion of 'technology intelligence'.
   Results: Reveals a clear and unambiguous definition of technology intelligence.
2. What are the key elements of the technology intelligence process found in literature and what are the implications of the STIP on these key elements?
   Method: Literature study on TI to reveal key elements of technology intelligence such as the process of executing TI and the methods used.
   Results: Answering this question reveals the key elements of TI. These elements will form part of the TI process design and the models. The implications of these elements for deploying STIPs are discovered. These implications are formulated as requirements.
3. What additional element(s) and requirements can be drawn from the environment in which the TI process is embedded?
   Method: Interviews and desk research are carried out to analyze current conduct of TI at the organization, and reveals the institutional setting.
   Results: Identification of elements and a set of requirements that serves as the key input for the design of the TI process and models. These requirements are for the analytical activities as well as the coordination of key stakeholders.
4. What does a preliminary design of the TI process look like that can be used to generate STIPs?
   Method: With aid of case study the elements and requirements are combined into a TI process and models for ranking research institutes. The TI process is modeled in the SADT (IDEF0) language and the inputs, outputs, control and support mechanisms for each process step are defined.
   Results: This results in a preliminary design of a *standardized technology intelligence process* and two models for ranking research institutes.
5. What does the preliminary design of model look like, which deploys bibliometrics for the appraisal of research performance of current and potentially new institutes, based on patent and publication data?
   Method: Literature on bibliometric indicators reveals what bibliometric indicators are, and how these can be deployed to assess research performance. A spreadsheet model is constructed in MS Excel to calculate research performance based on patent and publication data. Raw data is treated with the Vantagepoint 5.1

text-mining software to pre-process the data before it can be used in the model.
Results: This demonstrates how analysts can combine science and technology data, text mining software, and automated spreadsheet models to evaluate research performance of institutes, based on patent and publication data.

6. What opportunities for improvement can be made with regard to both designs, based on the execution of a case study, with regard to quality of outcomes and the speed of the process?
Method: Execution of a case study to test the preliminary design and the model for ranking research performance.
Results: Based on two cases studies carried out with technology domain experts in *sulfur lithium cells* and *augmented reality* the TI process and the model are tested and evaluated. Recommendations with regard to the quality of the outcomes and the the speed of the process are formulated.

7. What recommendations can be made to Volkswagen with regard to future use of STIPs?
Method: No specific method. Recommendations are made based on the outcomes of the prior questions.
Results: A number of recommendation are made with respect to improving the STIP for ranking research performance, future use of STIPs in the organization and the use of STIPs as means for TI in general.

1.6. Research methodology

This research project is carried out from a systems perspective. The systems perspective takes a holistic view of large scale problems and their proposed technological solutions. This means that not only the specific problem and the proposed solution(s) are studied, but also the relevant factors in the surrounding environment (Sage and Armstrong 2002). The systems perspective acknowledges that problems are embedded in an environment which may significantly impact the problem and the proposed solution(s).

The research problem and the proposed solution, standardization of the TI process, provide a valid example. A technical solution involving standardizations and automation of activities, software tools and models can reduce lead times of projects and make the overall TI process more efficient, but does not guarantee effective coordination of actors, and overall quality of results. For that reason, this research project takes the technological side of the problem into account, the TI process, as well as the environment in which the TI process is embedded.

The TI process for can be characterized as a *socio-technical system*. The notion socio-technical system is introduced by Emery and Trist (1960) to describe the ‘dynamic linkages between the social and the technical system in the context of industrial organization and development’. The TI process can be classified as a socio-technical system in that it contains both technical elements; the execution of analytical steps using information databases, software tools and computer models; and the exchanges of information and power between different actors that are involved in the TI process. The social and technical systems are necessarily linked and mutually dependent on each other; e.g. the social system affects the performance of the technical system; the technical system cannot function without the social system. The linkages between the social- and technical system make it difficult to derive a clear set of requirements and then design a technical artifact (the design)(Bots 2007). The research methodology applied in this research project is based on two models:

Models
The first model, the *evolutionary process model* describes how a complete software system is developed in a process with several repetitions of three phases, which constitute the life-cycle of any systems engineering effort (Sage and Armstrong 2002): *definition*, *development* and *deployment*. In the definition phase the problem is demarcated and analyzed. Analysis in this sense consists of breaking the problem down into smaller elements and the investigating relationships among these elements. In this phase requirements are formulated which the designed system (in this case the TI process) must meet. In the development phase the system is designed and tested, to see its performance. The deployment phase considers the implementation and maintenance of the system. The evolutionary process model acknowledges that a complete set of user requirements cannot be obtained initially (at the start), and proposes a

series of repetitions instead, in which the system design is refined with each repetition.

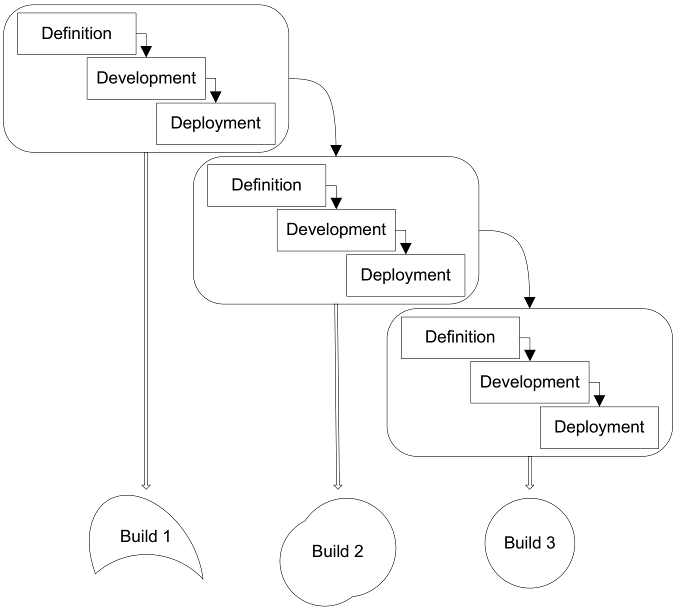


Figure 1.3.: The evolutionary process model, source: Sage and Armstrong (2002)

A second useful model is the *meta-model for design* by Herder and Stikkelman (2000) (see appendixC. Originally intended for the design of complex technical artifacts (e.g. methanol clusters), the model's utility has also been proven for the design of complex technical systems with a social component (Koppenjan and Groenewegen 2005). The meta-model is more pragmatic than the previous model since it lays down a set of predefined activities in order to reach a final design.

The model starts off with the definition of *requirements* which the artifacts need to fulfill. After this the *objectives* and *constraints* of the system are defined. Constraints specify boundary conditions within which the designer must remain (Bahill and Dean 2009). Goals can refer to a specific value for a (mandatory) performance requirement, but may also refer to a desirable direction of change (e.g. a goal could be to reduce cycle time of the analysis to as small as feasible). So, constraints and goals can alternatively be referred to as requirements. The *solution space* consists of potential design alternatives, or parts of design alternatives (i.e. building blocks). The *solution space* is developed by analyzing the current TI process, and taking useful elements from literature. The requirements, constraints and goals are then used to filter promising elements from the solution space, in order to arrive at a *preliminary* design.

Research methodology deployed in this thesis

The methodology applied for this project combines elements from the *evolutionary process model* and the *meta model for design*. The methodology starts off with the the formulation of the problem and corresponding research question(s). The next step is a system analysis, in which the relevant elements of the system are identified and their relation studies. This step, in addition to the preceding step provides a set of objectives, requirements and a solution space for the system. Iteration to the definition step may be necessary. The design step is aimed at arriving at designs for the various system components. Design is an evolutionary process and therefore characterized by iteration and continues refinement of intermediate designs. The output is a preliminary design, which is tested by means of a case study. This leads to new insights which can be used to further refine the design. The interpretation is aimed at validation of the designs, formulation of conclusions and recommendations for further improvement. Finally the entire research project is evaluated.

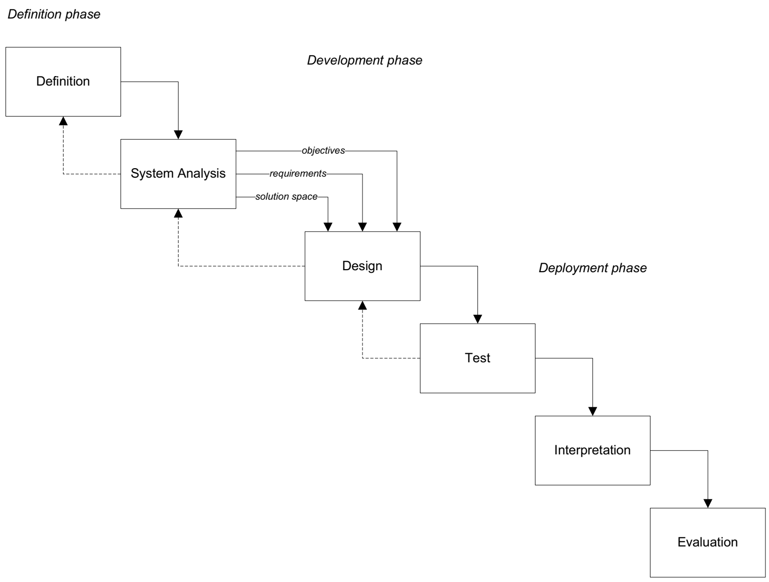


Figure 1.4.: Research methodology applied in this project, adapted from Sage and Armstrong (2002) and Herder and Stikkelman (2000)

1.6.1. Design requirements

Specific attention is paid to the design requirements. Requirements describe the attributes the TI process needs to have, and the functions it performs in order to have 'utility' (Grady 1993). The customer's requirements are the 'ultimate' requirements. Requirements state *what* the system (i.e. the TI process) is to do, but not *how* this is to be achieved.

Two types of requirements can be distinguished: mandatory and preference requirements. Mandatory requirements are requirements that must be met by the system (they are strict requirements). Preference requirements are requirements that the system may fulfill, but they are less stringent than the mandatory requirements. This allows for comparison of alternatives, and a choice based on how well different alternatives satisfy the requirements. The risk of only formulating mandatory requirements, without room for trade-offs, is that no solution is available that satisfies all requirements (Bahill and Dean 2009).

Although requirements constitute an important element of this research project, no strict distinction is made between mandatory and preference requirements. The reason being that this research project deals mainly with the design of intangible artifacts, and that the state of these artifacts cannot be measured quantitatively. This entails that trade-offs between requirements cannot be investigated in a straightforward way, as would be the case with systems that can be measured quantitatively (e.g. the costs of developing an engine versus the power in kW). The requirements introduced in the next chapter are largely mandatory requirements [1]. This does not mean that trade-offs between requirements are ruled out entirely. On the contrary: the previous section introduced the two main evaluation criteria (speed and quality) and explicitly stated that these stand in sharp contrast. Therefore the contrast between these criteria will be evaluated in the conclusions section.

[1] Alternatively, these may be considered as propositions

1.7. Structure of the report

This chapter has introduced and demarcated the problem and has presented the research questions. The research methodology is explained. Chapter 2 identifies the key elements of TI and reveals the requirements that apply for the design of the TI process and models for the STIP. Bibliometrics, a methodology that can be used for the appraisal of research performance is also discussed in chapter 2.

In chapter 3 the organizational setting is studied. This reveals an additional element —the TI process— which is considered essential to upscaling the TI process. Chapter 3 also discusses the current situation. The first part of chapter 3 discusses a TI platform which is considered an essential element for upscaling the TI process. The second part of chapter studies the organizational and institutional setting of the TI process. The third part of chapter 3 describes the primary relations between the TI analyst and other actors using the analogy of a principal–agent relationship.

In chapter 4 the elements and requirements from chapters 2 and 3 are used for the design of the TI process and ranking models. A case study carried out to test these designs is found in chapter 5. Chapter 6 deals with the verification and validation of the designs. A reflection on this research project is found in chapter 7. The final chapter, chapter 8, contains the conclusions and recommendations. An overview of definition for TI can be found in Appendix B.

2. The elements of technology intelligence

2.1. Introduction

This chapter aims to identify the elements of which TI is constituted, since this will aid the design of a process and model for STIPs. Furthermore this chapter reveals requirements that are used for the TI process design and models. Literature on technology intelligence appears to be fragmented. A large part of the literature focuses on specific methods and tools for retrieving knowledge from information (see Firat et al. (2008)). Literature on technology intelligence *processes* is available but is scarce (Mortara et al. 2008) and does not address the actual conduct of TI within organizations. Porter and Cunningham (2005) have discussed the conduct of TI and have shown how technology management issues can be solved by particular methods (Porter 2007). Few examples of TI products that are similar to the STIP have been provided (see Porter (2005) and Porter and Cunningham (2006))

Choosing which elements are relevant to TI depends on the perspective taken. The perspective could focus primarily on the methods and tools for extracting knowledge from information, or could focus on the analytical activities by which TI is created. The perspective deployed in *this* research project involves the methods and tools, the analytical activities but also considers the technology manager or decision maker that will make decisions based on the TI provided. Based on this perspective, TI is considered to be composed of four key elements:

1. Management of technology questions (MOT): questions that technology managers and decision makers have;
2. Science and technology information;
3. A systematic process and
4. Technology intelligence methods.

These four elements are considered essential to each form of TI. Since the aim of this chapter is to provide insight into the elements as well as identify requirements that apply to the design of the process for STIPs. Before starting off to explain the four elements, TI is placed in positioned in a broader context using the technology delivery system. From this broader perspective it will become evident that TI is part of a much wider system than might appear from studying the individual elements.
In the sections that flow the four individual elements are discussed. These elements are generic in that thet apply to every form of TI (not limited to the STIP or detailed TI product). Therefore the implication for the STIP are formulated for each element (denoted by the ➢ symbol). The fourth element discusses generic TI methods but also elaborates on the method that is deployed in this thesis: bibliometrics. This chapter ends with a summary of the requirements.

2.2. Positioning technology intelligence: the technology delivery system

Technological innovation is crucial to the competitive position of companies (Porter et al. 1991). Innovation in this sense is 'the process by which technological idea are generated, developed and transformed into new business products, processes and services that are used to make a product and establish marketplace advantage'. (Mogee 1993). The way in which organizations innovate has shifted to the early 'technology push' and 'technology-pull' approaches to complex inter- organizational innovation networks. Organizations no longer innovate by themselves but engage in relationships with suppliers and customers and form strategic alliances with other organizations (Tidd et al. 2005). National and regional governments realize that technological change is the major driver for economic productivity and therefore have a great interest (Porter et al. 1991). Moreover, they are aware that technological organizations are almost always the institutes that deliver the technology, making private technological organizations the key player for the economic productivity of a country or region. Governments stimulate innovation by funding research programs of R&D labs and universities, or act as 'facilitators' in bringing actors together in joint research projects to boost innovation. Because of the effects technology has on society, governments give direction to the content of innovation through the allocation of funds and targeting of legislation at regional, national or EU level. The process of technological innovation including the various actors discussed, can be described using the 'technology delivery system'(TDS) model. The TDS model describes the technological linkages involved in the development of a single technological innovation (retrieved from Porter et al. (1991)). This model includes only formal linkages, informal linkages exist and may in some cases be at least as important.

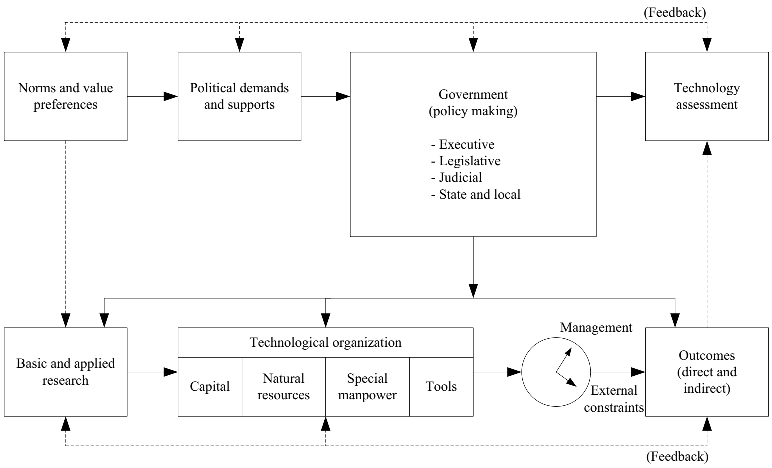


Figure 2.1.: The technology delivery system (TDS). Source:Porter, Roper, Mason, Rossini, Banks and Wiederholt (1991)

The TDS has four main elements (Porter et al. 1991);

1. Inputs to the TDS system, which includes the capital to make investments, natural resources, (skilled) labor, knowledge from basic and applied research, norms and values.
2. Institutions and organizations that are active in the TDS and modify and control the output of the system. This may include organizations such as Volkswagen AG and also their suppliers, private as well as organization research labs, governments at various levels etc.
3. System processes by which institutions interact through exchange of information, markets, political arenas, legal systems and social systems.
4. System outcomes, which include both direct (intended) and indirect (unintended) effects on the social and physical environments. System outcomes result mainly from the technological innovation produced by firms, which has (indirectly) been influenced by the societal values and directly by the research conducted by universities and research labs; and the influence of governments.

Multiple institutes are directly involved in the development of the technology. This includes universities, researchers, individuals and research labs that conduct basic and applied research and create ideas. The content of this research is motivated by societal and individual norms, values and preferences about different aspects of technologies. They pass these ideas on to technological organizations that combine capital, manpower, resources and tools to further develop these technologies. This is often referred to as R&D. The term R&D refers to the activities covering early acquisition of knowledge and understanding towards the commercial implementation of goods, services and processes

(Schilling 2008). The outcomes are new and improved products and services, prototypes, cost savings, technological improvements, quality improvements. The outcomes of the systems eventually have both a direct (intended) and indirect (unintended) effect on the social and physical environment of the system.

2.3. Element 1: Management of technology questions

Chapter 2.2 introduced the technology landscape in terms of the TDS model. At the heart of this model stands the technological organization, which will eventually combine knowledge from research with capital, natural resources and manpower for the production of marketable products and services. But for the organization to innovate it needs to deal with certain issues. These issues involve; the identification and choice for particular R&D areas; development of new products and markets, acquiring knowledge through mergers, acquisitions or alliances (Duysters and de Man 2003); exploitation of intellectual property; assessment of competitors; forecasting of technologies; and strategic technology planning (see Porter and Cunningham (2005)) for an overview.
Each of these issues can be explored and answered using one or multiple, management of technology questions. Porter and Cunningham (2006) identify issues and link issues to MOT questions. For the case of Volkswagen Research, the issue is *to collaborate with the best research institutes in different technology fields in order to stimulate technological innovation* (see B.3). Several MOT question can be posed in order to resolve this issue:

1. Which research labs lead in this technology field?
2. Which research labs lead in particular aspects of this technology?
3. With whom are our main competitors collaborating on particular technologies?
4. What is the performance of our current research partners?
5. ...

Implications for the STIP
Like other TI products, STIPs set out to answer MOT questions. Usually these MOT questions are unknown at the start and need to be elicitated through an an explorative and iterative process. In other cases questions may not even be stated explicitly. The STIP does address explicit pre-defined question(s), since the question determines what information must be collected, what methods should be used, what the answer should look like. The number of questions is limited and depends on broad or narrow the issue is. Predetermining the question *before* the analysis is referred to as *standardization of the question(s)*. The corresponding requirements are formulated as:

➢ STIPs address predefined (fixed) MOT questions.

➢ One STIP will address one or several predefined questions.

For this research project a question is selected from an available list of common questions; “Which universities or research labs lead in this technology - overall or in particular aspects?”(Porter and Cunningham 2005). The assumption is that the performance of universities or research labs is reflected in the patents and publications that they have issued.

2.4. Element 2: Information resources

The actors in the TDS (2.2) interact and exchange science and technology information. Research institutes conduct research and publish their findings in scientific journals or conferences proceedings, and patent their ideas. Publications and patents are essentially the outputs of R&D activity of research institutes. Patents and publications reflect both the cognitive and the social dimensions of science. The cognitive dimension covers the content and structure of science (i.e. the ideas and the linkages of these ideas), whereas the social dimension addresses questions of the type “*who* is doing *what* in science and technology”(van Raan 2004)?
Furthermore the details of patent and publication records also make visible the network of arrangements between

institutions, innovators and initiators in funding, conducting and disseminating. R&D activity is often also reflected in the details of publication and patent records (Porter and Cunningham 2005).

Patents and publications can be retrieved from databases in which they are collected, sorted and stored. Well known examples of such databases are Thomson Innovation, Scopus, Science direct, Web of Knowledge, INSPEC etc. Figure 2.2 depicts and example of a patent record.

DWPI Accession Number	2009P21710
Title - DWPI	Maneuver assistant for detecting and preventing collision to park e.g. automobile, has monitor or screen for displaying augmented reality image formed by superposition of image of ego-vehicle on selected anterior image
Inventor - DWPI	ABAD F,,,, | BENDAHAN R,,,, | BOUGNOUX S,,,, | VESTRI C,,,, | WYBO S,,,,
Assignee - DWPI	IMRA EURO SAS,,,,
Assignee Code - DWPI	IMRA|N|IMRA EURO SAS
DWPI Class	T01 E | X22 E
DWPI Family Members	FR2929196A1
Priority Date	31.03.2008
Priority Number	FR20081770A
Count of Citing Patents	0
Count of Cited Refs - Patent	3
Abstract - DWPI	The assistant has a selection unit selecting an anterior image e.g. departure anterior image, taken by a camera (3), stored in a memory. Positioning units position an image of ego-vehicle obtained from a pre-stored model with respect to the anterior image selected by comparing an actual position of a vehicle e.g. motor vehicle (1), provided by an odometric device (4) with determined position of the vehicle when taking the selected anterior image. A monitor or screen (6) displays an augmented reality image formed by superposition of the image of the ego-vehicle on the selected anterior image. An INDEPENDENT CLAIM is also included for a maneuver assistant method for a vehicle. Maneuver assistant for detecting and preventing collision to park a vehicle or ego-vehicle e.g. motor vehicle i.e. automobile. The monitor displays the augmented reality image formed by superposition of the image of the ego-vehicle on the selected anterior image, thus displaying the non-visual information directly accessible for the driver in a manner to allow the driver to view all the visible and invisible obstacles with respect to the vehic
DWPI Manual Codes	T01-J07D1 | T01-J40C | X22-E09A | X22-J05
IPC - Current	B60Q000126 | B60Q000148
ECLA	B60R000100 | B62D001502H2
US Class	

Figure 2.2.: Example of a typical patent record. The full record can contain over 100 fields.

Implications for the STIP

Other TI products also use the data that is retrieved from the science and technology databases. With respect to the STIP it is important that the information source is fixed, depending on the MOT question(s) to be answered. Since the MOT question are also fixed, this determines which information sources will be deployed: The question to be answered and the methods chosen to answer this question determine exactly what information is needed. Since for the STIP the question is standardized and the method(s) are standardized, the required information can exactly be specified. The requirement that can be drawn from this is that STIPs use fixed information sources, to answer the MOT question(s). This involves both choices with regard to the information *type* (e.g. patent or publication records) and *part*; the fields (which part of the record, see Thomson Innovation (2010)). Referring back to figure 2.2: the entire record reflects the type, which is subdivided in several fields (e.g. ‘title -DWPI’, ‘DWPI-class’ etc).

- ➢ STIPS deploy fixed information sources
- ➢ STIPS deploy predefined record types and fields

2.5. Element 3: the TI process

2.5.1. Introduction

In chapter 1 the TI process is characterized as a socio–technical system. This section explores both the social and the technical system and concludes why the technical system cannot function without the social system and vice versa. The technical system focuses primarily on the set of systematic activities that are carried out by the analyst to provide an answer to a MOT question, or —in line with the definition TI— the set of activities that involve the '*collection*, *analysis* and *delivery* of relevant information about emerging or existing technologies'.
The social system describes the necessary interactions between the analyst and other actors such as the client, decision maker and technology experts that take place in the process of executing TI. First the technical system is described as a set of activities to be carried out with use of a *9-step model*. The second section focuses on the social system. Then it is concluded why the technical and social system together, constitute the TI process.

2.5.2. Technology intelligence process as a technical system

TI-PROCESS

This research employs the 9-step 'tech-mining' model (Porter and Cunningham 2005) to describe the set of systematic activities that are carried out to produce the TI product. . The literature on TI processes is scarce (Mortara et al. 2008). From the various models studied, the 9-step model is the most pragmatic. This model consists of three general phases; a *definition phase* in which the issue is defined and information is collected, an *analyses phase* that leads to new insights from the information retrieved, and a *choice phase* in which the outcomes of the analyses are presented, interpreted and utilized by the client. These phases are largely in line with the primary systems engineering steps of formulation, analysis and interpretation (Sage and Armstrong 2002) and is in line with that of other authors (Reger 2001).

Each phase consists of three steps and the output of each step forms the input of the proceeding step. The first phase accounts for roughly 50% of the total time. The majority of this time is need for information retrieval. The second phase accounts for approximately 30% of the total time and the final 20% is needed for the third phase (see Kunze (2000) and Michaeli (2006)). Although the process appears linear on paper, it is characterized by frequent iterations and cycles that may take place to: further demarcate the issue, improve the substantive quality; adopt to chancing requirements etcetera. The exact nature of these iterations depends on the issue at hand, and on the situational context and is therefore difficult to generalize. A graphical representation of the model is depicted in figure 2.3
The nine steps will be briefly discussed:

Definition phase

1. The first phase starts off with the formulation of the clients' issue and corresponding MOT-question (s) (discussed in section 2.3). In the context of this research the issue is *to collaborate with the best research institutes in different technology fields in order to stimulate technological innovation*. The corresponding research questions may be 'Who are leading research institute in technology field X' and 'What is the performance of Volkswagen's research partners in technology field X'?

2. The second step involves the selection of information sources; e.g. patents, publications, conference proceedings, business literature etc. It also involves deciding which parts of a patent or publication record will be retrieved (2.4. This depends on the MOT question(s) formulated in step 1.

3. In the third step the *search query* is defined. The primary function of the search query is to demarcate what information is relevant, and what is not. In the context of this research, the search query involves determining what characteristics belong to technology field X and what not (the key words which are entered to retrieve information using 'Google' are search queries too).

   The definition of the search query is an iterative process in which the query is continuously refined based on the results retrieved. There are two aspects to formulating an effective search query (Porter and Cunningham 2005). First the 'breadth' of the search query needs to be considered. A broad search query can be formulated that misses minimal relevant items (but may include many irrelevant items) or a query can have a sharp focus (i.e. obtaining a minimal of irrelevant items).

The second aspect to be considered is choosing between natural or scientific language. Natural language is spoken by scientists as well as by other individuals and is therefore rich, expressive, deeply but unfortunately often deliberately ambiguous. 'Scientific language' on the other hand is precise, structured, and unambiguous but unfortunately has limited expression power. Scientific language is more useful for search query definition.

The process of search query definition requires the contribution of both analyst and technology experts, since analysts lack the technological expertise to give the query the right balance between breadth and sharpness, and technology experts often lack the skills and knowledge of scientific language to formulate an effective search query.

Once the search query satisfies the information is retrieved from the science and technology databases and stored (downloaded).

Analyses

4. The first step involves exploring the data to see whether the information retrieved meets the desired 'breadth'. The remainder of this step involves data-cleaning, an essential activity in almost any analysis that involves dealing with raw data (numbers or text). Data cleaning involves cleaning the data through (among other activities) removing duplicate records, removing identical records and perform fuzzy matches to various fields (e.g. organization name may be spelled different as 'Volkswagen' or 'Volkswagen AG').
The main purpose of cleaning data is to be make it suitable for the analysis. The data cleaning step is common in any analyses of data and involves removing or modifying parts of the data that would otherwise distort the results. Data cleaning does the following(Porter and Cunningham 2005):
    - Removal of exact duplicate records (documents)
    - Match and remove those records with certain fields identical (e.g. 2 papers by the same author published in the same journal)
    - Perform fuzzy 'near matches' to various degrees on desired fields (e.g. special fuzzy match on author giving higher weight on probable last name matches than on first names and initials)
    - Combine exact and fuzzy matching on multiple fields to maximize removal of true duplicates with minimal loss of actually distinct records
    - Normalize field data to make it compatible to existing filters and indicators
5. The following two steps concern the actual analysis. The line between 'basic analyses' and 'advanced analyses' is not very distinct. The basic analyses step involves retrieving lists and co-occurrence matrices from the data.
6. The advanced analyses goes beyond direct measurements and is aimed at deriving more general and salient patterns (Porter and Cunningham 2005).

Choice

The choice phase involves "deriving alternative innovation opportunities from the analyses phase and then selecting the right innovation opportunity, based on the decision makers' criteria" (Porter and Cunningham 2005). This phase involves presentation of the results, interpretation and utilization of the results.

7. The representation involves presentation of results that are relevant to the client, an aid the decision making. The presentation may take shape in presentation slides, reports, spreadsheet models, or one-pagers. The main purpose of this step is communication of results to the client. In the case of this project, a fixed presentation

format is chosen to present the results of the assessment of research partners.

8. The interpretation step concerns deriving useful conclusion from the outputs produced in the previous step. A presentation involves graphs, trend plots and lists means little to a client without an additional explanation being offered. In the presentation phase there is also room for offering arguments to support the authority of the analyses, e.g. by presenting choices, limitations, sources etcetera. The interpretation of results should be adjusted to the client. The interpretation step goes beyonf the scope of this research project.

9. The utilization step concerns how the client uses the TI results for decision making. The utilization step however does not fall within the scope of this research project.

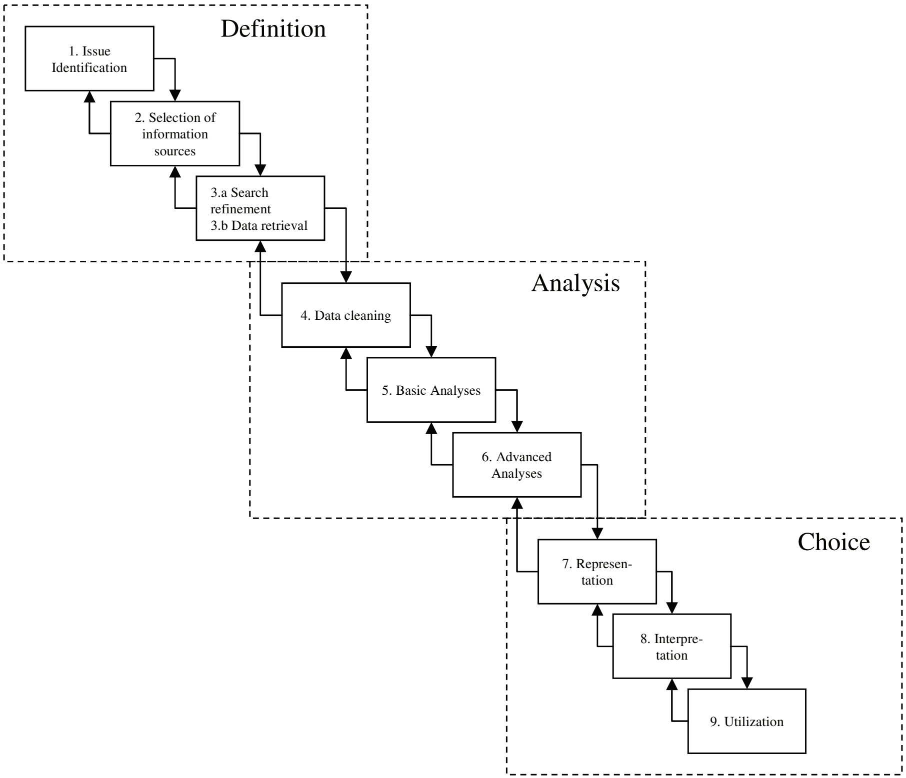


Figure 2.3.: The general TI process, based on Porter and Cunningham (2005). The three dashed boxes are the phases of the TI process: definition, analyses and choice. The nine boxes represent the steps. The waterfall model structure expresses the iterative feedback that exists between the different steps.

Implications for the STIP

The STIP involves taking all of the 9 steps shown in figure 2.3 but has some specific characteristics. Although all 9 steps are included in the model, the latter two steps (interpretation & utilization) do not fall within the scope of this research project. STIPs are created through a *systematic process*. The term systematic process may need clarification. The process refers to the set of analytical activities. A *systematic process* thus refers to a process that is methodical in procedure: i.e. characterized by order, rationality and consistency. Many of the choices made in steps 1-9 are predetermined and many of the activities are conducted according to predetermined procedures and automation: The issue identification and selection of information resources are predetermined since each STIP addresses predetermined MOT questions and information resources. The activity which is most important for the STIP is that of 'search query definition'.

Since STIPS are largely standardized, the search query (which defines the search query) is the only 'unique' aspect *of each STIP*. The definition of the search query cannot be automated, since each technology field is unique, but the procedure for defining a search query *can* be standardized. Data cleaning *can* be standardized, and the same goes for the basic and advanced analyses. Representation and interpretations of outcomes can be standardized and automated.

- ➢ STIP are created through a systematic process, which is pre-defined.
- ➢ The activities *issue identification* and *selection of information sources* are predefined.
- ➢ The procedure for defining search queries is pre-defined.
- ➢ Data cleaning is standardized.
- ➢ Basic and advanced analysis is standardized.
- ➢ Presentation of outcomes is standardized.

2.5.3. Interaction between the TI analyst and other actors

The social system describes the necessary interactions between the analyst and other actors such as the client, decision maker and technology experts that take place in the process of executing TI. The question to be asked is: why is interaction between analyst and actor essential for the TI process?

Actors play different roles in the TI process, they can act as: initiator of the TI effort and users of the TI products (the client), those affected by the outcomes of the analyses, and those necessarily involved for ensuring the quality of the analyses (the technology specialists). Therefote performing TI necessarily entails the multidisciplinary engagement of analyst, technology specialists and clients.

The success of TI relies on the interaction with actors for a number of reasons (Porter and Cunningham (2006),de Bruijn and Porter (2004),de Bruin and ten Heuvelhof (2002):

- interaction enhances the quality of the analysis since the technological knowledge of experts is used
- interaction helps to build up credibility for the analyses
- interaction makes users familiar with strengths and weaknesses of TI
- interaction is needed to be able to provide the right blend of information.

Essentially, interaction is crucial for ensuring the products of TI are indeed of high *quality*; for ensuring that the products have a good *fit* and clients are able to interpret and use the results.

Implications for the STIP
A TI process which is characterized by frequent interactions between analyst and other actors stands in sharp contrast with the process for developing STIPs. From a technical perspective, interaction is an essential but time consuming activity. However, since STIP involve many standardized activities and predefined choices, most interactions can be reduced (since the output is known at the start). Nevertheless, despite predefined choices and standardization of activities interaction between analyst and technology expert remains essential for the definition of the *search query*, since at this point the technology specialist bring their specialist knowledge into the process. A second requirement states that the process defined *when* interaction takes place with actors. A third requirement is that the TI process prescribes *what* this interaction is about.

- ➢ The TI process states when interaction with actors takes place.
- ➢ The TI process prescribes what this interaction is about.

2.6. Element 4: Technology intelligence methods

2.6.1. General overview of TI methods

In the analysis phase the analyst derives useful knowledge from the retrieved data (search refinement and data retrieval). Depending on the issue at hand (defined in step 1) and the information sources, different methods and tools can be used for this analysis (see e.g. (Porter et al. 2004). A vast body of literature is available on TI methods. A study carried out with R&D intensive organizations revealed an extensive list of (foresight) methods used by these organizations (Reger 2001). A dense classification is presented in figure 2.4. Generally three groups of foresight (TI) methods can be distinguished:

- Cognitive and appellant methods
- Statistical and econometric methods
- Structural and causal methods

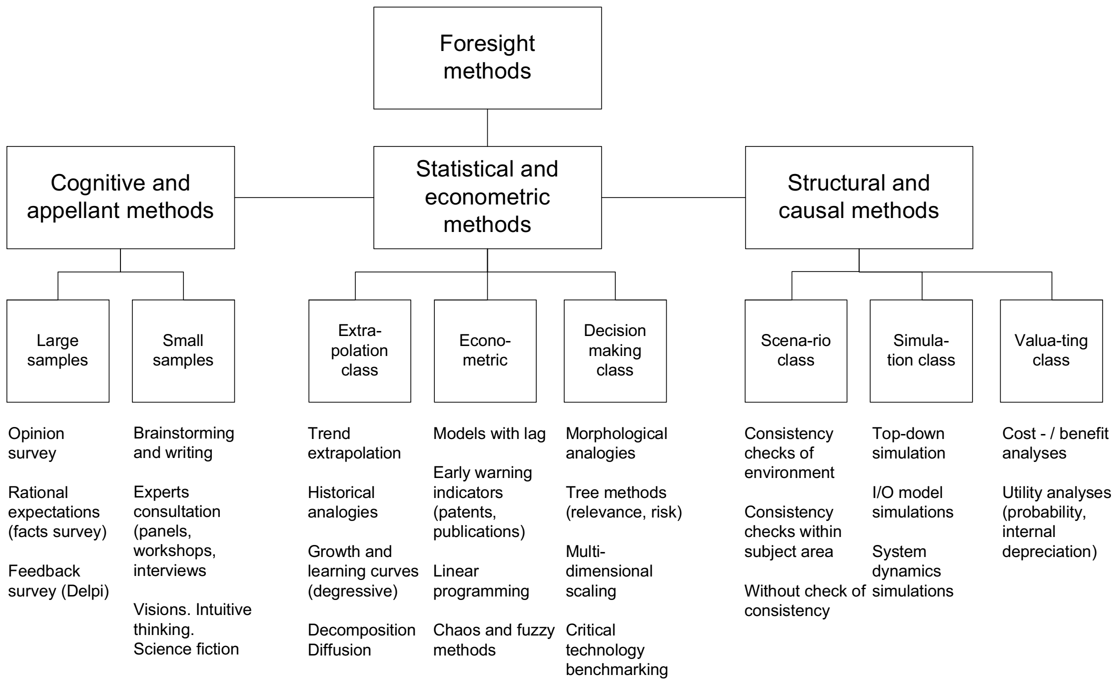


Figure 2.4.: A classification of foresight methods, based on Reger (2001)

Every method has different characteristics. According to the Technology Futures Analysis Group (see Porter et al. (2004)), certain methods are used to compile information, while other methods seek to research the interactions among events, trends and interaction. Some models are definitive (conclusive), while others are used to cope with uncertainty. Methods can be classified as 'hard' (i.e. quantitative, empirical) or more 'soft' (i.e. qualitative, based on tacit knowledge and judgment). A final characteristic reflects whether models are normative (the process is started with a perceived future need) or explorative (beginning the process with extrapolation of current technological capabilities). This diversity of models implies that methods are more or less time intensive, require different levels of user skills and use different information sources. The selection of TI methods depends on many factors.

Lichtenthaler (2005) offers insight in the factors that influence the empirical selection process for suitable TI methods by organizations. In a study Lichtenthaler conducted 147 interviews at 26 large technology intensive companies in Europe and North America. Based on these results it can be concluded that the choice of technology intelligence

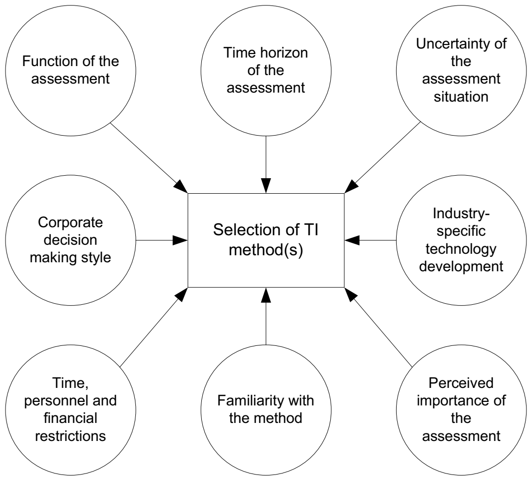


Figure 2.5.: Choice of technology intelligence methods in organizations. Adapted from Lichtenthaler (2005)

assessment forms and methods depends on various factors, see figure 2.5.

Implications for the STIP
The factors identified by Lichtenthaler refer to all TI products and therefore also STIPs. Some additional requirements for STIPS apply: STIPs are generated fast, which rules out participatory assessment forms and methods, as well as cognitive and appellant methods (figure 2.4): these are simply too time consuming.
The following requirements apply with regard to the choice of methods that can be used for the STIP: The methods are clearly normative (the perceived goal is clear at the start). Furthermore the methods can be classified as 'hard' and dealing with quantitative data (opposed to 'soft' methods involving qualitative data) since this allows for fast and (partially) automated execution of the methods. Thirdly the methods involve no additional actors besides the TI analyst. Finally the methods can be executed within the time, personnel and financial restrictions. The requirements are:

- The methods and tools used are 'normative'.
- The methods can be classified as 'hard'.
- The methods do not require involvement of actors besides the TI analyst.
- The methods can be executed within the time, personnel and financial restrictions.

2.7. Bibliometrics for assessing research performance

2.7.1. Introduction

This research project employs bibliometrics as the main methodology. The question to be answered is: 'Which universities or research labs lead in this technology - overall or in particular aspects?'. To reveal what institutes lead, their *performance* needs to be assessed and compared. This can be done using 'bibliometrics'.
Bibliometrics is the 'the field of science that deals with the development and application of quantitative measures and indicators for sciences and technology, based on bibliographic information' [1] (van Leeuwen 2004). Examples of bibliometric studies include the well known university ranking lists. Bibliometrics uses a wide range of quantitative (statistical) methods to derive useful knowledge from bibliographic information. This knowledge consists of trends, patterns of ownership, publication and use of science and technology information (Young 1983) (Jokic and Ball 2006).

[1] Bibliographic information, in this context, is constituted of science and technology information (publications and patents)

The most common applications are content and citation analyses (Chang et al. 2008). Porter and Cunningham (2005) provide a practical overview of the output of most bibliometric analyses[2]:

1. List i.e. activity counts that tell how much of something is taking place. Shows the development of technology fields, publishing activity of countries, organizations and individuals, patents issued by competitors etc.
2. Breakthroughs from those list e.g. top-10 Patent Assignees and combinations of two lists into a matrix (a 'profile').
3. Maps - showing relationships among a chosen type of data, such as keywords or authors.
4. Trends - showing changes in science and technology

Information resources

Section 2.4 mentioned that scientific output is reflected in scientific publications, journals, books, conference proceedings and patents. Each record (i.e. one paper, chapter, patent etc) contains a wealth of information regarding content (i.e. a technology, theory, model etc), linkages to other records (e.g. in the form of citations, co-word occurrences, co-authorships, origin of researchers etc). The assumption of bibliometrics is that the most important scientific findings will eventually end up in serial literature. This also implies that bibliometrics is less useful in science fields in which the internationally oriented scientific literature is not the main medium for communicating research fields to the community (van Leeuwen 2004).

2.7.2. Measuring research performance using indicators

The measurement of science can be done using *indicators*. Indicators measure the features of science that can be given a numerical expression (Moed et al. 2004). Within the context of this project, different indicators are used to measure different dimensions of research performance. The aggregate value, composed of the indicators that measure different dimensions of research performance, represents the overall research performance. This is equal to the sum of indicators values multiplied by the relative importance of each indicator (the weight). So, for every university or research lab i, a ranking value Y_i is established based on the indicator values C_x with corresponding weight values w_x, based on patent and scientific literature data (equations 2.1 and 2.2).

$$Y_p = w_1 \cdot C_1 + w_2 \cdot C_2 + w_3 \cdot C_3 + w_x \cdot C_x \tag{2.1}$$

$$Y_l = w_1 \cdot C_1 + w_2 \cdot C_2 + w_3 \cdot C_3 + w_x \cdot C_x \tag{2.2}$$

To determine which indicators to use, a literature study has been carried out. Patents and literature have different characteristics. Therefore, a set of indicators is required for both sources. There is no final theory of science that states *how to measure science* (van Raan 2004). Hence there is no consensus on what indicators to use and what weights to assign to these indicators. Fortunately the field of bibliometrics offers useful sets of indicators to measure science. These are discussed in the following two sections. This resulted in two sets of indicators; one set reflects scientific publications, the other patents. The following section provide a glance of these indicators.

Literature on bibliometric analyses offers many examples of indicators. Since the main goal of this section is to select a set of suitable indicators, rather than to provide a complete overview of all indicators available in literature, the decision is made to select indicators that are used by leading authors in the field of patent- and publication analyses using bibliometric methods. For patents this is the work of Ernst (Ernst 2003). Regarding scientific literature, the indicators are based on those provided by van Raan (van Raan and Noyons 2002) (van Raan 2003) (Moed et al. 2004).

Publication indicators

According to van Raan (2004), the crucial objective of bibliometric analysis is to arrive at a standardized and consistent set of indicators. This also implies that at this moment there is no such thing as a final set of indicators.

[2] They refer to bibliometrics as 'tech-mining'

His work (20 years and the analyses of thousands of institutes) on bibliometric analysis has worked towards such a set of indicators. The key indicators are presented in table 2.1.
The first indicator measure the quantity of papers published by a certain institute. The quality of these papers is determined by the number of *citations* that the papers receive. The assumption is that research quality is reflected in the citations that a piece of work receives. Other indicators correct the citations received with the impact of the journal, the average citations received in a certain domain (in certain domains citation rates are more frequent than in others) and the number of self-citations. A final indicator reflects how often papers do not get cited at all.

Table 2.1.: Indicators for measuring research performance based on papers

Indicator	**Description**
P	Number of publications
C	Total number of citations received, corrected for self-citations
CPP	Average citation rate per paper
%Pnc	Percentage papers not cited within time-frame
CPP/JCSm	Average impact of paper compared to the journal citation average
CPP/FCSm	Average impact of papers compared to the subfield citation average
JCSm/FCSm	Average impact of journals compared to the subfield citation average
%Sc	Percentage of self-citations

Patent indicators

The indicators for measuring research performance based on *patents* are based on the work of Ernst (2003). He presents a set of comprehensive indicators that provides insight in the research conduct of institutes (see 2.2). There are similarities between indicators for patents and publication. The first indicator for example measures the number of patents that an institution owns in a certain technology field. Two further indicators measure how this number relates to the total patent portfolio of the firm and to the the patent portfolio of all firms. Four other indicators measure quality aspects of patents; the share of granted patents (a fractions of patents is rejected by patent authorities), the technological scope, the international scope, the citation frequency (similar to publications). Finally three indicators are composites of the previously mentioned indicators: average patent quality (aggregate of the four 'quality' indicators), patent strength (product of quantity and quality indicators) and relative patent position (patent strength relative to patent strength of others).

Table 2.2.: Indicators for measuring research performance of firms, based on patents. Source: (Ernst 2003)

Indicator	**Description**	**Meaning**
PAif	Patent activity of firm i in technology field (TF) F	Extent of R&D expenditures in TF F (interest of firm i in TF F)
Technology share	PAif/PA of all competitors in TF F	Competitive position regarding technology F (quantitative)
R&D emphasis	PAif/Number of firm's (i) total patent applications	Importance of technology field for the firm
Co-operation intensity	Number of joint patent applications with partners in TF F / PAif	Access to external knowledge (plus identification of partners)
Share of granted patents	Granted patents of firm i in TF F / PAif	Technological quality of patent applications
Technological scope	Diversity and number of IPC classes in patent application	Technological quality of patent applications
International scope	Size of patent family and share of triad patents of PAif	Economic quality of patent applications
Citation frequency	Average citation frequency of PAif	Economic quality of patent applications
Average patent quality (PQif)	Sum of all indicators of patent quality (Q1-Q4)	Average total quality of all patent applications of firm i in TF F
Patent strength (PSif)	Product of average patent quality (PGif) and patent activity (PADif)	Technological strength of firm i in TF F
Technology share (qualitative)	PSif/PS of all competitors in TF F	Competitive position regarding technology (qualitative)
Relative patent position	PSif/Max. patent strength of a firm in TF F	Distance to the technological leader in TF F

2.7.3. Criteria for selecting indicators

Indicators form the basis of the analysis. An earlier section discussed requirements that the analysis must meet (2.3). From this it is possible to derive that the final set of indicators should be suitable for their purpose (should help answer the main research question). Secondly the calculation of the indicators can be standardized and automated, e.g. having a team of experts read and value research papers on a 1-10 scale may be a good *indicator* for quality, but is not something that can be standardized and automated). Thirdly, the set of indicators should not favor or disfavor particular parties; i.e. they should be unbiased. Fourthly the indicators should be transparent to those who use them and those who are involved with the outcomes. In other words, acquiring information about researcher performance from commercial parties is not transparent since the underlying mathematical transformation is 'a black box' and hence it is not possible to reproduce the results without using the information given to us by commercial third parties. A fifth requirement is that multiple indicators are selected since a single indicator may provide an incomplete picture of a unit's research performance (van Leeuwen et al. 2003). The sixth requirement states that the indicators measure data that is available within the organization.

Table 2.3.: Requirements for indicators

Requirements for indicators regarding STIP's
1. The indicators are suitable for analysis of the question(s)
2. The calculation of the indicators can be standardized and to large extent automated
3. The indicators are unbiased
4. The indicators are transparent to those that use them
5. There are multiple indicators
6. The data resources to calculate the indicator values are available

2.8. Summary of requirements derived from literature

The previous sections have provided insight in the elements of TI, and of STIP's in particular. This chapter ends with the identification of *requirement* for the design of the TI process. Table 2.4 sums up the requirements which have been identified in this chapter. One additional requirement refers to the lengthy nature of the detailed TI product and is retrieved from the initial problem description in the introduction of this thesis. The requirement states that —since STIP address predefined question— there are no iterations to reformulate the issue.

- ➢ The process for STIPs minimizes the number of large feedback loops, especially those from the *analysis* and *choice* phases back to *problem definition*.

This requirement, together with the requirements and the four TI elements discussed in this chapter— form the input for the TI process design and the ranking models.

Table 2.4.: Requirements derived from literature

Elements	Requirements
MOT questions	STIPs address predefined MOT questions
	One STIP addresses one or several predefined MOT question(s)
Information resources	STIPs use fixed information sources to answer the MOT question(s)
	STIP use predefined record types (e.g. patents or publications) and fields (part of a record)
Systematic process	The activities in this process are specified and defined
	The process defines *when* interaction takes place with actors
	The process states *who* this interaction is with, and *what* it is about
	STIPs are created through a systematic process
Execution of activities	STIPs are created through standardized procedures and (partial) automation of tasks.
	The activities *issue identification* and *selection of information sources* are predefined
	The procedure for defining search queries is pre-defined
	Data cleaning is standardized
	Basic and advanced analysis is standardized
	Presentation of outcomes is standardized
TI methods	The methods are normative
	The methods can be classified as 'hard' and dealing with quantitative data
	The methods involve no additional actors besides the TI analyst
	The methods can be executed within the time, personnel and financial restrictions
Indicators	The indicators are suitable for analysis of the question(s)
	The calculation of the indicators can be standardized and to large extent automated
	The indicators are unbiased
	The indicators are transparent to those that use them
	There are multiple indicators
	The data resources to calculate the indicator values are available

3. Analysis of current situation

3.1. Introduction

Since the process that is developed for STIP does not start from a ‘green field’, it is necessary to analyze the current context in which the process will be embedded. The focus is on two primary elements; the elements that will constitute part of the TI process from a technical perspective, and the elements that affect *how* the TI process is to be carried out from a social perspective. The technical perspective has already been discussed in chapter 2. This chapter will introduce one additional element: a TI platform. The social perspective is comprised of the actor context and the organizational setting. Agency theory is introduced describe the relations between the TI analyst and two other relevant actors.

The detailed TI product has already been discussed in the introduction. In the next section (3.2) a TI-platform known as Di.Ana is discussed and it is argued that this is the fifth essential element of the STIP. Section 3.3 discusses the actor- and organizational setting of the TI process, which indicates *which* actors are involved in the TI process, and *how* these may be coordinated. The final section addresses agency theory.

3.2. The Di.Ana platform

Di.Ana has two main products. The first is the detailed technology analysis and has been discussed in the introduction.
The second product is the use of a TI platform known as Di.Ana. Di.Ana facilitates the required interaction between technology analyst (the methodological expert) and clients (content experts, decision makers). The basic idea behind the platform is to make the contribution of client or technology specialist input more efficient without jeopardiz

Di.Ana helps to speed up the analysis. Certain reoccurring tasks (e.g. search query definition) are automated, and the tasks of the analyst are partially replaced by software algorithms. In the extreme case, the role of the analyst in completely replaced by the platform, and clients are essentially carrying out their own technology analyses (Walde 2008).

Di.Ana facilitates the interaction between technology analysts (the methodological expert), technology specialists and clients (technology specialists and decision makers) and increases communication and user involvement in the TI process. With regard to communication: clients with access to the platform can view information about relevant technologies and also add content based on their individual expertise. This content is available to other users of the platform. This is in line with ‘Web 2.0’ applications such as blogs, Wiki’s and social bookmarking sites. Also, TI results can more readily be made available to clients as would be possible with other means of communication, e.g. presentations, spreadsheets or workshops.

The increased client and technology specialist involvement by means of the Di.Ana platform is beneficiary for multiple reasons. First of all the clients become more familiar with TI since they take part in the formation process. This creates understanding and may also lead to outcomes that are more suitable for decision making purposes. Furthermore results may be perceived more authoritative by the client, since they will have a higher degree of influence on the results.

Secondly client and technology specialist involvement in the TI process reduces the workload of the analyst and

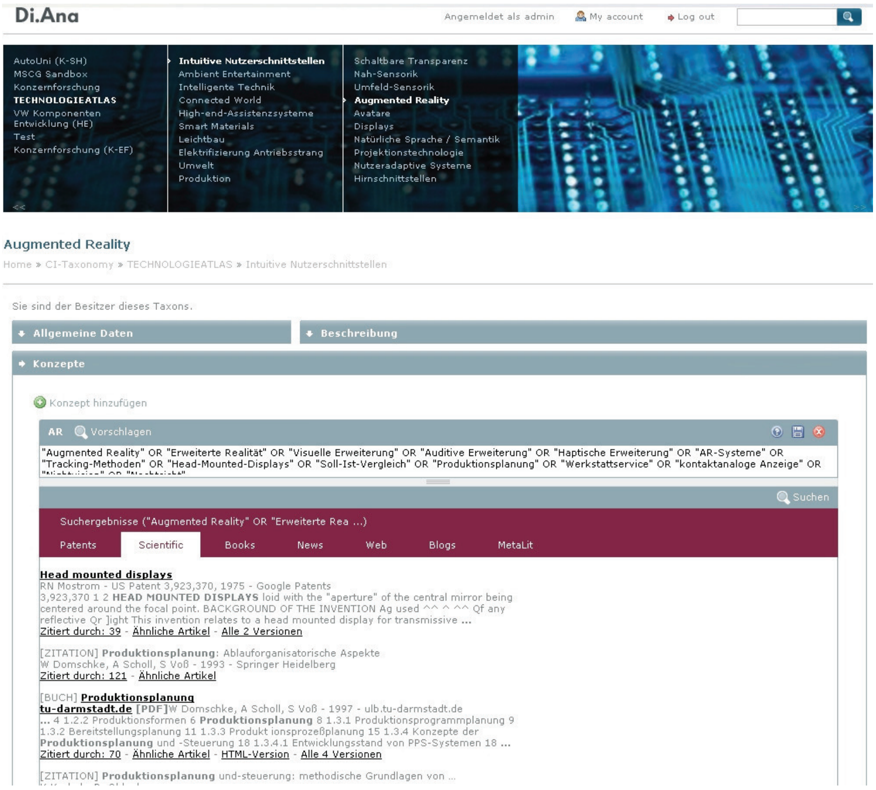


Figure 3.1.: Screen shot of Di.Ana showing the screen where users define and refine their search query

thus contributes to a more efficient TI process. This is especially the case for the definition of *search queries*. Search queries have a substantial degree of influence on the TI analyses. Therefore, the technological know-how of specialists is required for this activity. The process of formulating search queries is relatively time consuming for the analyst. However, the Di.Ana platform allows technology specialists to formulate, accept and evaluate search queries on their own, thereby reducing the workload for the analyst. Since the definition of search queries is such an essential part of the TI process, it will be explained in more detail:

Search query definition

The definition of search queries by users with aid of the platform works as follows: Users (familiar or unfamiliar with basic Boolean operators) define the *key concepts* of a technology and the *relationship* between these concepts. The user then receives recommendations on how to improve the search query (e.g. synonyms, translations, and related terminology). In a next step users apply their technological expertise to evaluate the quality of their search queries by viewing the retrieved results from patent-, publication-databases. Among the things considered are: are results missing, or are too many irrelevant results retrieved (i.e.: is the search query to ‘narrow’ or too ‘broad’?).
Whenever the search query satisfies, the results are stored on the platform and can be used by the TI analyst for the retrieval of information. Search queries can be viewed, edited or updated any given time.

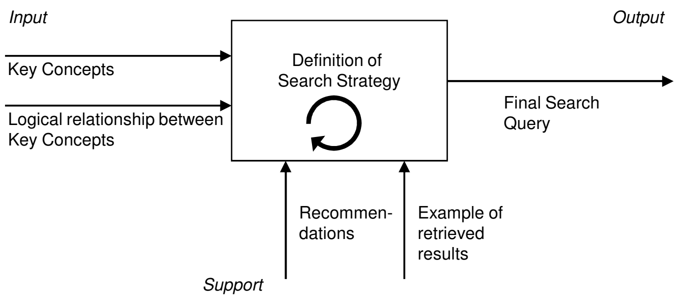


Figure 3.2.: Schematic representation of the process of search query definition by users. Source: own work

Implications for the STIP
The Di.Ana platform allows for the sharing of tasks between analyst and client, which leads to reductions in time since technology specialists define their own queries without involvement of the analyst. The definition phase, including the definition of search queries, covers roughly 40% of the time needed for a typical TI analyses (see Kunze (2000) and Michaeli (2006)). This time can be significantly reduced with aid of the DI.ANA platform, while keeping in mind that search queries have a large impact on the output of the analyses.

STIPS emphasize speed. Since within the context of this research project, the STIPs involve the ranking of research institutes in over 200 technology fields, use of the Di.Ana platform is essential to on-time completion of the overall project. The alternative measure, setting up meetings with around 200 individual technology experts, would be a far too timely consuming undertaking. Therefore a TI platform that allows for significant reductions in lead time while maintaining the quality of input would be a useful element for the STIP. At this point five 5 elements have been identified that are needed for the designs:
(1) Science and technology information, (2) Management of technology questions, (3) a systematic process (4) methods and tools and new elements which holds especially for STIPs, (5) a TI platform for search query definition. Therefore:The formal requirement is that:

➢ The TI process for STIPs uses the TI platform (Di.Ana) for the purpose of search query definition.

3.3. Institutional setting

3.3.1. Introduction

The TI process needs to 'fit' well into the organizational setting in which it is embedded. Previously, it has been mentioned that the success of the STIP depends on the interaction with various actors, including technology experts and clients. Therefore it is necessary to determine whether successful interaction between TI analysts and other actors can indeed take place. The aim of this section is to explore the institutional setting of the TI process by analyzing the actors involved in the STIP and the organizational structure which may impact the extent to which the TI analyst can coordinate interactions.

This section consists of two parts; the first part describes the various actors involved with the TI process, and the implication for coordination of these actors by the TI analyst. The second part focuses on the organizational surrounding of the TI process and the implications for the coordination of actors.

3.3.2. Actor context

An important step in working towards a process for STIP is to identify the important actors that are involved in the TI process, or actors that may have a strong influence on the realization. The reason for this is that particular actors provide an essential contribution to the TI process, or are able to influence the process in a particular way. The approach followed to identify the actor context is based on Enserink et al. (2004)

The first step towards drawing up the actor context is to define the objective statement of the actor that wants to initiate a change in the environment of the other actors (the problem owner). With regard to the STIP the Di.Ana team has set out the objective *to develop STIPs and use these to enhance decision making by technology managers within Volkswagen Research*.

This objective statement deliberately diverges from the objective statement of this research project, because it refers to the realization of an 'initiative' to be realized. The expectation is that when the objective is defined in such a way that this will aid to reveal what the stance of other actors is towards this initiative (Bekkering and Walter 2008). The second step is to inventarise those actors that are involved in, or impacted by this objective statement. Then for each actors the goals, interests and perceptions in relation to the objective statement are outlined. The goal indicates what an actor want to achieve. The interest indicates where the actors' stands in relation to the TI process. The perceptions indicate how the actor perceives the objective statement.

In a second step the *resources* of each actor are identified. Resources are assets that an actor can posses or control, and that are necessary to realize the objective or that can be used to block the realization of the objective. This step also reveals whether the problem owner is *dependent* on other actors because of the assets that they possess. Some assets are indispensable to the problem owner but the actor that carries these assets may be replaced by others (e.g. in case the actor is an external information supplier). Actors that hold indispensable assets and that cannot be replaced by others are considered *critical* to the TI analyst.

Critical actors are essential for ensuring that the objective of Di.Ana can indeed be met. Once the critical actors are identified it is investigated what these actors' goals and perceptions are with regard to the objective. The premise is that actors with converging goals and positive perceptions (dedicated actors) are positively related to realization of the objective whereas actors with diverging goals and negative perceptions (undedicated actors) are negatively related to the realization of the objective. The results of this analysis are summarized in figure 3.3. The area on the right side of the y-axis is most important since this contains the critical actors.

In order to determine what actors are involved and whether they are critical and dedicated, several interviews were carried out with colleagues at the department of Future Research. These interviews have also exposed underlying reasons that affect the level of dedication. The outcomes of these interviews can be found in appendix G.

The actor analyses has revealed a number of actors that are involved in the TI process, with varying levels of criticality to the analyst, and levels of dedication ranging from positive to negative.

In total 9 different actors were identified; clients of TI, the department of Future Research, research departments, individual technology specialists, head of research, head of the department, external information providers, external consultants, and potential clients for TI products. Based on their relation to the STIP, these can be classified in 5 groups. These will be briefly explained:

1. *Clients* can be technology managers, research department leaders or individual researchers. Clients initiate the TI process and act as 'customers' of TI. As customers they transfer funds (internally) for the requested TI. They are therefore considered critical to the TI process. Clients view TI as a means to answer questions which traditional research approaches cannot.

2. *Technology specialists* are individual researchers or research departments. They are often major clients and also fulfill the role of technology expert in the TI process. Technology specialists may also be impacted by the results of a TI analyses, e.g. in case this involves an assessment of their research performance. The technology specialists' perceptions vary from very positive to negative. On the positive side technology specialists see TI as a chance to learn new tools and techniques, and to engage in networks with other organizational members. Furthermore they perceive TI as a means to validate their own research approaches. Validation allows them to detect potential weaknesses in their own projects ('wind tunneling'). Finally, complementing traditional research with TI is seen as means to strengthen their argumentation line towards superiors.

On the contrary technology specialist remain skeptical towards analysis conducted by non-technology specialists, do not like interference in their work, have a fear of being 'quantified in numbers' and feel that incentives for cooperation are missing in the organization.
Since technology specialists possess the technological expertise that is essential to TI, they are considered critical to the TI process.

3. *Management* consists of those that have formal decision power: the head of Group Research, research department leaders and the head of the Future Research department. Management takes decision regarding project prioritization, financial decisions, employment of new analysts. Generally, management is positive about TI as long it can be used to improve the quality of research at Volkswagen. How TI is executed is of less concern, as long as the output is usable. Management in considered critical.

4. *External suppliers* to the TI process provide science and technology information and other forms of information and knowledge. External suppliers may be information database providers or external consultants, software programmers etc. External suppliers possess major resources but are not considered critical because they can be replaced by other marker parties.

5. *Potential clients* are actors that may be clients in the future and are mainly organizational member other than those from Group Research but from Marketing, Procurement, Development, Auto-Uni (an in-house university). Potential clients have no clear perception regarding TI, because they are not familiar with it. Potential clients are considered non-critical.

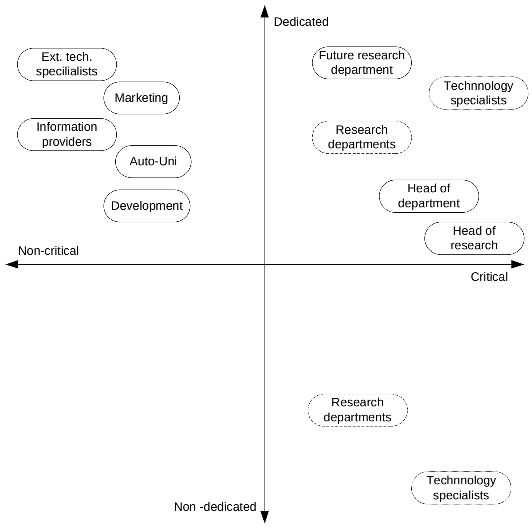


Figure 3.3.: Actors

Conclusions actor analysis

The preceding section identified the major actors with regard to the TI process and with regard to the objective to deploy STIPs. Recall that the focus is on execution of the TI process in order to produce STIPs. This also implies that the actual implementation of the TI process into the organization is not considered in this research project. This demarcation choice has important consequences. Based on the actor analysis it is possible to conclude that the TI analyst are positioned in a multi-actor network situation, with varying levels of dependencies among actors, and varying perceptions towards TI. However, when only the execution of the TI process in order to produce STIPs is considered, only two major actors remain: the clients of TI and secondly the technology specialists who provide the required technological expertise to the TI process. Since in many cases the client is a technology specialist, only one critical actor has to be considered. Conclusion: the technology specialist is the most critical actor and is characterized by a variety of levels of dedication towards TI and corresponding levels of dedication.

➢ Technology specialists and clients are the main actors in the TI process for STIPs.

3.3.3. Organizational setting

The institutional setting determines *how*, and the the *extent* to which actors are able to coordinate other actors within the organization. The previous paragraph indicated that the primary interaction in the TI process takes place between TI analyst and technology specialists. This will also be the focus of the section.

Suppose the organizational setting can be characterized as 'hierarchical' [1] and the analyst is superior (based on formal position) to the specialist. In this case coordination could take place in a 'command and control' manner. However, in more network type settings[2] where both actors have comparable formal positions, alternative coordination mechanisms are needed because hierarchical steering will fail (de Bruijn and ten Heuvelhof 2004).

A practical example is the following; say the final process relies on hierarchical intervention to coordinate the involvement of technology specialists in the TI process. Suppose that the organizational environment is characterized by a high degree of professional employees; coordination by management is done through mutual adjustment rather than hierarchy; and teams that work semi-autonomous on their own projects, then hierarchical intervention is likely to fail to achieve the desired results. Thus by determining the organizational setting, it is possible to adjust the coordination mechanisms to the environment.

To reveal what coordination mechanisms are most promising for the analyst to coordinate interaction with technology specialists, the organizational setting of the TI process is studied. A more elaborate summary of the findings can be found in appendix E, this section contains the conclusions:

The Volkswagen Group is controlled through a wide variety of structures, ranging from the divisional structure to small sized semi-autonomous units (adhocracies) in the areas of research and development. Of most interest is Group Research since this in the environment in which the TI process is embedded and where the majority of technology specialists can be found.

Group Research conducts research in a wide range of technologies. At the highest level, Group Research is split into 8 different main technology fields; ranging from transmission, car electronics to virtual technologies. The department of Future Research is as this same level. At the second level 5 main technology fields each have in 2-5 sub technology fields. At the third level, 2 sub technology fields are further divided into 5 sub sub technology fields. At the fourth level, the third level fields each have another 3-7 technology fields. This is a description of the formal structure.

In addition to the formal structure, project teams are formed that focus on a particular topic or aspect of a technology. Projects often consist of several (multidisciplinary) team members. In 2008 there were around 200 different projects (based on internal documents: Hochschulkooperation). Each project has a leader, who is part of one of the 7 first level technology fields (excluding Future Research).

3.4. Agency problems

3.4.1. Introduction

In the previous section the institutional setting has been presented. This has revealed that different actors are more or less critical to the TI process, and have perceptions that range from positive to negative. Besides the TI analyst,

[1] A machine bureaucracy in terms of Minzberg
[2] professional bureaucracy or adhocracy in terms of Minzberg

two primary actors are considered critical for carrying out TI:

- Clients which initiate the TI process and play an active role in the issue identification. Clients also bear costs of the analysis. Within the context of this research project, the head of Volkswagen Group Research is the primary client.
- Technology specialists which hold the indispensable technological expertise and play a vital role in safeguarding the quality of the analysis. Therefore the technology specialists' contribution is vital to the TI process.

It follows from the previous sections that the specialists' perception of TI is very diverse, ranging from positive to negative, with corresponding levels of dedication. Meanwhile the analysts' ability to manage and control the contribution of technology specialists is limited, because the organizational structure inhibits direct intervention. Even when direct intervention is exhibited, the resulting effect on the provided input is unknown. Furthermore, since the input from the specialist is often very specific, the analyst in unable to verify the quality and truthfulness of the input provided because he lacks the required (technological) expertise. Agency theory is used to describe the dual relations betweens analyst and specialist, and analyst and client.

3.4.2. Agency theory

Agency theory describes the problems that arise when one actor —the principal— is delegating a task to another actor —the agent. Agency theory uses the metaphor of a contract to describe the relation between principal and agent. The relationship between principal and agent is according to Jensen (2003): *"an implicit or explicit contract in which one or more persons —the principal(s)— engage another person —the agent— to take actions on their behalf that involve the delegation of some decision-making authority to the agent"*.

According to agency theory, problems arise with the (metaphoric) contract due to (1) conflicting goals of the principal and the agent and because of (2) incomplete or asymmetric distribution of information among principal and agent. Goal conflict is present when the principal and agent have different goals, and both attempt to self maximize their individual utilities (Shavell 1979). The principal wants the agent to behave in a certain way to maximize its own utility but the agent chooses to behave in a way that maximizes its own utility. Alternatively an agent is likely to have multiple principals with conflicting goals. As a result an agent may attempt to maneuver in a way that meets the goals of multiple principals (Shapiro 2005)

The principal–agent relationship is characterized by incomplete information and information asymmetry. The lack of information on the principal's side may be the reason for delegating the task in the first place: the principal cannot execute the task because he lacks the required knowledge or expertise. Furthermore the principal has limited knowledge of what the agent is doing. The principal hires the agent to pursue the interest of the former, but cannot verify (at reasonable costs) whether the agent is doing so, due to incomplete and asymmetric distribution of information (see figure 3.4). As a result the agent in may behave strategically: the agent can act defensively to shield itself from the principals' intervention, or choose to act offensively by taking actions to increase its own strategic positions and harming the interests and positions of others (Williamson 1996). As a result of goal conflict and asymmetric distribution of information the problems of *adverse selection* and *moral hazard* are introduced:
Adverse selection
Due to incomplete or asymmetric information on the principals' side, the principal makes 'wrong' choices. Adverse selection is likely to appear ex-ante to the contract between principal and agent. The problem of adverse selection is well known in insurances where insurers deal with a disproportionate number of insurance claims for particular products. Here the clients know they have a good expectation that they will actually need to file for a claim, and have therefore taken up insurance. On the other hand: clients who do not expect that they need the insurance are less likely to take up the insurance. The insurer on the other hand is —due to asymmetric information— unaware of the fact that the clients are very likely to file for a claim and makes an adverse choice: selection of the wrong customers. So here the agent benefits from the absence of information on the principals' side. Adverse selection can also take place when an agent claims he has certain skills or experience when he is hired by a principal. The principal

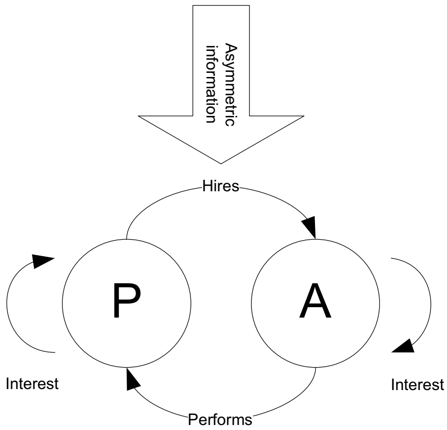


Figure 3.4.: Schematic representation of principal-agent problem

on the other hand cannot completely verify whether this is the case and adverse selection may arise (Eisenhardt 1989).

Moral hazard
Moral hazard refers to lack of effort on the agents' side. This is manifested when the agent simply does not put forward the agreed effort (Eisenhardt 1989). However, due to absence of information on the principals' side, the principal may not be able to verify the behavior of the agent. The agent in turn is aware of the asymmetric distribution of information and starts behaving in such a way that maximizes its own benefit, but not that of the principal. Insurance companies face the problem of moral hazard when the insured (the agent) start behaving less risk averse because he is aware that the insurer will cover the costs of his actions. The insurer however, is unable to verify whether the insured acted negligent.

3.4.3. Principal–agent research and positivist agency theory

There are two main streams in agency theory: principal agent research and positivist agency theory (Eisenhardt 1989) (Shapiro 2005).

Principal–agent research

Principal–agent research addresses the general theory of the principal–agent relationship, which can refer to employee–employee, lawyer–client, buyer–supplier and other agency relationships (Eisenhardt 1989)
The focus in principal-agent theory is on "Modeling the structure of the preferences of the parties, the nature of uncertainty and the informational structure" of contracting practices (Shapiro 2005). Principal agent research is more mathematical than positivist agency theory and involves accurate specification of assumptions and logical deduction. Critics claim that principal agent theory concerns the treatment of highly complex but trivial problems, and that forms is often more important that substance (Shapiro 2005). As a result, the treated problems are although mathematical and therefore traceable, less useful in many settings because the problems it addresses are too 'sterile'.

Positivist agency theory

Positivist agency theory focuses on identifying situations in which principal and agent have a conflict of goals and where asymmetric distribution of information prevails, and then describes the mechanisms that limit the agent's opportunistic behavior (Eisenhardt 1989). Positivist agency theory is more pragmatic and empirical than principal-agent research (Shapiro 2005). Since positivist agency theory relaxes the strict assumptions of principal agent research (Shapiro 2005), it is applicable in a wider range of settings.

The application of agency theory is very diverse and includes accounting, economics, finance, marketing, organizational behavior, sociology (Eisenhardt 1989) as well as knowledge sharing (Nan 2008)(Yang and Wu 2008). Numerous other examples can be given, for example in the fields of economics, management political science and law (Shapiro 2005).

3.4.4. Resolving agency problems

An important characteristic of principal agent research is that of 'money changing hands'. A premise of principal–agent research is that financial incentives are used as a means for aligning the interests of the principal and agent, thereby stimulating cooperative behavior. For example this mechanism is found in aligning board members with the goals of stockholders, the goals of a CEO with that of the board management, or sales agents with that of their executives.

Positivist agency theory is less mathematical than principal agent research and has more resembles to organizational and political theory rather than economics. Apart from financial rewards, positivist theory uses other incentives for the co-alignment of goals. According to Eisenhardt (1989) the two views complement each other: *"The positivist stream lays the foundation and explains that agency problems exist and that various contract types are available. The principal-agent stream is directed more at the contract between the principal and agent and indicates what contract type is more suitable under given circumstances".*

Solutions

An assumption in agency theory is that the principal can solve problems of unobservable behavior caused by moral hazard and adverse selection by two main mechanisms (Eisenhardt 1989). The first (a) is monitoring to discover the agents' behavior. This can be done by investigating information systems such as: project management systems or budgeting systems. Monitoring reveals the agents' behavior and will induce a shift towards more complete information. The second mechanism concerns (b) contracting on the behavior of the agent, or on the outcomes of the agent's behavior. This introduces incentives for the agent to co-align goals with the principal. Contracting behavior provides an incentive for an agent to behave in a certain way whereas contracting on the outcomes provides an incentive to agents regarding the outcome, regardless of their behavior. Formally these are (Eisenhardt 1989):

1. "When the contract between the principal and agent is outcome based, the agent is more likely to behave in the interests of the principal"; and
2. "When the principal has information to verify agent behavior, the agent is more likely to behave in the interest of the principal".

Choosing a particular mechanism depends —from an organizational perspective— on a variety of factors (see Shapiro (2005):

- The length of the principal–agent relationship. The duration of the relationship can affect the information asymmetry and incentives for opportunistic behavior.
- Organizational structure and form of the environment. Depending on the organizational structure different mechanisms can apply, e.g. financial incentives versus incentives that have a positive impact on the intrinsic motivation of agents.
- Characteristics of the industry, the organization and the employees. In different industries and organization types different mechanisms may be found: in the banking sector outcome based contracts may be common (e.g. bonuses that account for a significant part of an employees' salary), whereas in production settings behavior based incentives may be more common (e.g. hourly wages for workers).
- The programmability of the task (Eisenhardt 1989). The programmability of tasks makes behavior based contracts more suitable because this makes it more suitable for behavior based contracts.
- The organizational environment (e.g. dynamics)

3.4.5. Risk, agency costs and uncertainty

The relation between the principal and agents is characterized by at least three aspects: uncertainty, the risk for the principal or agent, and the agency costs. Uncertainty is applicable to various aspects of the principal agent relationship. The principal is —due to asymmetric information— uncertain about the agent's behavior and the outcomes provided by the agent. The agent can be uncertain about the necessary investments in the contract from the agent's side, or be uncertain about the principal's true intent. The second aspect is risk. The principal, the agent or both, face a share of risk when engaged in a contract. For example, the principal may face risk of moral hazard or adverse selection. The agent may in turn risk investing time and resources at the risk of not being awarded for his effort, e.g. due to behavior of the principal or external events that endanger the contract. The third aspect concerns agency costs: although principals try to minimize them, all principals face agency costs. Agency costs rise from different sources (Shapiro 2005): "the costs of recruiting agents, adverse selection, moral hazard, specifying or discerning preferences, providing incentives, shirking, stealing, corruption, monitoring, self-regulation, bonding and insurance, mutual adjustment by other agents, and costly failures". Basically the agency costs are the costs that result from the problems of contracting an agent by the principal.

3.4.6. Applying the principal–agent relation to the STIP

An earlier section indicated that technology specialists are essential for their contribution of knowledge to the TI process. In the development of a STIP, technology specialists formulate search queries that are an important input for the analysis. With regard to this activity, two main actors are involved: The TI analyst serves as the principal who asks the technology specialist to contribute his knowledge to the process. Secondly, the technology specialist possesses the specialist knowledge and may share this knowledge with the TI analysts, through the TI platform.

For the case of the detailed TI product the client is charged (internally) for the costs of the analysis. Assume that the head of research at Volkswagen (CEO) serves as the client. The client assigns funds to the TI department for carrying out the project. Funds are also allocated to the research departments which employ the technology specialists that are involved. Furthermore these research department can also be the users of the TI or be impacted by the outcomes of TI (conversation Walde).

In order to *frame* the relations between client and analyst, and analyst and specialist as principal–agent relations it is necessary to state the primary assumptions since this will reveal under which circumstances the proposed solutions are valid. These assumptions are:

1. There is likely to be goal conflict between the TI analyst and the TI specialist. The convergence of goals is assumed to be very small. The actor analysis revealed the following reasons (see G: (a) additional time needs to be invested, (b) the effort is not rewarded by superiors, (c) an overall negative attitude towards TI and (d) there is a fear of being 'measured' (e) sharing knowledge puts at risk losing the strategic advantage of having expert knowledge. To put it simple: the analyst' goal is to maximize the contribution of specialist, and the specialists' goal is to minimize this contribution. Furthermore agents are expected to be risk averse, since they may risk negatively affecting their own employment but have little to gain from cooperation.

2. The information between TI analyst and technology specialist is distributed asymmetrically, and as a result the analyst cannot fully verify the *behavior* of the specialists or the *outcomes* of the contract: The analyst cannot verify whether the specialist has delivered *high* quality knowledge or *low* quality knowledge, because he lacks the technological know-how to evaluate the specialists' knowledge contribution. For this reason it is difficult for the analyst to verify whether the output 'O' is truly of high quality 'O_h' or whether it is actually low quality 'O_l', i.e. there is outcome uncertainty. In addition the analyst may not always be able to determine whether O_l is truly the result of low effort (E_l) or the result of high effort (E_h).

3. There is an asymmetry of information between client and analyst. The analyst (agents) cannot fully verify the wishes and needs of the client (principal). The client cannot observe the actions of the analyst and is not able to assess the authority of the outcomes of the analysis.

4. The TI analysis is paid for by the client
5. Specialists are expected to be risk averse since they risk negatively affecting their own position yet they have little to gain from the contract.
6. The relationship between client and analyst is assumed to be long-enduring, whereas the relationship between analyst and specialist is expected to be relatively short–term.
7. The analyst has a limited ability to assess the quality of input provided.

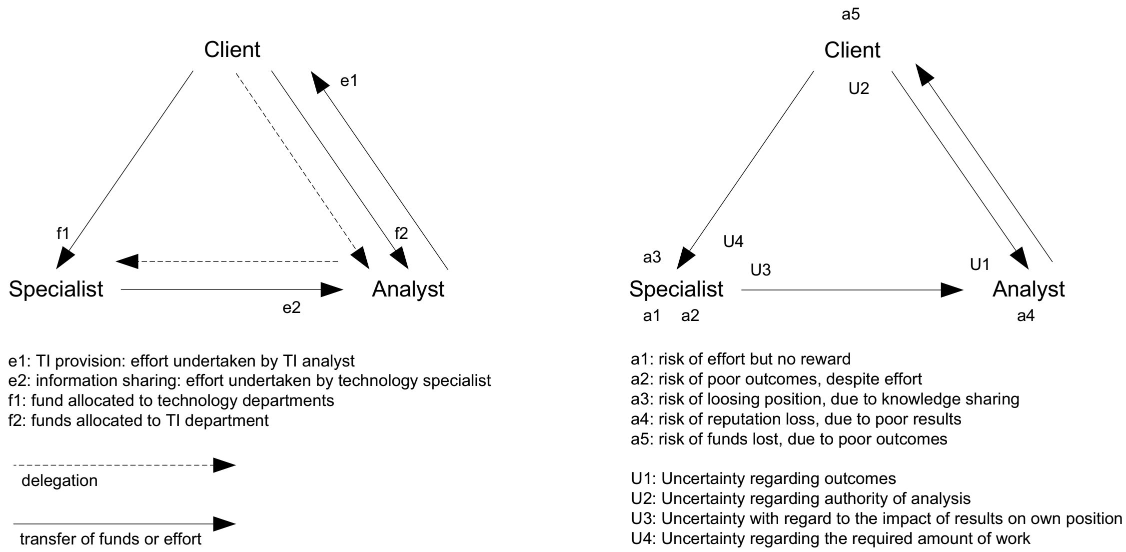


Figure 3.5.: Schematic representation of principal–agent relationships for the traditional TI product

The left figure provides a schematic representation of the two principal–agent relationships. Assume that the client is initiator of the TI, and asks the TI analyst to carry out this task. Then the client serves as principal who delegates a task to the analyst — the agent. The client allocates funds to the analyst and in return the TI analyst offers his services to client. The analyst then turns to the technology specialist for specific technology expertise: e.g. he delegates the search query definition activity. The technology specialist is rewarded for his effort by the client who assigns funds to his department. The technology specialist delivers his knowledge to TI analyst, who used it for the analysis. Tracing back the flows of funds, it can be concluded that the client pays for all agency costs involved in this simple model.

The right figure depicts the uncertainties and risk in these principal agent relations. The client of TI may be uncertain about the outcomes of the analysis. Since the client lacks specific knowledge concerning TI, he cannot verify whether the TI analyst has indeed carried out the analysis correctly. It is assumed that the clients' ability for monitoring is limited to formal project management systems, and that he is able to verify neither the actual conduct of the TI analyst nor the authority of the outcomes. As a result the client allocates the funds and also bears the financial risk of the transactions.

The analyst serves as an *agent* in relation to the client but as a *principal* in relation to the specialist. The first relationship has been discussed in the previous paragraph. With regard to the second relation the analyst delegates tasks to the technology specialist. The technology specialist provides information. However due to the information asymmetry on the analysts' side, the analyst is not able to assess the outcomes provided by the specialists. This leads to uncertainty on the analysts' relating to the information provided by the specialist. When poor outcomes are used for the analysis then this will lead to poor overall outcomes of the TI analysis (directed towards the client).

This also means technology managers and decision makers are provided ‘wrong’ TI, which may lead to a loss of funds (allocated by the client) and overall reputation loss for the TI analyst.

3.5. Strategies for dealing with agency problems

Different mechanisms can be applied to deal with the principal–agent problems. First the the client–analyst relation is discussed. Then the analyst–specialist relation is addressed.

3.5.1. The interaction between client and analyst

In the present situation the client allocates the funds to those involved in the TI analyses: analyst and technology specialist(s). This entails that the client also bears the financial risk of any TI project (see figure 3.5). The client is unable to verify the behavior and the outcomes of the contract it holds with the analyst due to the risk of moral hazard and adverse selection. These two points will be discussed below:

This also implies that the analyst —who carries out the analysis— is less risk averse than the client, since he does not bear the financial risk. However since client and analyst are involved in a longer relationship, the analyst is likely to behave more in the interest of the client (Eisenhardt 1989). Nevertheless, letting the analyst allocate funds to the technology departments rather than the client would be a more efficient way of contracting (which reduces agency costs), since the analyst is in a better position to judge the behavior and outcomes the contract it holds with the technology specialist. Furthermore this would shift an amount of risk to the analyst, who now has an incentive to reduce agency costs.

The client is not able to assess the outcomes of a TI analysis and has a limited ability to monitor the behavior of the analyst. Moral hazard exists because the client cannot observe whether, and the extent to which the analyst is delivering the promised effort. Adverse selection is present because the client cannot observe whether and if the outcomes of the TI analysis have the right ‘quality’. It is advisable for the client to assess the quality of the contract outcomes from the analyst,for example by having (external) technology specialists validate the analysis.

3.5.2. The interaction between analyst and specialist

To deal with the goal conflict and unobservable behavior, mechanisms are proposed to (a) alternative allocation of funds, and (b) dealing with unobservable behavior.

Re-allocation of funds

The re-allocation of financial compensation (funds) has already been discussed above. There are two options: compensation based on the *outcomes* of the contract or compensation based on the *behavior* of the specialist. The outcomes (e.g. the search query) can be verified by asserting the quality. Assume that the analyst is able to verify the output, then there are three outcomes: (i) no outcome is returned (ii) an outcome of insufficient quality is returned, (iii) an outcome is returned appears to be of sufficient quality. Based on this classification, the analyst can rate the quality of the outcome provided and base the financial incentive on the results. The assumption is that incentives make the specialist more risk neutral since this positively impacts the prospect of gain. Furthermore since the analyst (the principal) allocates the funds the specialist is expected to act more in the interest of the former (Eisenhardt 1989) However in case a large number of technology specialists are involved it becomes impractical to compensate all individuals separately because this will significantly contribute to high agency costs. The second option is to not compensate the specialist individually but instead reward the technology department for which their work. Then the department can reward individual specialist for their time spent on TI-activities. In this way the compensation would legitimate the additional time spent on TI towards superiors in the department, and positively affect the risk perception of specialist since the rewards since TI becomes part of their formal task.

Dealing with unobservable behavior due to moral hazard or adverse selection

In case the analyst is not able to observe the behavior of the specialist due to moral hazard or adverse selection, he has two options (see section 3.4.3. The first is two discover the specialists' behavior using information systems, and the second is to contract on the outcomes of the specialists' behavior.

For the STIP, specialists contribute their knowledge using the TI platform (DI.ANA). Since the platform demands the user to try out different combinations of concepts. These are all stored on the platform and can be viewed by the specialist as well as the analyst. *Thus the agents' behavior can be monitored using the TI platform, which make the agent more aligned with the interest of the principal.*

The second option is to contract on the outcomes of the agent's behavior. Outcome-based contracts has a positive effect on behavior because it aligns the agents' preferences with that of the principal (Eisenhardt 1989). However, contracting on the outcomes entails that risk is transferred to the agent (since outcomes are not fully caused by behavior). When the outcome uncertainty is higher (e.g. the agent is not able to formulate an effective search query due to inability, problems with the platform) then this introduces additional risk for the agent. Therefore when outcome uncertainty increases, it becomes more expensive to shift risk to the agent despite the motivational benefits (co-alignment of incentives) of outcome based contracts (Eisenhardt 1989).

3.5.3. Conclusions

Central to both options is that the funds for the technology specialist are allocated by the analyst, and not by the client. This solution is Pareto optimal: The client benefits from this since risk is shared with the analyst. The analyst faces more risk but increases its bargaining positions towards the technology specialist. Thirdly the technology specialists benefit (or at least they do not experience a loss) from being rewarded for their effort.

Part II.

Design and Test

4. Design of a TI process and ranking models

4.1. Introduction

The design is constituted of two parts. The first part is a detailed description of the process for STIPs. This involves a description of the necessary activities as well as means to support and control the TI process. It also states when and what the contribution of clients and technology experts should make to the TI process. The first part of the design if made using the modeling language SADT or IDEF0. The model distinguishes different activities, with corresponding inputs, outputs, support and control mechanisms. The second part of the design involves a detailed description of the bibliometrics model, for ranking research institutes. Together, these different parts constitute *one* design of the socio technological system. The inputs to this chapter are the four elements of TI and the section about the TI platform, and the list of requirements presented in section 2.8. The designs are created in a process that involved the assessment of research institutes for *Sulphur Lithium Cells*. This is in line with the design approach that corresponds to the evolutionary life cycle model discussed in section 1.6.

4.2. Design of the process for STIPs

This design specifies the *process* through which STIPs are created. The major inputs for this design are the objectives formulated in chapter 1, the solution space presented in chapters 2 and 3, and the design requirements as formulated at the end of these chapters. The result is a *generic* description of a TI process, that can be used for STIPs. Generic implies that the application of this process is not restricted to the STIPs for the ranking of research performance but can address other issues as well.

The first design aims to specify what activities the system, software and organization need to perform in order to achieve the desired outputs. [1]. The TI process design is modeled using the structured analysis and design technique (SADT)[2]. SADT is developed in the 1950's for the design of complex systems (Levis 2009). SADT has been widely use for the functional analysis of systems and (business) process design.
SADT is considered a suitable way to represent the TI process because the approach allows for the specification of activities, as well as a detailed description of the factors that support and control these activities.

SADT has five primary elements (Levis 2009):

- A function or activity is represented by a rectangle and is described by verb-noun phrase (e.g. collect data). Each activity is numbered to indicate its position within the process (level and sequence).
- Inputs to the system are represented by arrows that enter from the left. Inputs can be materials or data.
- Outputs leave the activity from the right.
- Controls enter from above. Controls determine 'how' the activity is carried out.
- Mechanisms enter from the bottom. These may be resources that support the activity (e.g. data analysis tools).

The flow of material or data is represented by arrows entering an activity on the left and leaving the activity on

[1] In systems engineering this is referred to as 'functional analysis' and forms part of the design process
[2] alternatively this can be referred to as IDEF0

the right. The arrows that enter or leave an activity are labeled. A key characteristic of SADT is that it allows for hierarchical decomposition: The A-0 level describes the top level-activity. This is depicted as one activity which includes all inputs, outputs, control ands and mechanism. This is also referred to as the context diagram which shows the boundaries of the system or process being modeled (Buede 2009). It also states the purpose of the model and the viewpoint taken (Levis 2009). A second level –the A0– level decomposes the top level into several activities and the functional relationships between these activities. Activities in the A0 level (denoted by A1-A6) can be further decomposed if necessary.

The backbone for this design is the nine step 'tech-mining' model (Porter and Cunningham 2005). The first 7 activities of this model constitute the final design, since the latter two (interpretation and utilization) go beyond the scope of this research. Reoccurring attributes of these activities are fixation, standardization and automation. The first two activities, the *issue identification* and *selection of information sources* are predetermined. *Search refinement* is the most complex task, which is conducted by the technology specialist with use of the TI platform. The remaining activities; *data retrieval*, *data cleaning*, *basic & advanced analysis* and *presentation*, are standardized and involve high degrees of automation. Table 4.1 provides a more detailed description of the activities.

The process for STIPs is displayed in figure 4.2. The primary components of this design are (a) *activities* that are carried out in order to produce the STIP, (b) *procedures for the analyst to follow when carrying out the activities* (i.e. search refinement, data cleaning and analyses), (c) *supporting mechanisms* such as the Di.Ana platform, scripts and macro's, software packages, (d) *inputs to the system*: data- and patent records and request for TI (external) and all flows between activities (internal), (e) *actors*: the technology analyst and the technology expert and (f) *outputs of the system*: the STIP in form of a one-pager and the search query. Figure 4.1 displays the search query definition in more detail.

(a) The activities in the design of the STIP process are in line with those defined by Porter and Cunningham (2005). However, the latter two steps, interpretation and utilization, are not part of the design since these go beyond the scope of this research project. The STIP ends with the *presentation* of results. The first two activities of the STIP deserve are always equal, regardless of the *technology.* This means each STIP solves the same question or set of the same questions, and uses fixed information sources. Fixing information sources refers to the *sort* of data is used (e.g. patent or publication records) and also to what *part* of the record is going to be used. Because these first activities are fixed, the lines around these activities are dotted.

(b) The second component is related to the way in which the activities in (a) are carried out. The design makes use of the fact that procedure and routine can drastically speed up the process. Therefore procedures apply to the way in which: the search query is carried out and the records are retrieved, the data is cleaned, and the analysis is carried out [3]. The procedures prescribe all the choices that are made by the analyst in the process. These procedures will further elaborated in the next chapter: case study.

(c) The third component supports the carrying out of procedures by the analyst: the Di.Ana platform support the definition of search queries by technology experts, scripts and macro's automate steps that would otherwise be carried out by the analyst. Two final mechanisms are: access to information databases in order to be retrieve patent and publication records, and software to support data cleaning and analyses.

(d) External inputs to the systems is the request for the STIP by the client and the patent- and publication records that are retrieved from databases. Internal flows represent the flows between activities.

(e) Three actors are distinguished in the STIP process. The first is the technology analyst, who has the end-responsibility for all activities and coordinates the the technology experts. The technology expert adds his expertise to the process, in case of the STIP *only* for the definition of the search query. The client (who may also be the technology expert) and analyst collaboratively formulate the content of the *issue* which the STIP aims to resolve.

(f) Two flows exit the system: the STIP in form of a one pager, and the search query that demarcates the

[3] The bibliometrics ranking model *is* essentially the analysis procedure

Table 4.1.: Design components: TI process

Steps:	*Issue identification*	*Selection of information resources*	*Search refinement & data retrieval*	*Data cleaning*	*Basic & advanced analysis*	*Presentation*
Main characteristic	Fixed MOT question(s) are answered	Fixed information sources are used. This concerns the record type, fields, time span, etcetera	A TI portal is used, this largely replaces the role of the TI analyst	Largely automated, because the same procedure applies in case all preceding steps are equal	Standardized because the same procedure applies when all preceding steps are equal & largely automated	The output (the STIP) is standardized and has the form of a one-pager
Input	A request for TI regarding a certain issue	MOT-question(s)	Information sources	Raw data	Clean data	Analysis outcomes
Output	MOT-question(s) that aim to resolve the issue	Record type (patent or publication), selection (fields), time span, etcetera.	Raw data, search query	Clean data	Analysis outcomes	One-pager
Actor	Analyst and client	Information sources	Technology specialist and analyst	Analyst	Analyst	Analyst
Support	—	—	TI-platform	Scripts and macro's, analyses software	Analysis software	Analysis software, additional software
Coordination	—	pre-defined	Search query definition procedure, search procedure (for data retrieval), data cleaning procedure	Analytical procedure	Presentation format	

technology field and which may be used for other purposes later on.

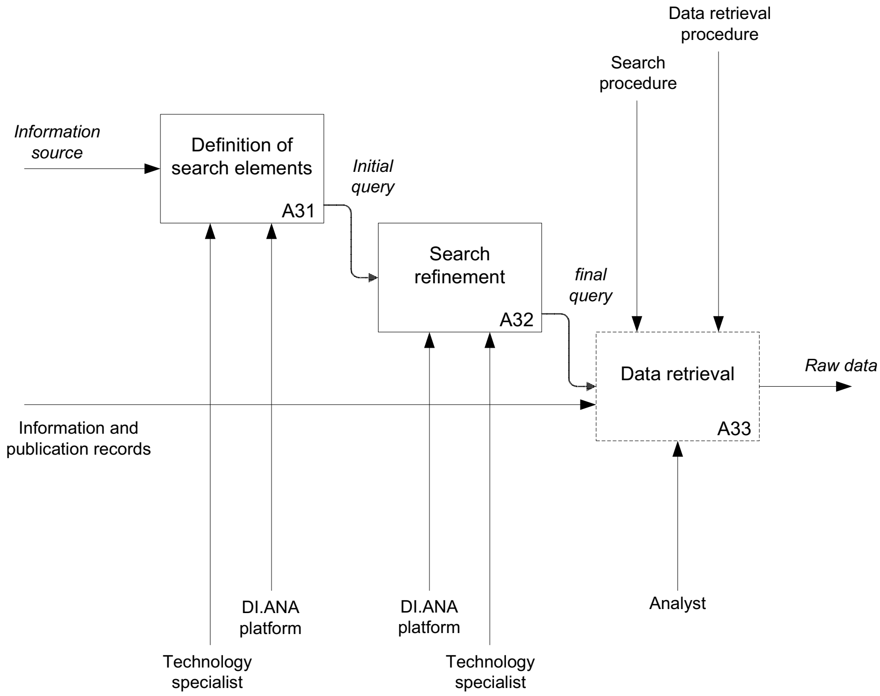


Figure 4.1.: Search refinement and data retrieval (A3)

Activity A3: search refinement & data retrieval

Activity A3 consists of three sub-activities *definition of search elements*, *search refinement*, and *data retrieval* (A31, A32, A33) (see figure 4.1). Chapter 3 indicated that search queries should be defined by the technology specialists, with aid of the Di.Ana platform. The platform and the technology specialists are indicated as support mechanisms for the activities *definition of search elements* and *search refinement*. For this purpose the Di.Ana platform handbook was constructed to point out the proper search query definition procedure (the control mechanism). Activity A33 shows that the analyst uses the search query to retrieve the relevant data from the R&D databases, according to the search- and data retrieval procedure.

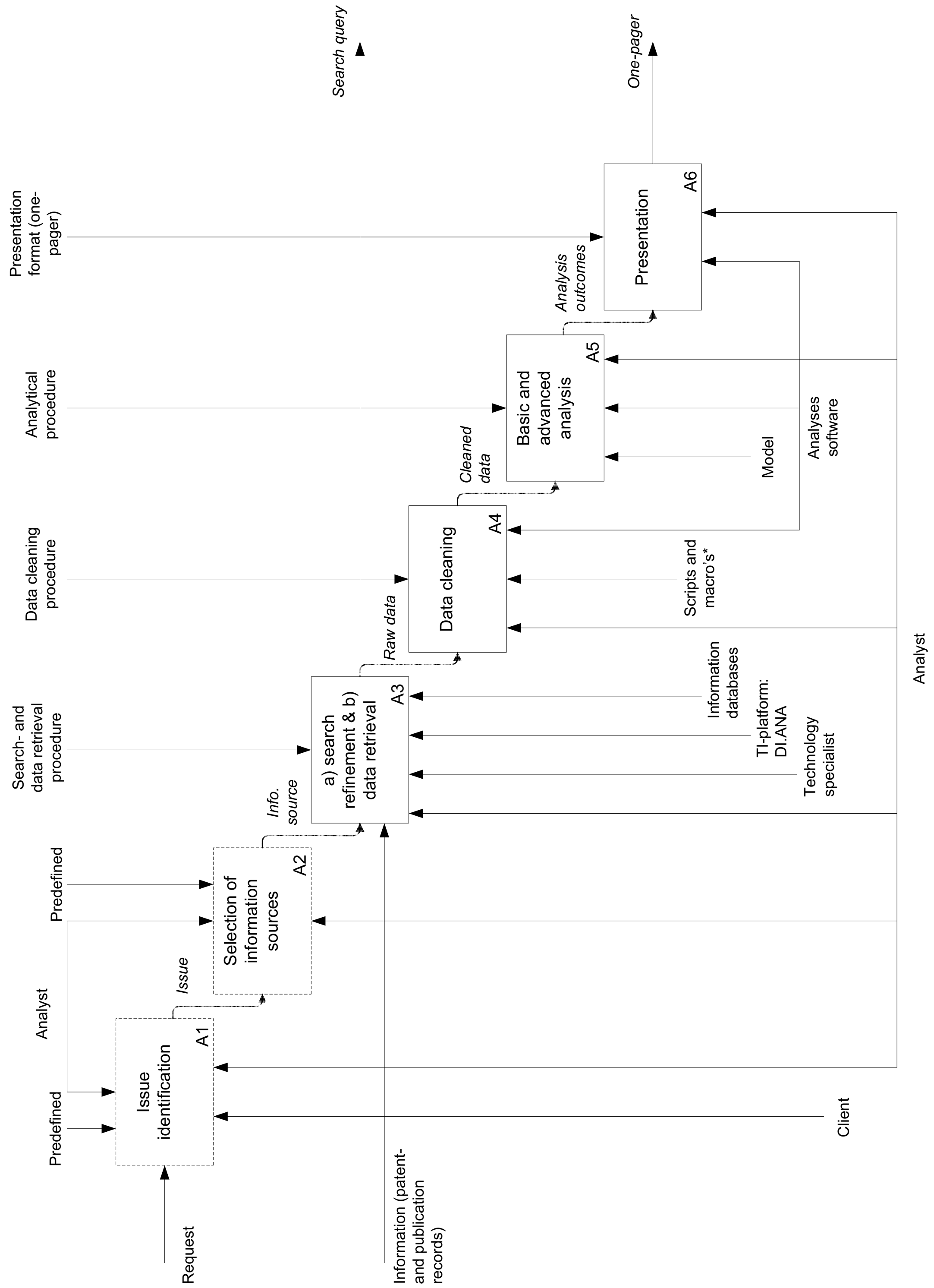
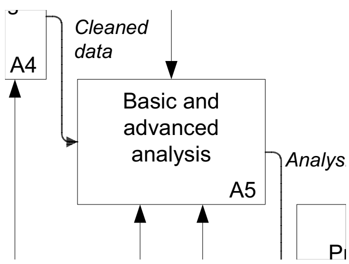


Figure 4.2.: The TI process (A0)

4.3. Design of bibliometrics ranking model

4.3.1. Introduction

In contrast to the generic design of the TI process, the bibliometrics model addresses the specific case of ranking research performance. The bibliometrics ranking model constitutes step A5: *basic and advanced analysis.* In this case the output of the basic analysis consists of producing lists and tables and forms the input for the advanced analysis. The advanced analysis is aimed at calculating the indicator values and the overall research performance based on both patent- and publication data.



This section combines the literature on indicators and the formulated requirements to design the bibliometric model. An earlier chapter provided an introduction to bibliometric indicators and revealed a set of indicators for the assessment of research performance based on both patent- and publications. Requirements were formulated for the selection of indicators which are suitable for STIPs. This has resulted in the definition of two sets of indicators. In order to apply these indicator to assess research performance, a model is required.

This section first introduces the final sets of indicators for both patent- and publication data. The preceding section shows what information from the previous analytical step *data cleaning* (A4) is needed as input for the model. The major calculations which constitute the basic analysis are also shown. The final section addresses the advanced analysis and introduces the models for ranking institutes on basis of their research performance.

Design choices
Two models are constructed: (1) model for ranking based on patents, (2) model for ranking based on publications. Both models are constructed in MS Excel 2007 spreadsheet software. This choice is motivated by several reasons: (a) A license for MS Excel 2007 is available, (b) the modeler is familiar with this software package, (c) MS Excel allows for easy transferral of data among users, (d) MS Excel is compatible with other software packages used.

4.3.2. Selection of indicators

Section 2.7.3 has introduced several requirements for the indicator sets. The calculation of indicator values can be standardized and largely automated; the indicators are unbiased, transparent to users, there are multiple indicators, the data sources to calculate indicator values are available, and finally the indicators are suitable for the the analysis of the question(s). Testing whether indicators are biased is currently being discussed in bibliometrics (see (Opthof and Leydesdorff 2010)) but goes beyond the scope of this research project. However multiple indicators are used to correct for bias on a single indicator. The information sources are available to calculate all indicators so this is not a decisive criteria. Indicators should be suitable for the analysis and therefore some indicators are not included (especially for patent data). All indicators are transparant since the underlying calculations have been identified. All indicators can be calculated thorugh standardized and automated procedures.

Publication indicators

Applying these requirements to the *publication* indicators yields 4 indicators. The % not cited, the % cited and the average impact of the journal are not considered relevant and are therefore not included. The total number of citations is not considerd, instead the average number of citations is used. The following indicators are used:

P	Number of publications
CPP	Average citation rate per paper
CPP/JCSm	Average impact of paper compared to the journal citation average
CPP/FCSm	Average impact of papers compared to the subfield citation average

Which are denoted as:

1. $C_{1(pub)}$ The number of scientific publications held by an institute: p
2. $C_{2(pub)}$ The average citation rate per publication: *CPP*
3. $C_{3(pub)}$ The CPP in comparison to citation rates in the same *journal* (the JCS): *CPP/JCS*
4. $C_{4(pub)}$ The CPP in comparison to citation rates in the same *field*: *CPP/FCS*

Patent indicators

Based on the criteria for the indicators, four different indicators are considered for measuring performance based on patents.

PAif	Patent activity of firm i in technology field (TF) F
Technological scope	Diversity and number of IPC classes in patent application
International scope	Size of patent family and share of triad patents of PAif
Citation frequency	Average citation frequency of PAif

Which are denoted as:

1. $C_{1(pat)}$ The number of patents held by an institute: p
2. $C_{2(pat)}$ The average number of DWPI classes per patent, in which an institute has published: $\overline{d}$
3. $C_{3(pat)}$ The number of TRIAD patents published by an institute: t
4. $C_{4(pat)}$ The average number of citations per patent received per patent by an institute: $\overline{c}$

4.3.3. Basic analysis: calculation of indicator values

The data needs to be cleaned and prepared in such a way, that it can be directly imported to the model. This can been done using dedicated text mining software (such as Vantagepoint) and results in *vectors* and *matrices*[4] which are then incrementally imported into the models. The basic analysis is conducted to calculate individual indicator values based on these vectors and matrices. So, the following activities are performed:
data cleaning and preparation → importing data into the model → intermediate calculation → calculation of individual indicator values → calculation of research performance.
First the primary input to the model is outlined. Then the necessary intermediate calculations are shown. Finally it is shown how the individual indicator values are calculated.

[4]These may be considered N · N tables with two axis

Primary input

The patent and publication data is cleaned in dedicated text mining software (Vantagepoint 5.0). This *cleaned* data is then incrementally imported to the bibliometrics model. The imported data consists mainly of lists and matrices.

For patents:

1. Matrix $A_{pi(pat)}$ is created to be able to link the patents p to institutes i. This is done using the unique identifier for each patent: the DWPI accession number.

$$A_{pi(pat)} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1i} \\ a_{21} & a_{22} & \dots & a_{2i} \\ \vdots & \vdots & \ddots & \vdots \\ a_{p1} & a_{p2} & \dots & a_{pi} \end{pmatrix}$$

2. Matrix $B_{pr(pat)}$ shows in which region r a patent p has been published: USA, Europe, Japan or WIPO (world patent). This is required for determining whether patents are TRIAD or not.

$$B_{pr(pat)} = \begin{pmatrix} b_{11} & b_{12} & \dots & b_{1r} \\ b_{21} & b_{22} & \dots & b_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ b_{p1} & b_{p2} & \dots & b_{pr} \end{pmatrix}$$

3. The vector $C_{in(pat)}$ represents the number of patents n that are held by institute i:

$$C_{in(pat)} = \begin{pmatrix} c_{i1} \\ c_{i2} \\ \vdots \\ c_{in} \end{pmatrix}$$

4. Vector $D_{jc(pat)}$ depicts the citations c received by institute i.

$$D_{jcc} = \begin{pmatrix} d_{i1} \\ d_{i2} \\ \vdots \\ d_{ic} \end{pmatrix}$$

5. Matrix $E_{jt(pat)}$ shows in which DWPI classes (and how frequent) d institute i has published:

$$E_{jt(pat)} = \begin{pmatrix} e_{11} & e_{12} & \cdots & e_{1d} \\ e_{21} & e_{22} & \cdots & e_{2d} \\ \vdots & \vdots & \ddots & \vdots \\ e_{i1} & e_{i2} & \cdots & e_{id} \end{pmatrix}$$

For publications:

1. Matrix $A_{ic(pub)}$ shows the number of citations c received by the institutes i.

$$A_{ic(pub)} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1c} \\ a_{21} & a_{22} & \cdots & a_{2c} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ic} \end{pmatrix}$$

2. Vector $B_{ip(pub)}$ displays the number of publications p per institute i.

$$B_{ip(pub)} = \begin{pmatrix} b_{11} \\ b_{21} \\ b_{ip} \end{pmatrix}$$

3. Matrix $C_{is(pub)}$ shows what the JCS scores s are for the different institutes i.

$$A_{ij(pub)} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1s} \\ a_{21} & a_{22} & \cdots & a_{2s} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{is} \end{pmatrix}$$

Calculating indicator values

The indicator values are calculated using the matrices presented earlier on. In several cases intermediate calculations are necessary. This section outlines these calculations for both the patent- and publication indicators.

Patents

The value of $C_{1(pat)}$ can be derived directly from vector $C_{in(pat)}$. The calculation of $C_{2(pat)}$ is done by summing each row for matrix $E_{jt(pat)}$, and then dividing this number by vector $C_{in(pat)}$. In order to calculate $C_{3(pat)}$ it is necessary to determine which patents are TRIAD, and which patents are not. The decision rule is that patents which have been published in the US, Europe *and* Japan *or* patents which are listed as WIPO, are considered TRIAD. TRIAD patents (t) are given a value equal 1, non-TRIAD patents are given a value equals 0. Thus matrix $B_{pr(pat)}$ is transformed into a vector $B_{triad(pat)}$:

$$R_{triad(pat)} = \begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_t \end{pmatrix}$$

The value of indicator $C_{3(pat)}$ is then determined by multiplying the matrix $A_{pi(pat)}$, by vector $B_{triad(pat)}$ in order to achieve vector $AB_{(pat)}$:

$$A_{pi(pat)} \cdot B_{triad(pat)} = AB_{(pat)} = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1i} \\ a_{21} & a_{22} & \dots & a_{2i} \\ \vdots & \vdots & \ddots & \vdots \\ a_{p1} & a_{p2} & \dots & a_{pi} \end{pmatrix} \begin{pmatrix} r_1 \\ r_2 \\ \vdots \\ r_t \end{pmatrix} = \begin{pmatrix} it_1 \\ it_2 \\ \vdots \\ it_t \end{pmatrix}$$

Finally, indicator $C_{4(pat)}$ is calculated by dividing the vector $D_{ic(pat)}$ by vector $C_{in(pat)}$ in order to achieve the new vector $DC_{i\overline{c}(pat)}$

$$D_{ic(pat)}/C_{in(pat)} = DC_{i\overline{c}(pat)} = \begin{pmatrix} i_1 \\ i_2 \\ \vdots \\ i_c \end{pmatrix} \div \begin{pmatrix} i_1 \\ i_2 \\ \vdots \\ i_n \end{pmatrix} = \begin{pmatrix} 1_{\overline{1}} \\ 2_{\overline{1}} \\ \vdots \\ i_{\overline{c}} \end{pmatrix}$$

Publications

The values $C_{1(pub)}$ are found in vector $B_{ip(pub)}$. The values for indicator $C_{2(pub)}$ are determined by dividing vector $A_{ic(pub)}$ by vector $B_{ip(pub)}$.
Indicator $C_{3(pub)}$ is calculated using matrix $C_{is(pub)}$. The value of the indicator is determined by taking the average value for each row. The forth and final indicator $C_{4(pub)}$ is calculated by comparing the individual citation rates

for all institutes to the field average. Thus the CPP/FCS ratio is calculated by taking the values from $A_{ic(pub)}$ and comparing those to the citation field average (FCS). The FCS in turn is determined by the citation average by all institutes.

4.3.4. Combining indicator values to aggregate performance values

In the advanced analysis the individual indicator values are combined in an composite ranking value. Tables 4.2 and 4.3 show the main set-up of the model. The columns contain the individual indicator values for institutes 1 - *i*. The composite value is the sum of the product of the normalized indicator values multiplied by the weight set.

Table 4.2.: Ranking model for patents

Indicators	Number of patents	Number of DWPI classes	Average number of TRIAD patents	Average number of cites	*RPP*	*Normalized RPP*
symbols	p	$\overline{d}$	t	$\overline{c}$		
criteria	C_1	C_2	C_3	C_4		
weights	w_1	w_2	w_3	w_4		
Name: ↓	max	max	max	max	max	
Institute 1 Institute 2 Institute 3 ⋮ Institute i						

Table 4.3.: Ranking model for publications

Indicators	Number of publications	Average citation rate	CPP/JCS	CPP/FCS	*Performance*	*Normalized performance*
symbols	p	CPP	CPP/JCS	CPP/FCS		
criteria	C_1	C_2	C_3	C_4		
weights	w_1	w_2	w_3	w_4		
Name: ↓	max	max	max	max	max	
Institute 1 Institute 2 Institute 3 ⋮ Institute i						

5. Case study

5.1. Introduction

The purpose of this case study is to *test* the designs of the TI process and the ranking models, and to retrieve further requirements. The case study also provides a more hands-on and in-depth demonstration of both designs. The case study involves the technology field *augmented reality*. This technology field is studied by a group of technology specialists, who will be involved in the definition of search queries. The second technology field, *Sulphur Lithium Cells* was also used for the TI process design and model and is therefore not fully discussed in this chapter. However the findings from this case study involve both technologies. The structure of this chapter is as follows. The first section (5.2) presents the case study set up. One of these two technologies, augmented reality, will be used to illustrate the execution of the case study. The next section (5.3) discusses the actual execution of the case study, using the designs for the TI process and both ranking models. The final section describes the major findings.

Figure 5.1.: An application of augmented reality; a head up display with laser projection in an unclassified Audi.

5.2. Case study setup

Recall that the purpose of this STIP is to rank research institutes for the technology fields in which Volkswagen is active. For the case of Volkswagen Research, this involves the assessment of research institutes in over 200 disparate technology fields. This case study involves *two* of these technology fields. For each of these fields, and for both patent and publication data, a STIP is created. The technology fields studied are *augmented reality* and *sulfur lithium cells*. Augmented reality (AR) is a term for a live direct or indirect view of a physical real-world environment whose elements are merged with (or augmented by) virtual computer-generated imagery - creating a mixed reality' (from: wikipedia). A practical example is a popular *iphone* application: The user makes a digital image of the environment (i.e. camera function) and the application combines GPS, a digital compass and data, to point the user to the nearest taxi stand, land mark, restaurant etcetera. Sulfur lithium cells are a type of batteries that can be applied in electronic devices as well as in vehicles with an electric drive train (cars, e-bikes etc). The process design specifies that technology specialists define search queries with use of the TI platform, DI.ANA. For each technology field 1-3 technology specialists have been involved for the definition of search queries. Similar for the design of the TI process, the activities ‘interpretation’ and ‘utilization’ go beyond the scope of this research project.

5.3. Case study execution

The case study is executed according to the process design. This means the prescribed steps A1 to A6 are followed. Each of these steps are described in more detail in the following paragraphs. The case of ‘augmented reality’ serves as an illustration.

5.3.1. Issue identification (A1)

The design specifies that STIPs address *predefined* issues. In collaboration with the client (management of Group Research) the issue is defined as: *to assess whether Volkswagen is collaborating with the best research institutes in different technology fields.* The corresponding MOT question to address this issue is formulated as ‘Which universities or research labs lead in this technology - overall or in particular aspects?’(Porter and Cunningham 2005). The outcome (the STIP) has also be defined as: a one pager which displays the top-10 highest performing research institutes, based on patent- and publication data.

5.3.2. Selection of information sources (A2)

The STIPs are based on *predefined* information sources. This concerns both the *type* of information (e.g. patents or publication records) and the *parts* of the record that are needed (see (Thomson Innovation 2010)). Access to databases is often available through institutional licenses; universities usually have access to a wide variety of databases (Porter and Cunningham 2006). The choice of database is thus dependent on the information that is contained, and the information which is most suitable for the issue or question at hand. Online platforms such as Dialog Online (2010) support this decision. Volkswagen does not have direct access to the same amount of databases that universities can deploy, but does have a license agreement with a leading science and technology information provider. This database covers a wide variety of different topics, but does not include all possible conference proceedings, books etcetera. Some more detail on the employed databases is given below.

Publications databases

Information is retrieved through a company license agreement with Thomson Innovation. This covers 4 major databases: the Web Of Science, the Current Contents Connect, INSPEC and Conference proceedings. The Web Of Science database covers around 9.300 of the most prestigious, high-impact research journals (Web of Science 2010). This includes the *Science Citation Index*®, *Social Sciences Citation Index* ®, and the *Arts & Humanities Citation Index* ®. The Current Contents Connect, a multidisciplinary database covers 8000 leading scholar journals and over 2000 books (Current Contents Connect 2010). The Science Citation Index (SCI) (Science Citation Index 2010) is a ‘citation index’ that provides insight into what publications are cited by other publications, how often articles are publications, what the most cited publications are etcetera. Since citation analysis is part of the ranking models, the SCI is a crucial input to the model. The SCI covers 8000 leading scholar journals and over 2000 books (Current Contents Connect 2010). The Science Citation Index (SCI) (Science Citation Index 2010) is a ‘citation index’ that provides insight into what publications are cited by other publications, how often articles are publications, what the most cited publications are etcetera. Since citation analysis is part of the ranking models, the SCI is a crucial input to the model. INSPEC, ‘the world’s leading bibliographic information service providing access to the global scientific and technical literature’,produced by the Institution of Engineering and Technology (INSPEC 2010). This database provides insight in the global technical literature in ‘physics, electrical engineering, electronics, communications, control engineering, computers, computing, information technology, manufacturing and production engineering’ (INSPEC 2010). Conference Proceedings covers the multidisciplinary literature which is published on the worlds most significant conferences, seminars etc, 70% of which is not published in journals (Conference Proceedings 2008).

Patent databases

Patents are retrieved through a license agreement with Thomson Innovation. These databases cover *Derwent World Patent Index* as well as World, US, European, Asia Pacific and more (DWPI 2008). The Derwent World Patents Index covers over 13 million inventions. These inventions have been classified and indexed by over 350 technology specialist, distributed across 41 different patent-issuing authorities. These specialists “rewrite patent titles and abstracts in English, using clear, consistent, industry-specific terms, to increase the accuracy of and speed your research” (DWPI 2008). The other databases cover patents issued at global level (WIPO applications) and at regional level (mainly US, Europe and Asia PAcific applications). Most applications are done in the English language (US: 100% and Europe: 60%)(DWPI 2008), other major languages are German, French, Chinese, Japanese and Korea. These patents are translated into English.

Fields within publication- and patent records

Each publication- and patent record contains a large number of fields. Each field contains a particular aspect of information about the record: e.g. fields may contain the authors, the institutes’ name, the number of citations received from other others, the key words, the abstract, the full article, the title etcetera. There is a good reason to select just the right fields, since selecting all fields may cause problems in the preceding steps of the TI process. A practical demonstration is the following: the TI analysis involves retrieval of records from from patent- and publication databases. A typical analysis may require that large amounts of records need to be retrieved from these databases, which can be a time-consuming activity. Cleaning all record fields, including those that are not needed, is inefficient and a waste of effort. For this reason there is a strong incentive to retrieve only those fields that are needed for the analysis. For patent data, the fields retrieved are listed in table 5.1 below. A brief explanation is given in the right column.

Table 5.1.: Selected patent fields

Field	Explanation
DWPI Accession Number	Identifier, every patent has unique number.
DWPI Title	Title written by DWPI experts to describe the invention.
DWPI Inventor	Link patents to inventors, technologies to inventors, identification of networks.
DWPI Assignee	The holder of the rights, in this case the universities and research labs.
DWPI Assignee Code	Code that is available for certain institutes.
DWPI Class	Shows technology class, according to DWPI classification.
DWPI Family Members	A set of patents filed with different patent authorities that refer to the same invention.
Priority Date	The date when the patent was filed.
Priority Number	A patent application number regarding the priority it claims.
Count of Citing Patents	Patents which a patent refers to.
Count of Cited Refs	Patents citing the patent at hand.
Patent Abstract - DWPI	Concise description of what the patent is referring to. Based on the original abstract and (re)-written in English.
DWPI Manual Codes	Detailed DWPI classification.
IPC	International Patent Classification code to which the patent is assigned.
Current ECLA	European Patent Office Classification code to which the patent is assigned.
US Class	US Patent Classification code to which the patent is assigned.

based on: (Thomson Innovation 2010)

5.3.3. Search refinement & data retrieval (A3)

Search refinement

Initial search query definition by technology specialist
The initial search queries to describe the technology fields, are defined by the technology specialists. This is done using the TI-platform (4.2). The definition of search queries using DI.ANA has been discussed in earlier chapters. It is possible that multiple search queries are defined, that describe different aspects of the technology. For AR, multiple search queries were defined to describe different sub-technologies of AR (see appendix F.1, tables: F.1 - F.6). These sub-technologies are:

- Visualization for research and marketing
- Augmented reality for planning, production and service
- Functional protection of vehicle design concepts

Three of the corresponding search queries are listed as examples below. The remaining set (a total of 8 search queries was defined for AR) are listed in F.1. The queries describe different sub-technologies and are expressed in both English and German.

augmented reality OR mixed reality OR spatial augmented reality OR projection based augmented reality OR head mounted displays OR hmd OR mobile displays OR head worn display OR mobile projectors OR tracking OR markerless tracking OR large area tracking OR motion capturing OR optical see through

digitale fabrik OR digital factory OR fabrikplanung OR factory planning OR soll/ist vergleich OR variance comparison OR planungsworkshop OR stoerkantenanalyse OR werkerfuehrung OR worker guidance OR fahrzeugservice OR car service OR worker assistance

(head mounted displays OR HMD OR tracking of users OR tracking of hand OR force feedback OR tactile feedback OR caves) AND (“virtual reality” OR “virtual environments”) size perception AND ((HMD OR “head mounted display” OR “head worn display” OR CAVE) OR immersive)

Figure 5.2.: 'Themescape', displaying the sub-technologies and their rate of increase based on patent data

Data retrieval

To find records, the analyst makes use of a fixed *search procedure*. The fixed search procedure guarantees that each analysis (for each technology field) is performed in exactly the same way. This contributes to transparency and makes it possible to reproduce the exact same results at a later time. It also contributes to speed, since once the procedure is defined analyst no longer have to worry about trying out different fields. The search procedure is the result of a process of 'trial and error'. This search procedure specifies the fields to search in, the data collection, and the time span considered. The search procedure in addition to the search query constitutes the 'search strategy'. Tables 5.2 and 5.3 list the search strategies for AR:

Table 5.2.: Search strategy: Augmented reality (patents)

Field	Search query
Title	augment* ADJ realit*
Abstract	augment* ADJ realit*
First claim	augment* ADJ realit*
DWPI manual code	T01-J40C
Application date	01-01-2004 to 26-11-2009 (current)
Data collection: Enhanced patent data from DWPI. 496 patents found	

Table 5.3.: Search strategy: Augmented reality (literature)

Field	Search query
All text fields	augment* ADJ realit*
Abstract	augment* ADJ realit*
Period: 01-01-2004 to 26-11-2009 (current) Data collection: Web of Science, Conference Proceedings and Current Contents Connect.	

The search queries, of which three are listed above, are combined with the search procedure in order to arrive at a suitable search strategy. The outcome is that the search queries defined by the technology specialists yielded insuitable results. The returned results included irrelevant items, but also excluded important items. Based on these results the choice is made to use a more generic search query (large breadth). For augmented reality this query is listed below. The '*' represents a 'wild card' which can take on any value. This search query covers both the English and German language. Tables 5.2 and 5.3 list the search strategies.

augment* ADJ realit*

5.3.4. Data cleaning (A4)

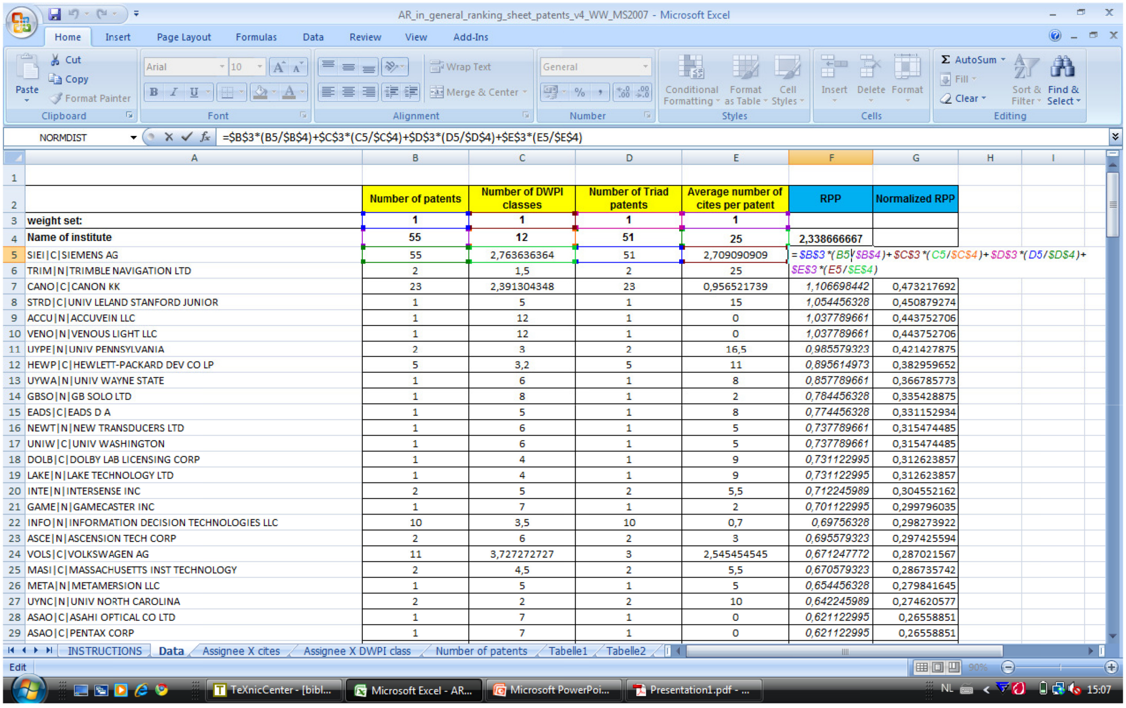
Data cleaning is essential since not carrying out this activity distorts the results. Data cleaning is conducted using Vantapoint 5.0 software. The choice of this package is motivated by two factors: (a) availability of a license at Volkswagen (b) relatively easy to use for non-programmers. However, basic knowledge of regular expressions , is needed for proper cleaning. For patent data, the data cleaning consists of:

- Removal of duplicate records. Since the databases often consist of multiple disparate databases, records may appear double. Duplicate records may match exactly (100% identical) or may show strong resemblences. Patent records may be filed in different regions, and as a result different patent records may reflect the same invention. It is necessary to correct for this effect as well.
- Reformatting of data. Data needs to be reformatted to be able to use in the different software packages (Vantagepoint and MS Excel). See appendix F.1, figure F.10 and the field 'Inventor - DWPI', ABAD F,,,, | BENDAHAN R,,,, | BOUGNOUX,,,, |. The | symbol means (natural language) 'and'. Since Vantagepoint and Excel to not recognize this, it is necessary to reformat the data to ABAD F, BENDAHAN R, BOUGNOUX so that the software packages indeed recognize that there are different authors. the ',,,,' need to be removed as well. Similar cleaning is needed for author fields.
- Fuzzy matching two combine multiple field entries that have the same meaning. For example company names as 'Volkswagen AG' need to be matched with 'Volkswagen' since they refer to the same institute. Other examples include 'Delft University of Technology' or 'TU Delft' and 'TU Berlin' or 'Technische Universität Berlin'. In other cases patents and publications are published under the author's names, rather than the institute's name. This can be corrected using filters and 'fuzzy matches'.

The TI process design explicitly specifies the use of procedures and partial automation through scripts and macro's. This works as follows: the software package used allows the analyst to execute the data cleaning procedure once, after which the procedure can be stored and repeated for other technology fields. Thus, once the procedure is automated using scripts and macro's, it can be repeated for similar datasets in a fraction of the required time as compared to data cleaning without scripts and macro's.

5.3.5. Basic and advanced analysis (A5)

The analysis step involves importing the cleaned data in to the ranking models shown in tables 4.2 and 4.3 that are constructed for the purpose of this research project. Several intermediate calculations (discussed in 4.3.3) are made, after which the individual indicator values are calculated in MS Excel. Once this is completed, institutes are ranked based on their research performance. This is done for both patents and publications. See appendix F.1 for a detailed description of how these ranks are calculated using the model. figure 5.3 depicts a screenshot of the ranking model.



=$B$3*(B5/$B$4)+$C$3*(C5/$C$4)+$D$3*(D5/$D$4)+$E$3*(E5/$E$4)

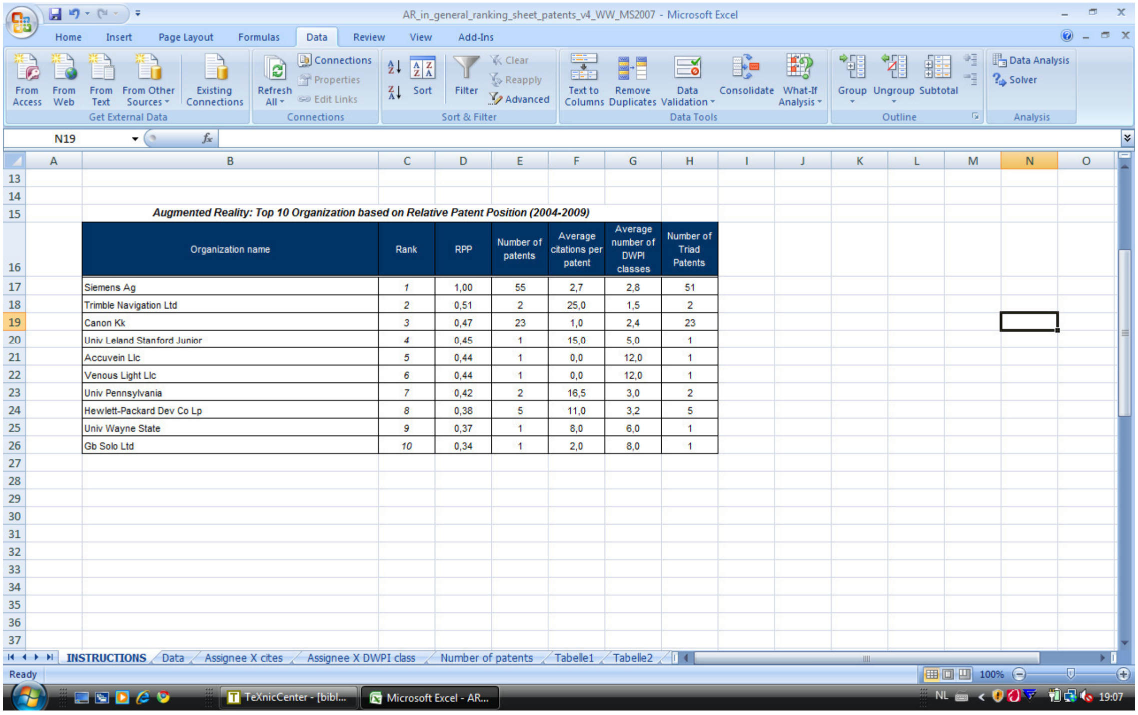
		Number of patents	Number of DWPI classes	Number of Triad patents	Average number of cites per patent	RPP	Normalized RPP
3	weight set:	1	1	1	1		
4	Name of institute	55	12	51	25	2,338666667	
5	SIEI|C|SIEMENS AG	55	2,763636364	51	2,709090909	= $B$3 *(B5/$B$4)+ $C$3 *(C5/$C$4)+ $D$3 *(D5/$D$4)+ $E$3 *(E5/$E$4)	
6	TRIM|N|TRIMBLE NAVIGATION LTD	2	1,5	2	25		
7	CANO|C|CANON KK	23	2,391304348	23	0,956521739	1,106698442	0,473217692
8	STRD|C|UNIV LELAND STANFORD JUNIOR	1	5	1	15	1,054456328	0,450879274
9	ACCU|N|ACCUVEIN LLC	1	12	1	0	1,037789661	0,443752706
10	VENO|N|VENOUS LIGHT LLC	1	12	1	0	1,037789661	0,443752706
11	UYPE|N|UNIV PENNSYLVANIA	2	3	2	16,5	0,985579323	0,421427875
12	HEWP|C|HEWLETT-PACKARD DEV CO LP	5	3,2	5	11	0,895614973	0,382959652
13	UYWA|N|UNIV WAYNE STATE	1	6	1	8	0,857789661	0,366785773
14	GBSO|N|GB SOLO LTD	1	8	1	2	0,784456328	0,335428875
15	EADS|C|EADS D A	1	5	1	8	0,774456328	0,331152934
16	NEWT|N|NEW TRANSDUCERS LTD	1	6	1	5	0,737789661	0,315474485
17	UNIW|C|UNIV WASHINGTON	1	6	1	5	0,737789661	0,315474485
18	DOLB|C|DOLBY LAB LICENSING CORP	1	4	1	9	0,731122995	0,312623857
19	LAKE|N|LAKE TECHNOLOGY LTD	1	4	1	9	0,731122995	0,312623857
20	INTE|N|INTERSENSE INC	2	5	2	5,5	0,712245989	0,304552162
21	GAME|N|GAMECASTER INC	1	7	1	2	0,701122995	0,299796035
22	INFO|N|INFORMATION DECISION TECHNOLOGIES LLC	10	3,5	10	0,7	0,69756328	0,298273922
23	ASCE|N|ASCENSION TECH CORP	2	6	2	3	0,695579323	0,297425594
24	VOLS|C|VOLKSWAGEN AG	11	3,727272727	3	2,545454545	0,671247772	0,287021567
25	MASI|C|MASSACHUSETTS INST TECHNOLOGY	2	4,5	2	5,5	0,670579323	0,286735742
26	META|N|METAMERSION LLC	1	5	1	5	0,654456328	0,279841645
27	UYNC|N|UNIV NORTH CAROLINA	2	2	2	10	0,642245989	0,274620577
28	ASAO|C|ASAHI OPTICAL CO LTD	1	7	1	0	0,621122995	0,26558851
29	ASAO|C|PENTAX CORP	1	7	1	0	0,621122995	0,26558851

Figure 5.3.: Screenshot of ranking model for patents

5.3.6. Presentation (A6)

The TI process prescribes uses a *format* (or 'template') for the presentation of the outcome: the *one-pager*. Figure 5.5 displays an example of such a one pager. The left side (the front) displays the tables containing the top-10 institutes based on patent-and publication data for AR. A time span of 5 years is considered. These tables are automatically generated from the ranking models. The right side of the one-pager (the backside) contains the 'Themescape' map. The idea is that a one pager is generated for each technology field.

Special attention is paid to the design of the STIP, that is: the content and appearance of the one-pager. This is important since the value of TI does not just depend on completeness or quality of the analysis. In the end it is essential that the effectiveness of decisions is improved (Moehrle and Isenmann 2006). Therefore, the results of the analysis have to be presented to the recipients in a suitable manner. There are numerous ways to accomplish this; In this research project, an 'attractive' looking design was found to suit best, since the clients are not experienced with the interpretation of complex data sheets. In addition, the standard design and layout is expected to greatly

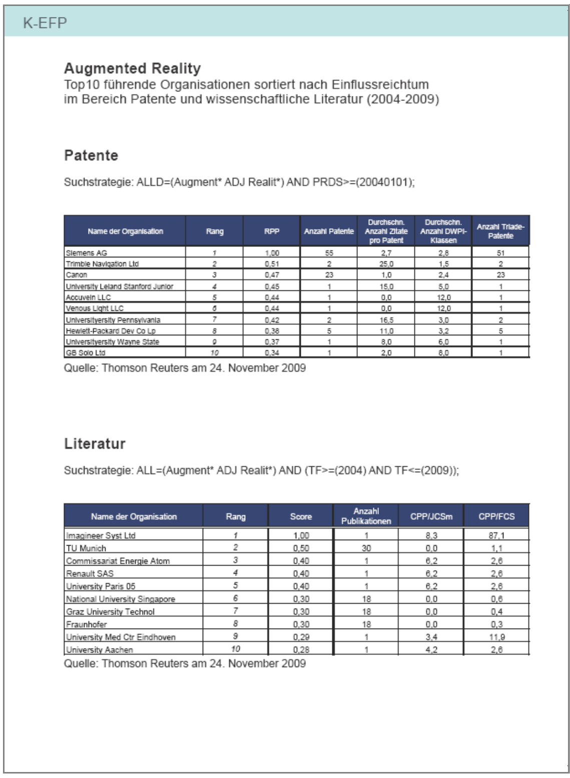


Augmented Reality: Top 10 Organization based on Relative Patent Position (2004-2009)

Organization name	Rank	RPP	Number of patents	Average citations per patent	Average number of DWPI classes	Number of Triad Patents
Siemens Ag	1	1,00	55	2,7	2,8	51
Trimble Navigation Ltd	2	0,51	2	25,0	1,5	2
Canon Kk	3	0,47	23	1,0	2,4	23
Univ Leland Stanford Junior	4	0,45	1	15,0	5,0	1
Accuvein Llc	5	0,44	1	0,0	12,0	1
Venous Light Llc	6	0,44	1	0,0	12,0	1
Univ Pennsylvania	7	0,42	2	16,5	3,0	2
Hewlett-Packard Dev Co Lp	8	0,38	5	11,0	3,2	5
Univ Wayne State	9	0,37	1	8,0	6,0	1
Gb Solo Ltd	10	0,34	1	2,0	8,0	1

Figure 5.4.: Screenshot of the calculation of ranks in the model

enhance readability and thus acceptability among clients and contribute to the automation of one-pager generation. The one-pager is depicted in figure 5.5.



K-EFP

Augmented Reality

Top10 führende Organisationen sortiert nach Einflussreichtum
im Bereich Patente und wissenschaftliche Literatur (2004-2009)

Patente

Suchstrategie: ALLD=(Augment* ADJ Realit*) AND PRDS>=(20040101);

Name der Organisation	Rang	RPP	Anzahl Patente	Durchschn. Anzahl Zitate pro Patent	Durchschn. Anzahl DWPI-Klassen	Anzahl Triade-Patente
Siemens AG	1	1,00	55	2,7	2,8	51
Trimble Navigation Ltd	2	0,51	2	25,0	1,5	2
Canon	3	0,47	23	1,0	2,4	23
University Leland Stanford Junior	4	0,45	1	15,0	5,0	1
Accuvein LLC	5	0,44	1	0,0	12,0	1
Venous Light LLC	6	0,44	1	0,0	12,0	1
Universityersity Pennsylvania	7	0,42	2	16,5	3,0	2
Hewlett-Packard Dev Co Lp	8	0,38	5	11,0	3,2	5
Universityersity Wayne State	9	0,37	1	8,0	6,0	1
GB Solo Ltd	10	0,34	1	2,0	8,0	1

Quelle: Thomson Reuters am 24. November 2009

Literatur

Suchstrategie: ALL=(Augment* ADJ Realit*) AND (TF>=(2004) AND TF<=(2009));

Name der Organisation	Rang	Score	Anzahl Publikationen	CPP/JCSm	CPP/FCS
Imagineer Syst Ltd	1	1,00	1	8,3	87,1
TU Munich	2	0,50	30	0,0	1,1
Commissariat Energie Atom	3	0,40	1	6,2	2,6
Renault SAS	4	0,40	1	6,2	2,6
University Paris 05	5	0,40	1	6,2	2,6
National University Singapore	6	0,30	18	0,0	0,6
Graz University Technol	7	0,30	18	0,0	0,4
Fraunhofer	8	0,30	18	0,0	0,3
University Med Ctr Eindhoven	9	0,29	1	3,4	11,9
University Aachen	10	0,28	1	4,2	2,6

Quelle: Thomson Reuters am 24. November 2009

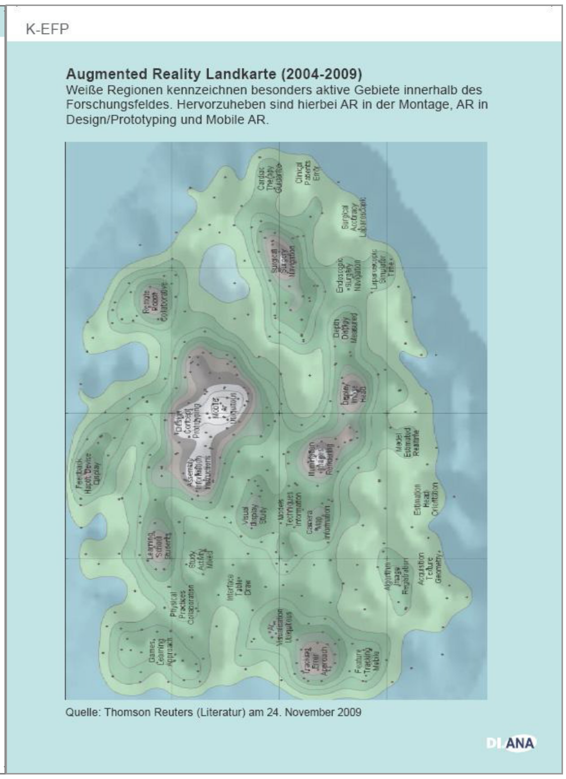


Figure 5.5.: Illustration of the STIP for *augmented reality*. Source: own work

5.4. Conclusions drawn from case study

The purpose of this case study was to test the designs of (a) the generic TI process for STIPs, and (b) the models for ranking research performance based on patent- and publication data. A second objective was to give a practical demonstration of the process and models. The problem exploration revealed two major evaluation criteria: (1) The quality of outcomes, largely determined by the equality of input and (2) the required time to complete a STIP, the lead time.

5.4.1. The TI process design

The specified process design was used for carrying out the case study. This included specification of the activities to be carried out, the inputs and outputs for each activity, and the control and support mechanisms. The primary elements of this process are:

- Technology specialists that define search queries for the technology fields of their specialism, with support of the TI-platform.
- A predefined issue and predefined information sources
- A predefined one-pager design, the STIP. This is the output of the TI process
- Specification of procedures for data retrieval, TI method, data cleaning and analysis, as well as (partial) automation of these activities through scripts and macro's.

The specification of issue and methods makes an explorative process redundant and instead a more linear process is followed. The specification of analysis tools, procedures and use of scripts and macro's helped to greatly reduce the required time to complete the project since iterations are no longer needed and the overall process becomes much more efficient. Nevertheless some unforeseen problems appeared:

The definition of search queries

The definition of search queries is an essential but complex process. Essential because it is during this activity that technology specialists contribute their individual expertise. Complex, because the search query definition process remains challenging. The expectation was that the TI platform would replace the role of the analyst in the process of search query definition, and thereby make the time-intensive interaction between technology specialist and analyst unnecessary. This was not the case and for both *Augmented Reality* and *Sulphur Lithium Cells*, the search queries formulated by the technology specialist had to be replaced by more relevant ones. Since the search query essentially determines the technology field of the STIP, a 'wrong' search query would lead to a 'wrong' representation of technology field F. As a result, the quality of the STIP would have suffered. The quality was maintained, but led to an increase in lead time.

Two major problems that were expected with search queries and the possible causes. The two major problems with search queries are: the queries yield too few results (too 'narrow'), or search queries yield mainly irrelevant results. In some cases this relates to how the concepts are defined: plurals not included, only defined in one language, concepts missing. In other cases it was caused by errors in syntaxes and Boolean operators; brackets in the wrong place and no or wrong use of advanced operators. A summary is listed in table 5.4

Table 5.4.: Problems and possible causes for poor search queries

Problem	Possible causes
Query yields to few results, while more should be expected	Query is too narrow (too many concepts, too precise)
	No use of advanced operators
	Errors in syntax and operators (e.g. '?' or '*' symbols)
	Errors in Boolean algebra
	Plurals absent
	Synonyms missing
	Wrong language
Query yields results, but irrelevant	Query is too broad (to few concepts, too broad)
	Errors in Boolean algebra
	No use of advanced operators

Data cleaning

The data cleaning is a second essential process. The process design prescribed that procedures complemented with scripts and macros would be used to execute the majority of the analysis. This was the case, but one task in particular, the matching of organizational names proved to be difficult to automate. Dependent on the level of perfection this can be a more or less time consuming activity. Since this STIP addresses only the top 10 of institutes, cleaning 90% of the organizational name fields will be sufficient. However, this relatively simple example does lead to the conclusion that when considering a certain STIP, and thus a certain type of output, analysis methods, and information sources, the TI analyst must take into account the data cleaning procedures.

5.4.2. The models

The models for ranking research performance worked fine. At this point data is still imported incrementally, but it is possible to automate these steps further. The second criteria, the required time, is definitely met. With regard to quality, the quality of output relies heavily on the quality of input and is mainly the result of the activities of the process discussed above.

5.4.3. Overall outcomes process and models

Based on the execution of two case studies, the overall evaluation of process and models is positive. The case study has provided a demonstration of the application of STIPs within a large technology oriented organization. The process design has increased the role of the technology expert in the TI process. Some issues arose with the search query definition. Assuming that technology specialists *are* willing to cooperate and provide the right input, then additional measures are required to support technology specialists in formulating more effective search queries. The solution may lie in learning specialists more on the factors affecting an effective search query, and providing the means to enhance this learning. Additional requirements that can be retrieved from this are:

6. Validation and verification

6.1. Introduction

This chapter aims to evaluate the TI process design and ranking model. Both designs undergo the verification and validation. The definitions for verification and validation appear to vary slightly depending on the researchers' background. Whereas certain methodologies such as *agent based modeling*, *discrete simulation modeling* and *decision support systems modeling* prescribe ways to verify and validate designs, no procedure has been found for *process designs* or *ranking models*. This research project deploys the following definition of verification and validation, which is used by NASA in the verification and validations of designs: *"Verification of a product shows proof of compliance with requirements — that the product can meet each 'shall' statement as proven though performance of a test, analysis, inspection, or demonstration. Validation of a product shows that the product accomplishes the intended purpose in the intended environment — that it meets the expectations of the customer and other stakeholders as shown through performance of a test, analysis, inspection, or demonstration"* (NASA 2007).

This chapter is organized as follows: a first section addresses the verification of both designs. Verification entails checking whether the designs satisfy the targeted requirements formulated in earlier chapters. Hereafter the validation of the designs is discussed. Conclusions with respect to the verification and validation are found in the final section.

6.2. Verification

The verification involves examining whether the designs meet the requirements formulated in chapters 2 and 3. Two designs have been presented: a design of a TI process, which can be used to develop STIPs on a large scale, and two models which are used to evaluate research performance of institutes based on bibliometric indicators. The detailed results of this can be found in appendix H.

Tables H.1 and H.2 provide an overview of the list of requirements and shows whether these requirements have been met by the designs or not. Satisfied requirements are denoted with a '☑', if the requirement is moderately satisfied this is denoted with a '☐', and in case the requirement has not been met this is denoted with a '☒'.

Conclusions
From tables H.1 and H.2 it follow that almost all requirements appear to be incorporated in both designs. There are two exceptions:

- The process should minimize the number of large feedback loops, especially those from the *analysis* and *choice* phases back to *problem definition*. This requirement has been moderately satisfied. The case studies which use the designs show that the number of 'large' feedbacks is reduced. This is explained by the fact that the issue is fixed at the start of the process, which makes iterations regarding the content of the analysis obsolete. At the same time the Di.Ana platform is used to replace the role of the TI analyst in the definition of search queries by the technology specialists. As the case study demonstrated, technology specialists may be unable to formulate effective search queries on their own. As a result, involvement of the TI analyst is still required at this stage. Since this usually involves taking several iterations, the feedback loops are not completely removed. Since the requirement stated to *minimize* the number feedback loops and not *eliminate* them completely, the argument is that the requirement has been satisfied to an extent that lies somewhere between moderately and fully satisfied (☑☐).

- The coordination mechanisms may not negatively impact the quality of the input provided. Although these coordinations mechanisms are formulated to improve the quality of search queries provided, it cannot be irrefutably determined whether this is indeed the case. Furthermore, the recommendations have not been incorporated into the case studies.

6.3. Validation

According to the definition of validation deployed in this thesis, validation:“..shows that the product accomplishes the intended purpose in the intended environment — that it meets the expectations of the customer and other stakeholders as shown through performance of a test, analysis, inspection, or demonstration (NASA 2007). Three aspects are validated: the TI process design, the model for ranking research institutes and the recommendations made to deal with the coordination of technology specialists.
Many approaches to validating models are available, but these are less useful for designs that are to a large extent intangible: such as the TI process design. For this reason, the validation of the TI process is limited to ‘external validity’: it is concluded to what extent the research outcomes can be generalized to other settings outside Volkswagen.

6.3.1. Validation of TI process

Since literature offers few examples of TI processes, a study is carried out to learn more about the elements of TI and the relationships between these elements. The focus here is especially on TI processes for developing STIPs. This literature study reveals four key elements for the TI process. The backbone for the process design is the ‘tech-mining’ model discussed by Porter and Cunningham (2005). Both the individual elements and steps are broadly mentioned in literature. So is the relationships between the elements. Therefore, it is perceived valid to conclude that these four steps are indeed part of the TI process. The implication for the STIP—formulated as requirements—follow logically from the characteristics of the STIP.
A fifth element of the TI process is discovered during the analysis of the current situation. This element involves the TI platform and is considered a key element to ‘upscaling the TI process’, since this allows for a significant reduction of time for the most time-intensive activity: search query definition. However, this elements has not been found elsewhere in the literature.
The conclusion is that the TI process design is grounded in scientific literature but that it also involves choices made by the analyst and factors in the institutional setting of the TI process at Volkswagen. The overall conclusion it that the process design can be generalized for other STIPs within the same setting, but does not provide a universal design of a TI process for STIPs. Nevertheless, it does provide a valid representation of *a* TI process that may be useful for others outside Volkswagen.

6.3.2. Validation of models

The models are used to assess research performance of institutes based on patent and publication data. The major elements of the models to be validated are:

- The information input
- The preparation of the data
- The individual indicators
- The calculation of ranks by the model: essentially the output of the model.

Information input

The information input is fixed and is retrieved from Thomson Innovation databases. With regard to patents, Thomson Innovation is the worlds' most comprehensive database of enhanced patent documents (DWPI 2008). With regard to scientific literature, the databases cover scientific literature from a variety of sources. The assumption is that all relevant publication are covered by these databased. Nevertheless, it is virtually impossible to cover all scientific output that is generated globally. To conclude: the information input is considered valid but it is not practical to include all science and technology information. This entails that not all publications and patents that are issued by institutes are incorporated into the ranking.

Preparing the data

Making the data suitable for the ranking models (the basic analysis) involves several intermediate calculations, which are discussed in 4.3.3. These calculations have undergone a structural validation to verify whether the calculations are made right. This is done by asserting that each calculation is correct, and ensuring that the calculation are implemented into the model in the right way. The model calculates the desired matrices with use of the MMULT function in MS Excel. To double check that the calculation are correct, they have been replicated in Maple 14 software. Also, manual calculations of several samples were made on paper. These tests yielded the exact same results.

Individual indicators

The calculation of the individual indicator values is also done through structural validation. This involves: (1) determining whether formulas are translated to the model correctly (2) the outcomes of the indicators values correspond to the expectations. The first step involved manual checking of the formulas for each indicators. The second step involved looking at the indicator values for different institute and comparing these to the raw data. So for example: for the patent indicator 'number of patents' the indicators value (an integer value >0) is compared to the number of patents found by organization i in the raw data that is retrieved from the patent databases. Execution of both steps confirmed that the calculations of individual indicator values is valid.

Rank based on indicators

A structural validation is carried out first: the ranking values of institutes are compared to assert whether the values made sense. This entails checking whether institutes with low values on the individual indicators have low overall ranks as well, and whether institutes with high values on individual ranks have high overall ranks as well. This confirms the structural validity of the model.
To arrive at conclusions regarding the *external* validity several options are available. The first is a replicative validity. This would entail comparing the outcomes of the model, to outcomes produced with a different model. This however, is not considered a feasible option since: (a) no such model is available; outcomes are often published but the underlying models remain disclosed (b) even if alternative models are available, this would involve the assessment of very large amount of data, since these models are often used for the assessment of research performance of all universities worldwide or even countries, (c) validating the model is not the main purpose of this research project.

Instead a sensitivity analysis is carried out to study the effects of important changes to the models' parameters on the outcomes. The outcomes of this analysis are discussed in the next section.

6.4. Sensitivity analysis

Appendix I contains a detailed description of the sensitivity analysis. This section contains the primary conclusions.

This sensitivity analysis aims to investigate the sensitivity of the model by making changes to critical model parameters. Three types of critical model parameters are distinguished;

- The formulas that are used to calculate the indicator values
- The set of indicators
- The relative importance that has been assigned to the indicators (weights)

The first type addresses the calculation of the indicators that have been retrieved from literature on patent and publication analyses. These indicators have been widely discussed in literature and are widely adopted. It is not the aim of this research to validate these indicators.
The second type of model parameters refers to the set of indicators that has been selected in chapter 2, based on the requirements for the STIP. Literature provides no indications on the perfect set of indicators to 'measure science' but does point towards several requirements (see section 2.7.2).
The third type of parameters refers to the relative importance of indicators. The relative importance is expressed with weights. This section explores the sensitivity of the model's outcomes to systematic variation of the weights.
The sensitivity analysis is carried out in two parts: In the first part the weight sets are varied randomly and the effect on the institutes' rank is studied by examining changes in the composition of the top-10 institutes.
In the second part the focus is on changing the weights for one indicator, while keeping all other weights constant. For patents the weights of the 'average number of citations' and 'number of patents' are varied. For publications, the weights of 'CPP/FCS' (van Raan's crown indicator) and the 'number of publications' are varied.

Methods
The sensitivity analysis uses the actual data that is also used to construct the rankings. The sensitivity of the model is tested by making changes to the weight parameters. The Excel add-in RiskSim 2.30 is used to study the effect on the *rank* when changing the values of two non-random inputs (the weights).

6.4.1. Patents

Part 1 The first past studied the effects of the models outcomes due to random variation of weights. The weights sets used are: [1,1,1,1], [1,1,1,2], [2,1,1,1] and [1,0,0,1].

Where:

- w_1 = weight for *number of patents*
- w_2 = weight for *average number of DWPI classes*
- w_3 = weight for *number of triad patents*
- w_4 = weight for *the average number of citations received*

Outcomes
The changes in weights result in significant changes in the composition of the top 10 institutes, and cause changes in ranks. This can be explained by the large relative differences in indicator values of the different companies, i.e. looking at figure 6.1 certain institutes score very high on certain indicators (e.g. Trimble Navigation, Accuvein), and very low on others. As a consequence, changes in weights quickly lead to changes in ranks.

Organization name	Rank	RPP	Number of patents	Average citations per patent	Average number of DWPI classes	Number of Triad Patents
Siemens Ag	*1*	1,00	55	2,7	2,8	51
Trimble Navigation Ltd	*2*	0,51	2	25,0	1,5	2
Canon Kk	*3*	0,47	23	1,0	2,4	23
Univ Leland Stanford Junior	*4*	0,45	1	15,0	5,0	1
Accuvein Llc	*5*	0,44	1	0,0	12,0	1
Venous Light Llc	*6*	0,44	1	0,0	12,0	1
Univ Pennsylvania	*7*	0,42	2	16,5	3,0	2
Hewlett-Packard Dev Co Lp	*8*	0,38	5	11,0	3,2	5
Univ Wayne State	*9*	0,37	1	8,0	6,0	1
Gb Solo Ltd	*10*	0,34	1	2,0	8,0	1

Figure 6.1.: Augmented reality; patents; weight set 1,1,1,1

Part 2 In the second part the weights of two indicators are systematically varied, while all other weights remain constant. The changes in ranks of the top-8 institutes are observed. Figures 6.2 and 6.3 display the outcomes.

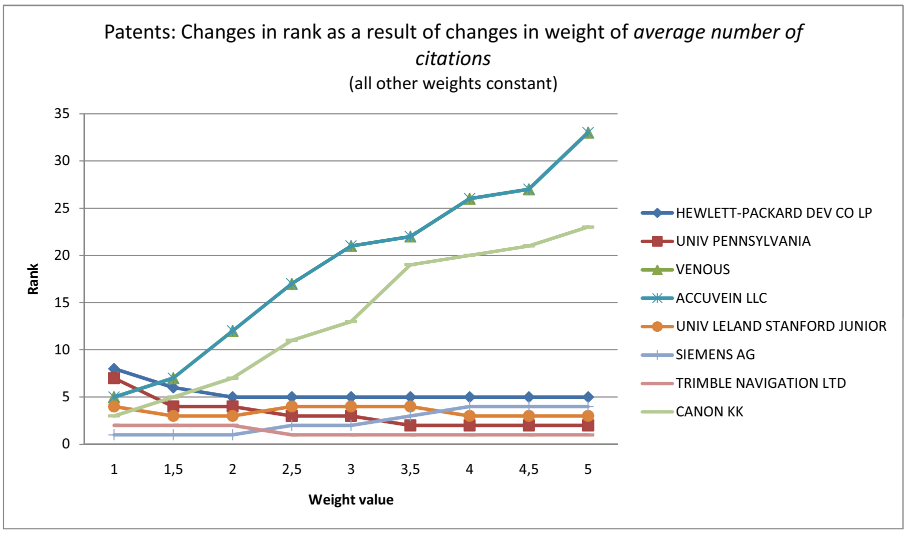


Figure 6.2.: Augmented reality; effects of gradual weight increase for citations on rank

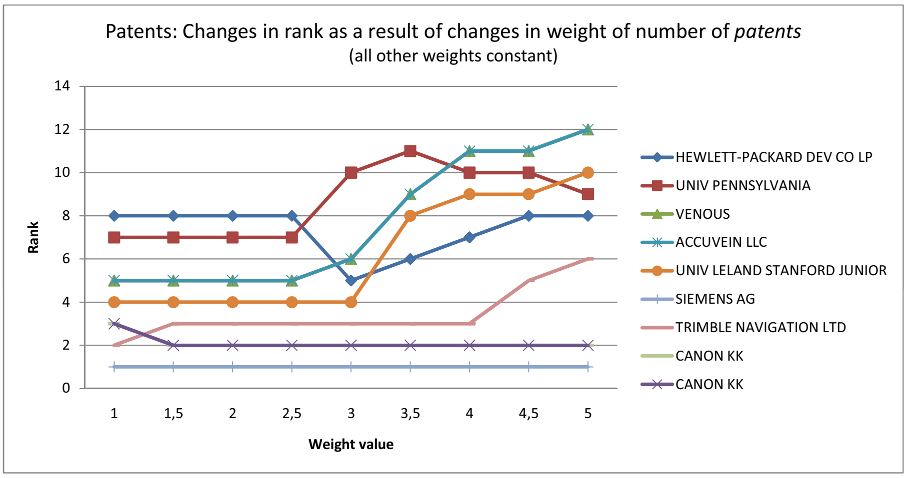


Figure 6.3.: Augmented reality; effects of gradual weight increase for publication on rank

Outcomes
A ranking model insensitive to changes in weights would show 8 parallel lines, with no points exceeding the 8th rank. When changing the weight of citations, the model is relatively robust with the exception of 3 institutes; Venous, Accuvein and Siemens. When changing w_1, lines begin to intersect which means that the 8 institutes' relative positions are changing. The explanation for the model's sensitivity to changes in weights can be explained by the fact that the institutes score very differently on the four different indicators.

6.4.2. Publications

Part 1 The sensitivity analysis carried out for the model based on publications is similar to the patent model, due to the great similarities between the two models.

Similar as for patents, the weight sets are varied and the effect on the institutes in the top 10 list is studied. The weight sets used: [1,1,1,1], [1,1,1,2], [2,1,1,1]and [1,0,0,1].

Where:

- w_1 = weight for *number of articles*
- w_2 = weight for *CPP*
- w_3 = weight for *CPP/JCS*
- w_4 = weight for *CPP/FCS*

Organization name	Rank	Relative Position	Number of Publications	CPP/JCS	CPP/FCS
Imagineer Syst Ltd	*1*	1,00	1	8,3	87,1
Tech Univ Munich	*2*	0,34	30	0,0	1,1
Commissariat Energie Atom	*3*	0,28	1	6,2	2,6
Renault Sas	*4*	0,28	1	6,2	2,6
Univ Paris 05	*5*	0,28	1	6,2	2,6
Cnrs	*6*	0,27	4	1,4	22,4
Univ Oxford	*7*	0,26	4	1,3	21,8
Univ Med Ctr	*8*	0,24	1	3,4	11,9
Univ London Imperial Coll Sci Technol & Med	*9*	0,21	6	0,7	15,6
Natl Univ Singapore	*10*	0,20	18	0,0	0,6

Figure 6.4.: Augmented reality; publications; weight set 1,1,1,1

Outcomes
The random changes in weights results in expected behavior of the model. Changes in ranks take place, especially by those institutes that score high on some indicators and lower on others indicators.

Part 2 This part examines the sensitivity of the model, by systematically changing the weights of one indicator, while all other weight values remain constant. The model is starts off with weight set $w = [1,0,0,1]$ (on the bottom left corner of both figures). Then the weight of the fourth indicator is increased with steps of 0,5 unit, while all other weights remain constant. This test includes the top 8 companies listed. Figure 6.5 depicts the results. The TU-Munich is performing best. Figure 6.6 displays the developments of the ranks, as the weights of indicator CPP/FCS is varied from 1-5, while keeping the value the indicator *number of publications* constant.

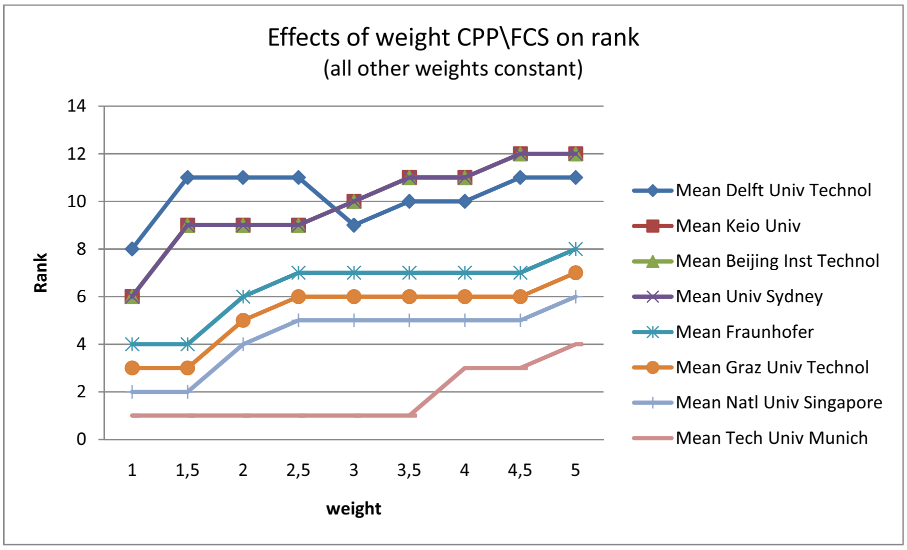


Figure 6.5.: Augmented reality; effects of weight CPP/FCS on rank

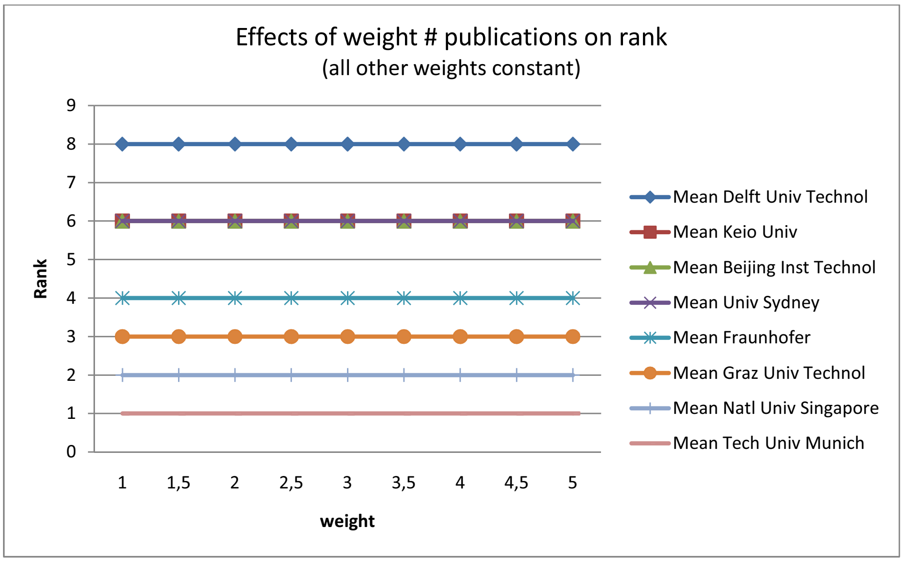


Figure 6.6.: Augmented reality; effects of weight # publications on rank

6.5. Conclusions sensitivity analysis

Both models have shown that changes to important model parameters have not resulted in unexpected behavior. Changes in ranks take place due to the fact that institutes' scores on different indicators vary significantly. Overall it can be concluded that:
Both models, based on patent and based on publication data, have proven sensitive to changes in model parameters. The model which deals with patent data is slightly more sensitive than the model which deals with publication data (i.e. larger effect on outcomes as a result of changes in weights). However the changes in ranks as a result of changes in weights was expected and does not lead to unexpected (extreme) behavior of the model.

The information that served as input to the model is heterogeneous, which means the ranks are relatively easy changed when the relative importance of the indicators changes. This is clearly illustrated by the institutes with only one publication and very high citation rates and institutes with many publications and average citation rates. The heterogeneity can be partly reduced by introducing threshold values (e.g. institutes must have a minimum number of articles). It also raises the question of whether *institutes* can effectively be compared, because of their significant differences in attribute values. One way to deal with the incomparability is to assign institutes with similar characteristics to groups, and then compare the member with each group (Pruyt 2008).

One further point that came to light in this chapter is whether different indicators are *incommensurable*. Commensurable indicators allow for trade offs to be made between them (e.g. cost versus quality of a system or product), for incommensurable indicators this is more difficult (Pruyt 2008) (e.g. number of fatalities versus additional production costs for a car designer). With respect to the model this would mean that it may not be possible to make trade offs between certain indicators. As a result it may not be possible to determine one ranking value.

6.6. Threats to experimental validity

This section discusses the threats to external validity. External validity refers to the extent to which statements can be generalized to other settings.

The TI process and model designs are only partially generalizable Both designs are based on existing theory.

Nevertheless the final designs involve individual choices by the researchers. For the TI process these choices relate to the selection of activities and relations between these activities.

Whereas the functioning of the design has been tested by means of case study, the sample size is not large enough to make solid statements about all of the outcomes. It is safe to say that he design functioned well, but only in the setting studied. Further experimentation with the designs will verify whether the designs indeed function as desired. The current research set up violates has a low statistical power (to few case studies) and violates other assumptions of statistical tests (e.g. the non-random selection of respondents). As a result researchers must be weary of at least two threats to experimental validity:

1. Interaction of selection and treatment. The threat is that people who agree to participate in an experiment may be very different from those that refuse to take part. Therefore the results obtained from the first group may not be generalizable to the latter group (Cook and Campbell 1979). This threat may be manifested when the people involved in the case study are selected because they are already interested in cooperation. Other people may perform much worse.
2. Interaction of setting and treatment. The threat is that results obtained in one setting may not be obtained in other settings (Cook and Campbell 1979). This entails that results obtained within Volkswagen Group research may not apply to other settings, e.g. universities and other organizations.

The functioning of the Di.Ana platform for search query definition

Similar as for the designs, the Di.Ana platform is only tested on a limited number of actors. As a result, the same threats to external validity apply to the testing of Di.Ana with regard to search query definition. It cannot be stated that Di.Ana does not function properly with regard to search query definition, but the opposite is not true either.

The statements regarding agency problems between analyst and specialists cannot be generalized

Agency theory is applied to describe the dyadic relation between client and TI analyst and technology specialist and analyst. The assumptions underlying the application of this theory are stated clearly. Recommendations are formulated to deal with some of the problems that arise as a result of the agency problems. The validity of these statements is not determined through experimentation. Should this be desired then an experiment should be set up to verify whether the recommendations indeed lead to the desired results.

Part III.

Evaluation

7. Reflection

A reflection stands for "a thought, idea, or opinion formed or a remark made as a result of meditation", or "a consideration of some subject matter, idea, or purpose" (Merriam-Webster). In this research project the reflection provides an opportunity to take a step back and briefly formulate some considerations on the research methods, theories and designs used in this thesis. This chapter is organized in two parts: the first part deals with reflection on the *content* of this research, and the second part discussed more *personal* reflections.

7.1. Reflections on content

7.1.1. Research methodology

This thesis starts off with an envisioned end product: a *standardized technology intelligence product*, displayed in a *one–pager* format. Despite the relative simplicity of this product: no more than a piece of paper with —relevant— information printed on it, the complexity of creating such products soon manifests itself. It turns out that in order to create STIPs, processes are needed, actors need to be involved and analytical activities need to take place.

For this reason a research approach is chosen that allows the exploration of the different concepts that constitute technology intelligence, and also the synthesis of these concepts into usable artifacts. A design approach seems most suitable, because this deals with the exploration of a design space (the concepts), but also allows for the possibility to couple useful concepts in order to arrive at a design. Since the formulation of requirements is inherent to the TI processes, this approach will also outline the requirements that a process for creating STIPs must fulfill.

The research methodology deployed in this thesis is based on two generic models: the evolutionary model that recognizes that a complete specification of requirements can often not be obtained at the start of a design activity and therefore advocates the execution of multiple design rounds during which the design is continuously refined based on new insights; and the 'meta-model' for design which provides a more pragmatic approach to the design of complex socio-technical systems. The latter approach stresses the need for requirement definition by users and the development of a *test* to evaluate design options.

The methodology deployed in this thesis combines both models into a new one which is more tailored to the needs of this research project. The definition phase allows for specification of the objectives, demarcation of the research problem and a first problem exploration. The system analysis phase allows the identification of useful concepts and specification of requirements. The organizational setting provides the perfect setting for a case study (the test) and allows for intermediate testing of design elements.

Overall it can be concluded that this research methodology has a good *fit* to the research problem. It also provided a structured way for engaging a problem that was characterized by much uncertainty in the beginning. However the research approach does not fully apply to the design of a process or model.

7.1.2. Reflections on the theories used

This research project does not utilize a single theory but instead multiple theories are used: (a) theory on technology intelligence (b) theory on the conduct of technology intelligence (c) theory on measuring science based on innovation indicators (d) agency theory. The theory on measuring science is discussed in the next section. A reflection on the use of agency theory is discussed in the final section of this first part. With regard to the first two theories it is found that comprehensive theories on ‘technology intelligence’ and the ’technology intelligence processes’ are largely absent. Instead the majority of the theory studied is found in separate domains:

- Methods for knowledge retrieval from data are discussed separately
- Innovation theory is a separate domain
- Policy analysis addresses TI as a method but only as part of a wide array of methods
- The theory of measuring science is discussed in much detail but largely ignores the roles that different actors

This is not to say none of the authors studied have linked theories from various domains: Use of methods has been linked to organizations; TI processes in organizations are described; and the role of actors in the TI process has been discussed. Some authors addressed TI processes and discussed STIPs, yet statements remain rather general and empirical evidence appears to be scarce. It would be interesting to see more linkages between the different elements. This may also make the theory more accessible to business scholars.

This motivates the use of multiple theories in this research project instead of a single comprehensive theory. The benefit —from a research perspective — is the use of multiple theories can complement each other. A downside is that no theory can be exploited in full detail, due to the limited amount of time available for writing the Msc-thesis.

7.1.3. Reflection on the designs

Reflection on the ranking models

Choices made in the development of the ranking models

First a brief description will be given of the choices that led to the ranking models.
The purpose of the ranking models is to evaluate research performance of current and potential research partners based on patents and publications for all technology fields. The initial idea was to assess all of Volkswagens’ research partners (over 600) and determine the performance of these partners in comparison to other research institutes. Furthermore ‘collaboration maps’ are constructed to identify knowledge networks in order to determine whether research partners have access to the right resources (the assumption being that ‘networked’ actors are attractive collaboration partners).

This soon proved to be an impossible task — at least within the available time frame of approximately four months. Furthermore it is concluded that assessing individual research partners based on their overall performance (in all technologies) is less useful since the science and technology landscape appeared to be dominated by an ‘X’ number multinational conglomerates (e.g. Philips, Bosch, Siemens, NXP, Frauenhofer).

Therefore the choice was made to assess research institutes for the different technologies in which they are active (and not ‘science’ in general). Since Volkswagen Research is —at the time of writing— active in approximately 200 technology fields, the research institutes in all of these distinct technology fields need to be investigated.

The ranking models result from the idea that research performance can be measured along different dimensions of indicators. The choice for patent and publications to measure the output of research organizations is largely determined by the availability of access to particular patent and publication databases. Separate ranking models are constructed for patents and publication because it is founds that research institutes perform very different on both: Universities tend to focus more on publications, whereas private research institutes focus more on patents. The ranking criteria —known as indicators— are selected from well-known scholars in the field of bibliometrics and are used for research rankings in many instances.

So what are the consequences of these choices on the final ranking models? First the pathway that leads to these ranking models is paved at a relatively early start. The head of research at Volkswagen initially had the desire to determine ‘whether Volkswagen Research is collaborating with the best in the field’. This is a very complex and difficult tasks since ‘the best’ is a vague notion and can be interpreted in numerous different ways. The choices made in this research project demarcate the notion of 'best' (as a means for treating the complexity) but as a result, only provide one perspective on what distinguishes 'good' performing research institutes from 'moderately' performing research institutes. A second point to be made is that a number of the choices made in the construction of the ranking models such as (a) the use of patents and publications (b) the use of particular indicators, (c) the values of weights, may be perceived as 'subjective' by other scholars because they are the result of individual choices by the researcher.

Conclusions

Based on this one may contest the (scientific) value of these ranking models and claim that they are narrowly focused and based on subjective choices. However, the question is whether a universal definition of the 'best' research institutes can be given and operationalized at all. This seems a very challenging task and a solution seems far away.

The second point relates to the subjectivity of choices made in the development of the ranking model. Again, these choices are necessary because resources are available (patent and publications) or objective indications on the approach to follow are missing:

As van Raan indicated: there is no conclusive theory on 'how' to measure science. Indicators play the central role in ranking models. Indicators measure a particular dimension of science, and the combination of indicators thus provides a picture of performance based on several dimensions. The questions of: 'what are suitable indicators, and what should be the relative importance of indicators?' thus remains. The sensitivity analysis applied on the model used in this research project shows that results can significantly change based on the modelers' choices. Even well known and widely used indicators become 'contested'. This is clearly illustrated by a recent 'attack' (2010) on van Raan's crown indicator by Opthof and Leydesdorff (2010) and van Raan's defense titled: 'Rivals for the crown: Reply to Opthof and Leydesdorff' by (van Raan et al. 2010) as well as (Waltman et al. 2010). The subject of argumentation here is a widely used indicator for measuring research performance.

Completeness of indicators or selection criteria

This research project involves bibliometrics to evaluate research performance. Assuming that the indicators provide a valid representation of the research performance of institutes, then the question remains is whether the 'best' performing research institutes are also suitable research partners for Volkswagen. It is very likely that completely different criteria are considered in the selection of suitable research partners: e.g. access to capital and other resources, possession of relevant knowledge, experience, access to knowledge networks, geographical location, culture and transaction costs. To conclude: bibliometrics indicators provide a limited perspective on choosing suitable research partners. It may be worthwhile to incorporate more of these factors in future versions of the ranking models

Reflection on TI process design

Focus of the process

Other authors have different views on what a 'process' is. Reger (2001) for example describes the TI process as a series of steps and the wider embedding in the organizational setting: his description focuses more on the actors involved in, impacted by and studied by TI, rather than the analytical activities. The process design presented in this research project focuses more on the analytical activities and less on the actors involved. The reason for this is that the exact characteristics of the analytical activities were unknown, and that the focus was mainly on the execution of the TI process.

Nevertheless a focus on the broader context and implications of the TI process would be a valuable addition for the STIP. This research project is aimed at describing one specific TI product but it would be interesting to look at what the impact of a product like the STIP is in a broader organizational context. Specifically this would address questions such as: "What other application for the STIP are possible?" "How does the STIP relate to other TI products?" "How does STIP impact decision making by technology managers" "In which way can STIPs replace or advance current business processes?".

Tradeoff between standardization and flexibility

The TI process deployed in this thesis emphasizes standardization and automation. The benefits of this approach are that the process can be executed fast , and that it can be targeted at a large number of clients. However these benefits arise at the expense of other goals. One disadvantage is that the process is rather 'rigid' opposed to the processes that characterize the production of the traditional forms of TI. This latter process emphasizes repetition, learning, flexibility and continues interaction. It is likely that the majority of questions or issues cannot be answered by STIPs. As a result trade-offs are always necessary depending on the MOT questions at hand.

However, it is not unlikely either that particular questions re-occur within an organization and that a proportion of these question can be answered by STIPs. The ranking of research institutes demonstrated in this research project provides a valid example.

Transparency, constant quality and increased understanding

A frequent complaint by technology specialists at Volkswagen which is experienced while carrying out TI is that the results are not transparent, and therefore lack authority. A first consequence of the STIPs is that both the process and product are highly standardized and therefore it is relatively easy to communicate details about how TI is created to other actors. A second consequence of the standardization of process and product is that the output has a relatively stable quality which enables users to assess the strengths and weakness of the STIPs (Porter and Cunningham 2006). A third consequence of standardization is that the STIP increases the understanding of TI by client, which has a positive impact on the extent to which clients are able to use the products for decision making purposes (de Bruijn and ten Heuvelhof 2004).

7.1.4. Reflection on agency theory

The use of agency theory versus process management

Agency theory is used to depict the relationship between TI analyst and technology specialist. Prior to the selection of this particular theory an actor analysis is carried out to identify the different actors and their relation to TI. This revealed a wide range of actors. Based on this analysis, process management was selected to describe how actors should be coordinated in order to carry out the TI process. This proved a complex task, due the number and diversity of the actors involved. Furthermore it is concluded that most actors had little to do with carrying out the analysis, but were more related to investment and implementation issues. Thirdly it is concluded that only one actor besides the client is truly critical to the actor. Based on this a more suitable theory is used to describe and analyze the relation between analyst and specialist. The major benefit of agency theory over process management is that it can be more pragmatic than process management and that it focuses primary on dual relationships between actors. This simplifies the setting and makes it easier discuss problems and potential solutions to cope with these problems. Process management is considered a better choice in situations with more complexity, and where the entire life cycle of the TI process is considered (i.e. definition, development, deployment in terms of the systems engineering life cycle).

Incorporating the actor side of the TI process

The question can be raised as to why the 'social side' of system should be considered at all. After all a mono–disciplinary perspective would have demarcated the research project much further and would have left more time to study one particular element of this thesis in much more detail than is possible with a multi–disciplinary perspective. This is certainly true. However an important argument deployed in this research project is that the technical system cannot function well (i.e. result in high quality outcomes) without the proper functioning of the social system. By the latter is meant that actors —in this case technology specialists— provide the high quality input that is a necessary part of the analysis. Furthermore the importance of the social system goes much further in that it also impact the usability of TI by clients for enhanced decision making (see e.g. (Porter and Cunningham 2006) and (de Bruijn and ten Heuvelhof 2004)). Therefore it is considered necessary that these perspectives are combined, in order to improve the combination as well as the individual perspectives. This may especially be true in non-academic settings which provide a good basis for collecting empirical evidence.

7.1.5. Reflection on the STIP in comparison to other forms of TI

Other applications for the STIP

The STIPs used in this research project address the ranking of research institutes. Although this may be a reoccurring issue for an organization such as Volkswagen, the aim of this research project was not limited to the development of a STIP for this one issue. Rather the aim is to contribute to the investigation on how STIPs may become an integral part of TI at Volkswagen. This implies that using the design concepts from this thesis and applying those to include other issues and MOT questions.

STIPs do not replace other forms of TI

Both the STIP and the detailed TI product as used by Volkswagen have their respective advantages and disadvantages. For the STIP the major advantage is the standardization and speed, whereas for the traditional forms of TI is the in depth exploration and flexibility. Although both products have their disadvantages it may easier to think of arguments in favor of the detailed TI product than the STIP. Nevertheless it is preliminary to conclude that the traditional TI product is more useful than the STIP because it is difficult to assign an importance to the flexibility of the traditional TI product versus the speed offered by the STIP. Instead the benefits of both products can be emphasized, and both products can coexist parallel.

STIPs complement other forms of TI

STIPs may complement the traditional TI product. It is a well known problem in TI-related methods that technology managers are often unable to express their initial problems to analysts. STIPs may be feasible means for exploring the problem by solving standard questions that characterize the technology field at hand. Based on this characterization of the technology field more elaborate analysis can be carried out. The result is more focus and less redundancy. Secondly lessons may be learned from the STIP. The STIP involves an extreme case of standardization, but there may be intermediate options between the customized detailed TI product and the STIP. It would be interesting to explore whether particular parts of the traditional TI product can be standardized and automated. Recent literature has already worked towards this (see Porter (2005) and Porter and Cunningham (2006).

STIPs are a feasible way for expanding the use of TI within organizations

STIPs provide a feasible means to leverage the scale TI within organization, and increase widespread familiarization for TI. It is also a low-risk means for clients to get familiar with, and experiment with the use of TI without necessitating large investments. Clients who find the STIP interesting can request more detailed TI, whereas clients who find the STIP less interesting can choose to halt further analysis — without major financial investments.

7.1.6. Reflection on other principal–agent relations

The relation between TI analyst and technology specialist is described as a principal agent relationship. The same is done for the relationship between the client and the TI analyst. Other principal–agent settings can be found within the organizational setting.

The client —in this case the head of research— serves as the principal in relation to the TI analyst. But from a larger perspective it can be argued that the head of research fulfills the role of an agent in relation to the board of directors of the Volkswagen Group (in this case the principals). The board tries to delegate the task of say ‘effectively managing research at Volkswagen’ to the head of research. However the board may not be able to fully verify whether the head of research indeed possesses the required knowledge, experience or skills that he may claim to have. As a result the board of directors may select the wrong candidate for the task of leading Group Research (adverse selection). Alternatively the head of research, which is aware that the board cannot fully observe his behavior, may act strategically (moral hazard).

A second example of a principal–agent relationship is experienced when a principal attempts to measure an agents' research performance. Consider the TI analyst as the principal who wants to find the most knowledgeable researcher on say *sulphur lithium cells* —the agent. The principal performs a publication analyses and finds the researchers with most publications on sulphur lithium cells. The principal is aware that the sheer number of publications says nothing about the quality of the research and therefore also considers the number of citations received per publication. One researcher clearly performs best (most publication and most citations) and is invited for an interview. What the analyst does not know is that the researcher benefits from a large number of self citations and citations from his direct peers to positively impact his citation score: i.e. the researchers behaved strategically. Adverse selections arise because the analyst may have invited a different candidate, if he had complete information. In this case adverse selection could have been prevented if the analyst had done better monitoring to reveal the agent's behavior: he could have corrected for self-citations by the author and his peers from the same institute (this has been done in the ranking model for literature for this research project)

For both illustrations the problems are caused by information asymmetry and unobservable behavior. The solution for both illustrations lies in monitoring to reveal the actual behavior of the agent, and closing the information asymmetry between principal and agent. Another aspect these examples share in common is that in both cases the actual behavior of the agent can be revealed by analyzing science and technology information. The other way around it can be reasoned that agents may be aware that the principal is able to monitor their actual behavior and therefore do everything to make sure that principals are not able to so. Relating this latter point to this research project: technology specialist may be hesitant to cooperate in providing analyst with the means to monitor their behavior (i.e. search queries), because this will diminish opportunities for strategic behavior.

This section on principal–agent relations ends by arguing that TI allows for better monitoring of the behavior of agents in principal–agent settings using science and technology information. According to Eisenhardt (1989) monitoring of the agent by the principal will align the interest of the agent more in line with the former. Therefore TI provides a means for coping with agency problems in science and technology settings.

7.2. Personal reflections

Demarcation of the research problem

Since the author was unfamiliar with technology intelligence prior to writing this thesis, the first few months were spent on further exploring the subject and the conduct of TI at Volkswagen Group Research. The need for a STIP became apparent when the head of Group Research expressed the need to assess the research partners with whom Volkswagen is cooperating in over 200 technology fields. Furthermore it became evident that similar projects would be expected in the near future. STIPs were unheard of at this time. Based on these developments the author decided that this STIP would play a central role in his thesis project.

Two important choices were made. The first involved a focus on the process for generating STIPs rather than a focus on the the final product (the STIP). The reason for this is that the process could be re-used for other projects in the future. Thereby the thesis' contribution to Volkswagen would be more valuable. The second choice involved incorporating the actor perspective into the problem. During these first few months and while working on other TI projects, it became clear that multiple actors contribute to, are affected by or influence the conduct of TI. Attitudes towards TI vary and have a resulting positive or negative impact on the outcomes. It was concluded that the actors' side of the problem could not be ignored.

As a consequence of these two choices the thesis does not provide a full and in depth description of the actual ranking of research partners based on indicators. Nevertheless the author had to spend a significant amount of time on 'learning how to conduct TI'. This involved become experienced with searching in patent and publication databases and analyzing of large amounts of textual data using dedicated software. Unfortunately, the results of these efforts cannot fully be reflected in this thesis. Nevertheless the result is that multiple perspectives are combined and the added value lies mainly in combining these perspectives. The added value for Volkswagen is that the results are directly usable (and have been used).

Conducting a research project

Writing this thesis was a great and valuable experience. Of course the best insights became obvious at the end of the thesis. Reading a significant amount of (well written) scientific articles gave insight into the large amounts of work that are needed to write a good article. It definitely contributed to appreciation for other peoples scientific work. Working on this thesis also helped to judge less valuable contributions. In case of a follow–up scientific undertaking at any point in the future, the author will spend more effort on demarcation of the problem at an earlier stage and choose for a different balance between perspectives. Taking into account multiple perspectives appears to be a challenging task within the available amount of time for writing a MSc thesis.

Experience

Writing a thesis for a leading international automobile manufacturer was a fascinating experience. It gave insight into the great complexity which automobile manufacturers face, and particularly those that that own 10 different brands. It was very intriguing to see how these organizations manage this great complexity and prove to be successful despite it. It was equally interesting to contribute to a project that will have a severe impact on the quality of routine decision making by individual researchers.

8. Conclusions and recommendations

8.1. Conclusions

This thesis deals with technology intelligence (TI). TI is the collection, analysis and delivery of relevant information about emerging or existing technologies, for enhancing decision making through the identification of new opportunities and threats as well as the assessment of current performance.

The aim of this thesis is to develop standardized technology intelligence products (STIPs) that can be used for projects that involve a large number of technology fields and for which the current conduct of TI is inadequate. As an illustration this thesis describes a project that involves the appraisal of research institutes in over 200 disparate technology fields at a large automobile manufacturer.

Formally the research question is:

What does a process and what does a model look like, by which standardized technology intelligence products can be created that support decision making with respect to the appraisal of current and new research partners in over 200 disparate technology fields, based on patent- and publication data?

This research project has laid out the theoretical elements of TI, and has identified further elements by studying the conduct of TI at a large technology oriented organization. Furthermore requirements have been identified that are applicable for the design of processes and models that can be used for the production of standardized technology intelligence products. The focus is in particular on upscaling the process.

TI process and model

A design of a TI process and model for the assessment of research institutes in over 200 technology fields has been presented. These designs are based on the theoretical elements of TI which are modified to be applicable for STIPs (rather than other forms of TI). The TI process design is detailed desctiption of the necessary activities and how these activities can be carried out in order to generate STIPs. The model design is used for ranking research performance of institutes based on patent and publication data and are therefore specific to this STIP.

These designs are tested by means of a case study. The case study has demonstrated that it is possible to set up a TI process and models in manner that can significantly reduce the lead time of generating a TI product. Based on the case study it is concluded that it is possible to apply these designs to the remaining technology fields that need to be investigated. Therefore upscaling the TI process has come within reach of the organization. Nevertheless more experiments are needed to demonstrate the feasibility of upscaling the TI process.

Although the overall outcomes of the case studies is positive, additional measures need to be taken in order to improve the quality of search queries defined by technology specialists using the TI platform. The solution may lie in learning technology specialists more on the factors affecting an effective search query.

The model has proven to be suitable for STIPs for ranking research performance. The model is validated by examining the different model parameters and performing a sensitivity analysis. The conclusion is that both models are valid but are sensitive to changes in important model parameters. Furthermore it is concluded that the model does not provide a universal way of measuring science and that its strength lies mainly in providing insight in the different dimension of research performance than an absolute ranking value.

Conclusions with regard to speed and quality of the analysis

The first of the two evaluation criteria states that the STIP should have sufficient speed. This criterion is not operationalized and neither is the actual time to complete both case studies. The speed refers to the fact that the detailed TI product can not be deployed for projects tht involve a large number of technology fields because the required time to execute the analysis would by far exceed the amount of available time. Based on this research project it is concluded that when STIPs replace the detailed TI product for projects that involve a large number of technology fields, then project can be completed within the available amount of time. Hence, STIPs have the required *speed*.
The second criterion refers to quality of the product. Quality is considered high when the output is complete, authoritative, objective and relevant. Furthermore it is argued that the quality of the outcomes are large determined by the input provided by technology specialists. However it cannot be conclusively stated that the outcomes have the desired quality since neither the quality of the outcomes or of the input provided by technology specialists can be measured.

Agency problems

Technology specialists are an essential part of the TI process by contributing technological expertise. However the specialists' willingness to provide this expertise may be lacking. Application of agency theory to the analyst–specialist setting and the client–analyst reveals that reallocation of funds may contribute towards more effective contributions by technology specialists.

8.1.1. Recap of research questions

8.2. Recommendations

8.2.1. Recommendations to Volkswagen

1. *What recommendations can be made to Volkswagen with regard to future use of STIPs?*

The TI process

The TI process design is generic description on how to develop standardized technology intelligence products that can be applied on a large scale. Therefore the same process can also be used to address other issues and questions. The search query definition is a very important activity since this is where technology specialists contribute their knowledge to the process. In case of upscaling the process for each technology field is exactly the same with the exception of the search query. The case study has demonstrated that the process for search query by technology specialists' definition using the TI platform can be further improved. Improved search queries have a positive impact on the quality of the outcomes. The recommendation to improve the search queries are:

- Provide technology specialists with more knowledge on the use of Boolean operators (advanced search operators)
- Make changes to the TI platform so that it provide more accurate feedback on the search queries defined by technology specialists

With respect to the STIP for ranking research performance

A STIP is developed that addresses the ranking of research performance, based on patent and publication information. Although the ranking is based on well known and widely applied (bibliometric) indicators the question remains whether these indicators provide a complete picture of an institutes' performance. Furthermore the models' sensitivity implies that the indicators' relative importance may have a significant effect on the results studied. It is advisable that these aspects are taken into account when interpreting the results. A recommendation that can be immediately implemented is to clearly communicate the assumptions and restrictions of the STIP for ranking research performance.

- Take both the strengths and weaknesses of the STIP into account
- Communicate assumptions and restriction to clients

With respect to the STIP in general

The STIP for ranking research performance provides a clear demonstration. Nevertheless it is only one of the many possible applications for the STIP. It is recommended to further explore other possible applications. Furthermore it is recommended that while exploring new applications analyst follows both an *issue driven* approach as a *method driven approach*. The first approach refers to identifying reoccurring questions or issues and then determining which of these may be solved by a STIP whereas the second approach refers to departing from currently used methods and tools (e.g. bibliometrics) and then identifying questions or issues that correspond to that. The *issue driven* approach seems more promising this is expected to increase the extent to which STIPs are actually going to be used.

- Explore further applications for the STIP
- Follow both an issue driven as well as a method driven approach when identifying new applications for the STIP
- An issue driven approach seems more promising since this is expected to extent the degree to which STIPs are used.

STIP in relation to other TI products at Volkswagen

STIPs and the detailed TI products each have their advantages and disadvantageous. The STIP is a useful asset but only for those issues that can be answered by the STIP. The argument is that STIPs should not be applied in situations where the detailed TI product is more suitable. STIPs can complement other forms of TI. At Volkswagen technology managers and clients are often unable to express their initial problems to analysts. STIPs may be feasible means for exploring the problem by solving standard questions that characterize the technology field at hand. Based on this characterization of the technology field more elaborate analysis can be carried out. The result is more focus and less redundancy.

The STIP involves an extreme case of standardization, but there may be intermediate options between the customized detailed TI product and the STIP. It would be interesting to explore whether particular parts of the detailed TI product can be standardized, automated and reused for different projects. This may lead to a form of TI that lies somewhere between the STIP and the detailed technology product: a TI product that is generated through *building blocks*.

- Use STIPs in addition to the detailed TI products, but only in case the issue can be properly resolved by the STIP.
- Apply STIPs to increase the efficiency of the problem definition phase
- Use concepts from the TI process design to improve the efficiency of the detailed TI product and work towards just-in-time technology analysis

With regard to coordination of technology specialists

It is recommended to change the incentive structure for technology specialists that have technological expertise. At present technology expert receive either no financial compensation or receive a financial compensation directly from the client. It is recommended that the client allocates all funds to the TI analyst, who can then apply these funds to 'purchase' technological expertise. When the outcomes of this transaction does not meet certain standards (e.g. a poor search query), then the specialist is not rewarded for his effort. In this model risk is shared between client and analyst, and specialists have a reason for making valid contribution to the TI process.

- Change the fund allocation model so that technology specialist are rewarded directly by the TI analyst.

Interpretation and utilization

In the current TI process design the interpretation and utilization of outcomes by clients are not considered because this went beyond the scope of this research project. Nevertheless it is worthwhile to get feedback regarding utlization of results by clients since this may help to improve the STIP in the future. Therefore it is recommended to include interpretation and utilization in the future.

8.2.2. Recommendation for future research

Search query definition

Search queries constitute an important aspect of TI because they are the basis for information search in patent and publication databased. With regard to STIPs they are of even greater importance because they constitute the *only* input from technology specialists. Defining and effective search may require a significant investment in time from the technology specialists and TI analyst. Time which can be reduced by using a TI platform as demonstrated in this research project. However the platform does not function perfect yet. Further refinements are necessary so that technology specialist learn how to search and access eaxactly those pieces of information that they are looking for. Emperical research on such systems would increase the understanding of the mechanism that support this learning, and is therefore recommended.

Rankings based on (bibliometric) indicators

Literature on the measurement of science is extensive. However few practical guidelines are available on the selection of suitiable (bibliometric) indicators for a given purpose. Ranking values are obviously sensitive to changes in the relative importance of indicators yet guidelines on how to assign weights to indicators are absent or kept hidden by those selling this information commercially. At the same time financial allocation systems are based on the same systems. Research on these issues would be greatly beneficial to those involved in the appraisal of research performance, or affected by these appraisals.

References

Bahill, A. T. and F. F. Dean (2009). *Handbook of Systems Engineering and Management*, Chapter Discovering System Requirements, S. 205–264. Wiley.

Bekkering, T. and J. Walter (2008). *Management van processen, het realiseren van complexe initiatieven* (5th Aufl.). Spectrum, Utrecht. available in Dutch.

Bots, P. (2007). Design in socio-technical system development: three angles in a common framework. *Journal of Design Research 5*, S. 382–396.

Buede, D. M. (2009). *Handbook of Systems Engineering and Management*, Chapter Functional Analysis, S. 1091–1126. Wiley.

Chang, H., J. Gausemeier, S. Ihmels and C. Wenzelmann (2008). *Trends in intelligent systems and computing engineering*, Chapter Innovative technology management system with bibliometrics in the context of technology intelligence, S. 349–361. Springer Science and Business Media.

Conference Proceedings (2008, Februari). database used. `http://www.thomsoninnovation.com/ti/contentsets/literature/#conference_proceedings`.

Cook, T. D. and D. T. Campbell (1979). *Quasi-experimentation; design and analysis issues for field settings*. Houghton Mifflin.

Current Contents Connect (2010, Februari). database used. `http://www.thomsoninnovation.com/ti/contentsets/literature/#current_contents_connect`.

de Bruijn, H. and A. L. Porter (2004). The Education of a Technology Policy Analyst - to Process Management. *Technology Analysis & Strategic Management 16*(2), S. 261 – 274.

de Bruijn, J. and E. ten Heuvelhof (2004). *Management in Netwerken*. LEMMA, Utrecht.

de Bruin, H. and E. ten Heuvelhof (2002). Policy analysis and decision making in a network: How to improve the quality of the analysis and the impact on decision making. *Impact Assesment and Project Appraisal 20 (4)*(4), S. 232–242(11).

de Man, A. P. and G. Duysters (2005). Collaboration and innovation: a review of the effects of mergers, acquisitions and alliences on innovation. *Technovation 25*, S. 1377–1387.

Dialog Online (2010, May).

Duysters, M. and A. de Man (2003). Transitory alliances: an instrument for surviving turbulent industries? *R&D Management 33*(1), S. 49–58.

DWPI (2008, Februari). patent database used. `http://www.thomsoninnovation.com/ti/contentsets/patents/`.

Eisenhardt, K. M. (1989). Agency Theory: An Assessment and Review. *The Academy of Management Review 14*(1), S. 57–74.

Emery, F. and E. Trist (1960). *Management Sciences: Models and Techniques*, Volume 2, Chapter Socio-technical systems, S. 83–97. London: Pergamon Press.

Enserink, B., J. Koppenjan, W. Thissen, D. Kamps and G. Bekebrede (2004). *Lecture notes SPM2110: Analysis of Complex Environments*. TU Delft. (in Dutch).

Ernst, H. (2003). Patent Information for Strategic Technology Management. *World patent information 25,3*, S. 233–242.

Firat, A. K., W. L. Woon and S. Madnick (2008). Technological Forecasting – A Review. Working paper CISL.

Grady, J. O. (1993). *System Requirements Analysis*. New York: Mc Graw Hill.

Herder, P. and R. Stikkelman (2000). Metamodel for design UPDATEN.

INSPEC (2010, Februari). database used. `http://www.thomsoninnovation.com/ti/contentsets/literature/#inspec`.

Internal document (2009). Department of future research: Futuring at Volkswagen. Presentation.

Jensen, M. C. (2003). *A Theory of the Firm: Governance, Residual Claims, and Organizational Forms*. Massachusetts: Harvard University Press.

Jokic, M. and R. Ball (2006). *Qualität und Quantität wissenschaftlicher Veröffentlichungen – Bibliometrische Aspekte der Wissenschaftskommunikation*. Forschungszentrum Jülich GmbH.

Koppenjan, J. and J. Groenewegen (2005). Institutional design for complex technological systems. *International Journal of Technology, Policy and Management 5*(3), S. 240–257.

Kucz, I. (2010, Februari). Actor interview.

Kunze, C. W. (2000). *Competitive Intelligence: Ein resourcenorientierter Ansatz strategischer Frühaufklärung*. Shaker Verlag.

Levis, A. H. (2009). *Handbook of Systems Engineering and Management*, Chapter System Architectures, S. 479–506. Wiley.

Lichtenthaler, E. (2005). The choice of technology intelligence methods in multinationals: towards a contingency approach. *International Journal of Technology Management 32*(3/4), S. 388–407.

Martin, B. (1995). Foresight in Science and Technology. *Technology Analysis & Strategic Management 7*(2), S. 139–168.

Merriam-Webster.

Michaeli, R. (2006). *Competitive Intelligence: Strategische Wettbewerbsvorteile erzielen durch systematische Konkurrenz-, Markt- und Technologieanalysen*. Springer Berlin.

Minzberg, H. (1983). *Structure in fives: designing effective organizations*. Englewood Cliffs, USA: Prentice Hall Inc, USA.

Moed, H., W. Glänzel and U. Schmoch (2004). *Measuring science: capita selecta of current main issues*. Kluwer Academic Publishers.

Moehrle, M. G. and R. Isenmann (2006). *Technologie-Roadmapping. Zukunftsstrategien für Technologieunternehmen*. Springer Berlin.

Mogee, M. (1993). Educating Innovation Managers: Strategic Issues for Business and Higher Education. *IEEE Transactions on Engineering Management 40-4*, S. 410–417.

Mortara, L., C. Kerr, R. Phaal and D. Probert (2008). Technology Intelligence practice in UK technology-based companies. *International Journal of Technology Management 48, No1*, S. 115–135.

Nan, N. (2008). A principal-agent model for incentive design in knowledge sharing. *Journal of Knowledge Management 12*(3), S. 101–113.

NASA (2007). *NASA Systems Engineering Handbook*. NASA. available one : `http://education.ksc.nasa.gov/esmdspacegrant/Documents/NASA%20SP-2007-6105%20Rev%201%20Final%2031Dec2007.pdf`.

Opthof, T. and L. Leydesdorff (2010). Caveats for the journal and field normalizations in the CWTS (“Leiden”) evaluations of research performance. *Journal of Informetrics (in print)*.

Porter, A. (2007). How “Tech Mining” can enhance R&D Management. *Managers at work*.

Porter, A., W. B. Ashton, G. Clar, J. F. Coates and K. Cuhls (2004). Technology Futures Analysis: Toward Integration Of The Field & New Methods. *Technology Forecasting & Social Change 71*, S. 287–303.

Porter, A. and S. Cunningham (2005). *Tech Mining: Exploiting New Technologies for competitive Advantage*. Wiley Interscience.

Porter, A. and S. Cunningham (2006). Just-in-time technology analysis support. *International Journal of Technology Management 34*(3/4), S. 319–339.

Porter, A., A. Roper, T. Mason, F. Rossini, J. Banks and B. Wiederholt (1991). *Forecasting and Management of Technology*. John Wiley and Sons.

Porter, A. L. (2005). QTIP: Quick Technology Intelligence Processes. *Technological Forecasting & Social Change 72*(9), S. 1070–1081.

Pruyt, E. (2008). *Multi Criteria Decision Analysis: Multi Attribute Decision Making*. Course material SPM4121.

Reger, G. (2001). Technology Foresight in Companies: From an Indicator to a Network and Process Perspective. *Technology Analysis & Strategic Management 13*(4), S. 533–553.

Sage, A. P. and J. E. Armstrong (2002). *Introduction to Systems Engineering*. Wiley-Interscience.

Schilling, M. A. (2008). *Strategic management of technological innovation* (International edition Aufl.). Mc Graw Hill.

Science Citation Index (2010, May).

Shapiro, S. P. (2005). Agency Theory. *Annual Review of Sociology 31*, S. 363–284.

Shavell, S. (1979). Risk sharing and incentives in the principal and agent relationship. *The Bell Journal of Economics 10*, S. 55–73.

Thomson Innovation (2010, Februari). patent field definitions. `http://www.thomsoninnovation.com/tip/support/help/patent_fields.htm`.

Tidd, J., J. Bessant and K. Pavitt (2005). *Managing innovation. Integrating technological, market and organizational change.* (3 Aufl.). John Wiley and Sons, Ltd.

Uertz, G. (2010, Februari). Actor interview.

van Leeuwen, T. (2004). *Handbook of quantitative science and technology research*, Chapter Descriptive versus evaluative bibliometrics. Monitoring and assessing of national R&D systems, S. 373–388. Kluwer Academic Publishers.

van Leeuwen, T., M. Visser, H. Moed, T. Nederhof and A. van Raan (2003). The Holy Grail of science policy: Exploring and combining bibliometric tools in search of scientific excellence. *Scientometrics 57(2)*, S. 257–280.

van Raan, A. (2004). *Handbook of quantitative science and technology research*, Chapter Measuring science. Capita selecta of current main issues, S. 19–50. Kluwer Academic Publishers.

van Raan, A. and E. Noyons (2002). Discovery of patterns of scientific and technological development and knowledge transfer. In: *Gaining Insight from Research information.*

van Raan, A. F., T. N. van Leeuwen, M. S. Visser, N. J. van Eck, and L. Waltman (2010). Rivals for the crown: Reply to Opthof and Leydesdorff. *Centre for Science and Technology Studies, Leiden University, The Netherlands*.

van Raan, F. (2003). The use of bibliometric analysis in research performance assesment and monitoring of interdisciplinary scientific developments. *Technology Assessment -Theory and Practice 1,12*, S. 20–29.

Volkswagen Konzern (2009). Volkswagen AG Geschäftsbericht 2008.

Walde, P. (2008). DI.ANA: A digital intelligence service to support strategic decisions based on textual data - a report on 5 years of development and application experience at a global OEM. *Internal document*.

Walde, P. (2009). Interview regarding current conduct of TI at Volkswagen.

Walde, P. (2010, Februari). Actor interview.

Waltman, L., N. J. van Eck, T. N. van Leeuwen, M. S. Visser and A. F. van Raan (2010). Towards a new crown indicator: Some theoretical considerations. *Centre for Science and Technology Studies, Leiden University, The Netherlands*.

Web of Science (2010, Februari). data base used. `http://www.thomsoninnovation.com/ti/contentsets/literature/#web_of_science`.

Wehringer, J. (2010, Februari). Actor interview.

Williamson, O. E. (1975). *Markets and Hierarchies.* New York: The Free Press.

Williamson, O. E. (1996). *The Mechanisms of Governance.* New York: Oxford University Press.

Yang, H.-L. and T. C. Wu (2008). Knowledge sharing in an organization. *Technological Forecasting & Social Change 75*, S. 1128–1156.

Young, H. (1983). *The American Library Association Glossary of Library and Information Science*. American Library Association.

Part IV.

Appendices

A. Detailed TI

A.1. The detailed technology intelligence product

Every detailed technology intelligence product is custom, and so is the *process* of arriving at the final product. There is no formal description of this process, and therefore it will be described using the three general phases *definition, analysis, choice* presented in figure 2.3. In real practice these phases are not explicitly mentioned and the boundary between these phases is blurry.

In the *definition* phase the problem is defined, demarcated and the data (to be analyzed) is retrieved. These are essential steps in TI and thus in line with figure 2.3. The project starts of with a technology specialist, or technology manager who has a certain question, or issue that he would like to see resolved. This problem is broadly formulated and the technology field is demarcated through the definition of a search query. Data is retrieved (type of data depends on the issue at hand) and basic analysis is performed. Several iterations are usually needed to arrive at suitable search query.

The *analysis phase* is aimed at providing an answer to the clients' questions. Once results have been achieved the client is consulted to determine whether his question is answered and whether all items are present. Usually this is not the case after which the problem definition, search query definition, data retrieval and analysis are repeated. In some cases, this cycle is conducted several times before the client is satisfied or the project is postponed to a later point in time.

The *choice* phase consists of presentation, interpretation and utilization of the results by the client. The results are usually presented in a presentation containing the most significant conclusion regarding the question. Interpretation is done by the analyst. The transfer from the analyst to the client is, in many cases, done not by the analyst but by the department leader. No information is available on utilization of the results by the client. As a consequence of this absence of feedback it is difficult for Di.Ana to adjust TI based on client feedback.

- ➢ The process should minimize the number of large feedback loops, especially those from the *analysis* and *choice* phases back to *problem definition*.

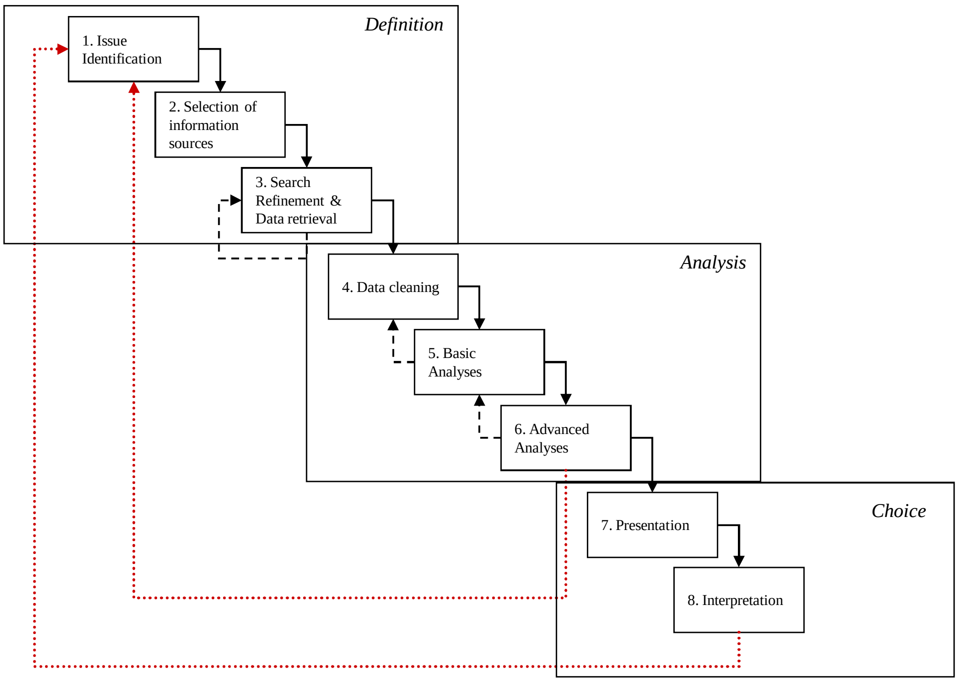


Figure A.1.: The current TI process. source: own work

B. Background

B.1. Defining technology intelligence

To prevent confusion, this section will set a clear definition for *technology intelligence*. There appears to be no clear definition for 'technology intelligence'. Multiple definitions can be found and synonyms include; 'technology futures analyses', 'technology foresight', 'technology assessment', and 'tech-mining' (Lichtenhaler 2005).
Technology futures analyses is defined as 'any systematic process to produce judgments about emerging technology characteristics, development pathways, and potential impacts of technology in the future'(Porter et al. 2004). This definition covers the broad technology foresight and assessment studies carried out in the public sector and the technology forecasting and intelligence studies in the private sector. Hence, the definition is rather broad.

Technology foresight is a term used by Martin (1995) a to describe a process of 'systematically looking at future developments in science, technology, the economy and society in order to identify areas of strategic interest and emerging generic technologies that may potentially yield the highest economic and social benefits in the future'. Martin explicitly states looking into the future (rather than for example examining current technology fields) and the focus seems to be on the identification of emerging technologies at the earliest stage possible.

Two other authors Reger (2001) and (Lichtenthaler 2005) independently studied how multinational firms in different industry sectors (i.e. pharmaceutical, automotive, telecommunication and electronic industries) deal with the issue of foresight in relation to technologies. Reger (2001) acknowledges that no common term is used for technology intelligence (he uses 'technology foresight') which he defines as: 'the systematic recognition and observation of new technologies ('weak signals') or existing technologies, the evaluation of their potential and their importance for the competitiveness of the company, and the storing and diffusion of information'. Note that this definition reflects the actual behavior of companies (private organizations) opposed to both the public and private industries that the prior definitions address.

Lichtenthaler (2005) provides a comprehensive definition: 'to exploit potential opportunities and to defend the firm against potential threats by a prompt delivery of relevant information about technological trends in the environment of the company. Technology intelligence encompasses the activities related to the *collection*, *analysis* and *communication* of relevant information on technological trends to support technological and more general decisions of the company. According to this definition technology intelligence includes the observation and analysis of individual competitors as well as universities and start-up companies'. This definition, although rather lengthy, is useful for a number of reasons: First of all it refers to the purpose of carrying out the activity: decision-making. Secondly, it is relevant for the type of activities carried out by actors in the private industry. Thirdly it focuses on the observation and analysis of relevant actors with relation to a certain technology.

The main characteristics of the definitions found are; they focus on technology characteristics; to enrich decision making regarding strategic or tactical issues; by systematic exploitation of information resources, and to derive relevant knowledge from this. This thesis uses the following definition of technology intelligence, with a focus on decision making: *Technology intelligence is the collection, analysis and delivery of relevant information about emerging or existing technologies, for enhancing decision making through the identification of new opportunities and threats as well as the assessment of current performance.* This definition is line with those of other authors (Mortara et al. (2008), Lichtenthaler (2005), and Reger (2001). For a comprehensive review of definitions the reader is referred to Lichtenthaler (2005)).

Implications for the STIP

This definition of technology intelligence applies to all TI products, ranging from detailed technology analyses to STIPs. This definition denotes that the focus of TI is on the technological domain(opposed to political, environmental and other domains), involves both the present and the future, and aims to enhance decision making.

B.2. Technology assessment

Technology assessment involves the analyses of emerging technologies and their implications. Technology assessment is used for decision making by institutes at various levels ranging from international (e.g. the European Union) to organizational (e.g. Volkswagen AG). The overall aim is to enrich decision making regarding issues such as (Porter et al. 2004), (Firat, Woon and Madnick 2008), (Porter and Cunningham 2005):

- Prioritization and allocation of R&D expenditures by organizations.
- Managing the risks of innovation
- The planning of new products
- Strategic decisions on mergers, alliances with other organization and the licensing, acquisition of technology and so forth.
- Research funding decisions from different sources: industry, government, education, nonprofit and cross national institutes

B.3. R&D alliances

Management of Volkswagen Research want to assess research performance of current and potentially new research partners. Mergers and acquisitions as well as strategic alliances are well known as means for firms to enter new markets and achieving economics of scale and scope. In the environment of increasing competitive pressure, rising costs of R&D in combination with decreasing technology life cycles, strategic alliances between organizations have become an important means for managing to coping with technological change (de Man and Duysters 2005). There are several key motives for organization to seek inter-organizational alliances in order to stimulate technological innovation (de Man and Duysters 2005):

1. Alliances can ease transactional and contractual differences between organizations (Williamson 1975).
2. When conducting large research projects the risk of failure is reduced
3. Innovation is increased through alliances because complementary because integration introduced complementary knowledge.
4. Alliances may reduce lead times of technologies, which offers significant competitive advantage.
5. Alliances enable firms to scan the technological environment for promising new technologies and weak signals (Duysters and de Man 2003). This allows organizations, from a research perspective, to put ‘many eggs and in many baskets’.

C. Models

The meta–model for design

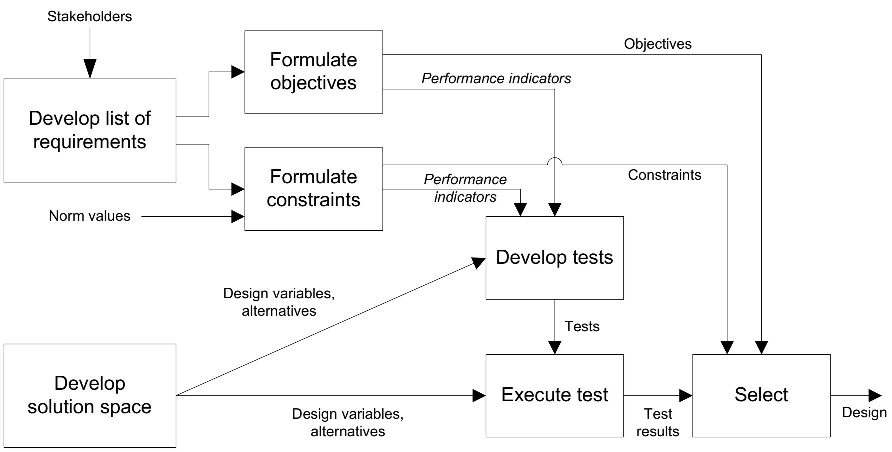


Figure C.1.: The meta model for design, source: Herder and Stikkelman (2000)

Relating the TI elements

This chapter has introduced the 4 key elements of technology intelligence. These elements will form part of the TI process and model for the STIP. As this chapter has revealed, the specific characteristics of the STIP put constraints on these elements (denoted by the [≻]). In other words, the specific characteristics of the STIP, determine the characteristics of it's elements. But the elements also affect each other. Based on the analysis it is possible to depict how these elements relate to each other. A framework for TI products is presented in C.2. The issue is found on the left. The issue determines the MOT question(s) (see (Porter 2005)). These question(s) can be addressed with one or multiple method(s). The question and method determine the information sources to be used. The methods specify the exact fields within these methods to be used. The framework may also start from the method(s), i.e. the available methods determine the questions that can be answered (Porter, Ashton, Clar, Coates and Cuhls 2004), and the issues to be addressed. This argument is supported by Lichtenthaler (2005) who has shown that the choice of methods does not solely depend on the questions to be answered 2.5. Starting from the methods and then identifying possible question has some consequences for the STIP. The characteristics of the STIP place particular restriction on the methods used and therefore limit the amount of questions that can be adressedd by STIP. However it is worthwhile to identify what other questions —besides the one adressed in this research project— can be adressed. Technology managers and decision makers can then select suitable questions from those identified, rather than the other way around.

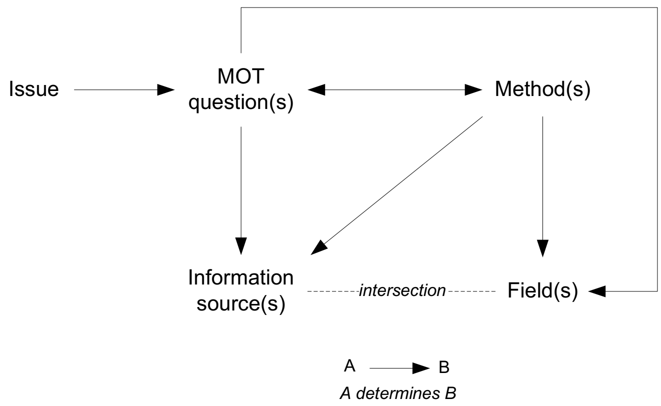


Figure C.2.: A framework for issue or method driven TI. Source: own work.

D. Minzbergs' 5 basic configurations

D.1. Minzbergs' 5 basic configurations

The first section provides a quick glance at Minzbergs' (Minzberg 1983) five configurations for the structure of an organization. These configurations are then used to describe the organizational context of the TI process at company level; divisional level; department level. Finally the implications of this environment for the coordination of technology specialists by TI analysts; the TI project definition; and the use of TI for decision making are discussed.

In his popular book 'Organizational Structures', Minzberg (1983) presents five basic configurations of structures that organizations can have. These structures are archetypes, in reality combinations of different structures may founds. These structures provide an introduction to describing the organizational structure of Volkswagen AG. From this description it is then possible to derive control mechanisms and the implications for managing the Technology Intelligence process. The five basic configurations are:

- The simple structure characterized by strong centralized power and absence of formal organizational structure and formalized work processes. Often this structure is headed by a single person, with a large span of control, while the rest of the structure consists of an organic structured work force that can be flexibly rearranged, often by the head. Decision making is done at the very top and since the authority is centralized at the very top, decision making is very flexible, intuitive, non-analytical and often based on personal opinion of the strategic head (Minzberg 1983)
- The machine bureaucracy. The major characteristics of this structure are the standardization of work processes; strict formalized procedures for workers; the abundance of rules, regulations and formalized communication; and the importance of the production units. There is a strong emphasis on controlling the organization. Decision making authority is done relatively central by and extensive management structure with a strong distinction between line and staff.
- The professional bureaucracy is essentially a bureaucratic organization which is not centralized. The work done is complicated and therefore those executing it have a decision making authority. The output of their work however is predictable and relatively constant and can therefore be coordinated through a mechanism that allows for both standardization and decentralization: the standardization of tasks. Decentralized decision making power entails that workers work closely with their clients, with absence of mutual adjustments between co-workers and direct supervision. Examples are the surgeon operating a patient, the teacher in a classroom. In addition to the democratic, bottom up way in which professionals are managed, there is often a
- The divisional structure consists of different parts (divisions) of the organization that function as semi-autonomous organizations. These divisions are controlled by the strategic head. The different divisions usually focus on different markets. Most power lies with the divisional managers (centralized power) and performance of the key indicators is controlled by headquarters. The major control mechanism is the standardization of output.
- The adhocracy consists of a very organic structure with little to no formalized behavior. This structure is often necessitated by the need for advanced innovation that is created through flexible, multidisciplinary project teams. Most members of the adhocracy are high educated individuals and their output cannot be standardized because this would lead to standardization, not innovation. These teams are lead by managers or project leaders who are often experts themselves. The decision making authority is equally distributed

among all levels of the organization, and is related to the type of decisions.

E. Organizational structures

E.1. Organizational structures in the environment of the TI process

Level 1: The Volkswagen Group
The Volkswagen Group consists of two divisions: the Automotive Division which includes 9 different car brands; and the Financial Service Division. The automobile division is responsible for the development of cars and engines, the production and sales of passenger cars, commercials vehicles, trucks and buses, and the production and sales of genuine car parts. The Financial Service Division includes dealer and customer financing, leasing, banking and insurance activities, and fleet management (Annual report Volkswagen AG 2009). In general the entire Group has divisional structure.

The automotive division includes 9 different brands (divisions), and further divisions that represent Volkswagen activities in other business areas. With a focus on the production and development of automobiles, there are branches for the different car brands as well as several branches for activities that influence the other branches (e.g. administrative offices, research, development, consulting services etc). Volkswagen Research is one of these branches, which serve all brands. Nevertheless, the individual brands conduct research within their own divisions.

Level 2: Volkswagen Group Research
Volkswagen Group Research conducts research in a diversity of technologies. It is directly controlled by the board member of the entire Group Research. A the highest level, Group Research is split into 8 different main technology fields ranging from transmission, car electronics to virtual technologies. The department of Future Research is as this same level. At the second level 5 main technology fields each have in 2-5 sub technology fields. At the third level, 2 sub technology fields are further divided into 5 sub sub technology fields. At fourth level, the third level fields each have another 3-7 technology fields. The structure describes the formal structure of Research.

In addition to the formal structure, project teams are formed that focus on a particular topic or aspect of a technology. Projects often consist of several (multidisciplinary) team members. In 2008 there were around 200 different projects (based on internal documents: Hochschulkooperation). Each project has a leader, who is part of one of the 7 first level technology fields (excluding Future Research).

The organizational structure of Volkswagen Research cannot be described using just one of Minzbergs' configurations. The formal structure resembles that of a professional bureaucracy: the majority of employees are high educated, skilled professionals and decision making regarding the daily work are is made by the specialists themselves. The head of research and the leaders of the 8 first level technology fields formulate the broad 'research strategy' and control important measurable (financial) parameters. The bureaucratic character also entails that there are strict guidelines for new policies, e.g. the employment of new personnel; new investments in software and licenses; etc.

However, there are elements that do not fit the professional bureaucracy: The first is the inability to standardize work processes, since research is unstructured and innovation cannot be achieved through standardized work processes (Minzberg 1983). The structure of the multidisciplinary project teams resembles that of adhocracies: organic, informal structures and multidisciplinary project teams that are led by technology specialists. The second mismatch lies in the power that management has over the professional. In a professional bureaucracy management is mainly there to ensure the functioning of the entire system, so that the professionals are able to perform their jobs. Strategy is formulated mainly by the professionals. At Volkswagen Research, management (head of research and 8 first level managers) are not solely responsible for ensuring that the system runs smoothly, but have a strong influence on the substance or topics on which the individual specialists work. This resembles the first configuration that was discussed: the simple structure.

Level 3: Department of Future Research & TI team

Department of Future Research, and Technology Intelligence. This department has 20 employees. Technology intelligence has around 4 full-time employees. The overall department resembles that of a simple structure. There are no formal organizational structures or work processes in place. Decision making is often intuitive and based on personal opinion of the department manager. The four sub-departments (called teams) however, operate relatively autonomous on how they carry out these projects. The TI department, the main focus here, works relatively autonomous and resembles the structure of an adhocracy. There are strong elements of the simple structure however, in that new projects are often initiated top down by the department leader. The TI department does no frequently interact with clients.

Conclusions

Volkswagen is a very large company has a large number of organizational structures. Volkswagen Research is formally characterized by multiple configurations including the professional bureaucracy, the adhocracy and elements of the simple structure. The TI department itself is characterized by the simple structure and adhocracy.

F. Protocol analyses

F.1. Augmented reality

F.1.1. Patents

Search refinement - step 3(a)

Initial search query definition by technology specialist The initial search queries to describe the technology fields, are defined by the technology specialists. This is done using the TI-platform (4.2). For augmented reality, multiple search queries were defined to describe different sub-technologies of augmented reality (see F.1 - F.6). These sub-technologies are:

- Visualization for research and marketing
- Augmented reality for planning, production and service
- Functional protection of vehicle design concepts

Findings and altered search queries The search queries shown in F.1 to F.6 are not of sufficient quality. Two, F.2 and F.3 yield a very large amount of patents (2637 and 75000 patents respectively) but are largely unrelated to the TF at hand. Queries F.4, F.5 and F.6 yield fewer records (263, 0 and 68 patents respectively), but most are irrelevant nevertheless. Only F.1 yields good results (71 patents). A closer look a the search queries reveals the following problems and potential causes, see F.7. This table is bij no means a conclusive list of problems and causes - for that a more elaborate study would need to be conducted - but is does point out that a good search query depends on a lot of factors.

Based on the results the search queries yielded, it was decided to reformulate a search query that does yield good results. The term “augmented reality” yields more useful results (by judgement of the analyst, not the specialists). Plurals and German spelling (augmentierte Realität) are considered. The final search query is defined as “augment* ADJ realit*”. More advanced search criteria are: look in *either* title, abstract, first claim, and manual code (all DWPI data). The considered period is from 01-01-2004 to present (requirement). For the detailed search criteria, see F.8.

The title fields shows the title of the patent in english, formulated by DWPI specialists. The abstract describes the content of the patent. The DWPI abstract is the enhanced abstract prepared by the DWPI editorial team (Thomson Innovation 2010). This rewritten abstract corrects for strategic behavior of the patent applicant. A patent applicant may have reasons to minimize the risk of others finding the patent, while ensuring the rights nevertheless. A DWPI patent claim is the precise legal definition of the invention, identifying the specific elements of the invention for which the inventor is claiming rights and seeking protection. The information in the claims of a patent is what determines what rights the patent holder has. In other words, if an inventor wants to protect specific element of his invention, that element needs to be included in the claims. source:

Table F.1.: Search query: Visualization for research and marketing (1)

((spectral rendering) OR (btf) OR brdf OR (projection on arbitrary surfaces) OR (realtime raytracing))

Table F.2.: Search query: Visualization for research and marketing (2)

((markerless AR natural feature ADJ tracking) OR (tracking OR (augmented ADJ reality))) AND (((cell OR mobile) ADJ (phone* OR telephon*)) OR phone OR symbian OR android OR pda)

Table F.3.: Search query: Visualization for research and marketing (3)

augmented reality OR mixed reality OR spatial augmented reality OR projection based augmented reality OR head mounted displays OR hmd OR mobile displays OR head worn display OR mobile projectors OR tracking OR markerless tracking OR large area tracking OR motion capturing OR optical see through

Table F.4.: Search query: Augmented reality for planning, production and service

digitale fabrik OR digital factory OR fabrikplanung OR factory planning OR soll/ist vergleich OR variance comparison OR planungsworkshop OR stoerkantenanalyse OR werkerfuehrung OR worker guidance OR fahrzeugservice OR car service OR worker assistance

Table F.5.: Search query: Functional protection of vehicle design concepts (1)

(head mounted displays OR HMD OR tracking of users OR tracking of hand OR force feedback OR tactile feedback OR caves) AND ("virtual reality" OR "virtual environments") size perception AND ((HMD OR "head mounted display" OR "head worn display" OR CAVE) OR immersive)

Table F.6.: Search query: Functional protection of vehicle design concepts (2)

realtime simulation flexible objects OR realtime simulation rigid bodies OR natural grasping OR display calibration

Table F.7.: Problems and possible casuses for poor search queries

Problem	Possible causes
Query yields to few results, while more should be expected	Query is too narrow (too many concepts, too precise)
	No use of advanced operators
	Errors in syntax and operators (e.g. '?' or * symbols)
	Errors in Boolean algebra
	Plurals absent
	Synonyms missing
	Wrong language
Query yields results, but irrelevant	Query is too broad (to few concepts, too broad)
	Errors in Boolean algebra
	No use of advanced operators

Table F.8.: Search criteria: Augmented reality (patents)

Field	Search query
Title	augment* ADJ realit*
Abstract	augment* ADJ realit*
First claim	augment* ADJ realit*
DWPI manual code	T01-J40C
Application date	01-01-2004 to 26-11-2009 (current)
Data collection: Enhanced patent data from DWPI. 496 patents found	

Data retrieval - step 3(b)

The results yielded by the search criteria (F.8) need to be downloaded from the Thomson Innovation database. Before this can is done a choice needs to be made regarding what fields of the record are needed. What fields are needed depends on the research question and the analysis methods used. Also there is an incetive to reduce the number of fields: a smaller datafile is easier to overlook and makes downloading faster. In this case all 'DWPI fields' are retrieved. See F.10 for what such a patent record looks like. In case of 500 of patents, 500 hundred of these records are downloaded. The benefit of DWPI fields is that they are in suitable structure, this requires less data cleaning and makes mining easier.

Table F.9.: Search criteria: Augmented reality (literature

Field	Search query
All text fields	augment* ADJ realit*
Abstract	augment* ADJ realit*
Period: 01-01-2004 to 26-11-2009 (current) Data collection: Web of Science, Conference Proceedings and Current Contents Connect.	

Table F.10.: Retrieved patent fields

Field	Explanation
DWPI Accession Number	Identifier, every patent has unique number.
DWPI Title	Title written by DWPI experts to decribe the invention.
DWPI Inventor	Link patents to inventors, technologies to inventors, identification of networks.
DWPI Assignee	The holder of the rights, in this case the universities and research labs.
DWPI Assignee Code	Code that is available for certain institutes.
DWPI Class	Shows technology class, according to DWPI classification.
DWPI Family Members	A set of patents filed with different patent authorities that refer to the same invention.
Priority Date	The date when the patent was filed.
Priority Number	A patent application number regarding the priority it claims.
Count of Citing Patents	Patents which a patent refers to.
Count of Cited Refs	Pantents citing the patent at hand.
Patent Abstract - DWPI	Concise description of what the patent is referring to. Based on the original abstract and (re)-written in English.
DWPI Manual Codes	Detailed DWPI classication system, more detail than DWPI class.
IPC	International Patent Classification code to which the patent is assigned.
Current ECLA	European Patent Office Classification code to which the patent is assigned.
US Class	US Patent Classification code to which the patent is assigned.

based on: (Thomson Innovation 2010)

Data cleaning - step 4

Data is cleaned using Vantapoint 5.0 software. The choice of this package is motivated by two factors: a) availability of a license at Volkswagen b) relatively easy to use for non-programmers. Basic knowledge of regular expressions however, is needed for proper cleaning. In this case cleaning consisted of:

- Removing duplicate records
- Reformat data. Data needs to be reformatted to be able to use in the different software packages (Vantagepoint and Excel). See figure F.10 and the field 'Inventor - DWPI', ABAD F,,,, — BENDAHAN R,,,, — BOUGNOUX,,,,—. The — symbol means (natural language) 'and'. Since Vantagepoint and Excel to not recognize this, it is necessary to reformat the data to ABAD F, BENDAHAN R, BOUGNOUX so that the software packages indeed recognize that there are different authors. the ',,,,' need to be removed too. Similar cleaning is needed for author fields.
- Perform fuzzy match two combine multiple fields that have the same meaning. For example company names as 'Volkswagen AG' are matched with 'Volkswagen'.

Basic and advanced analysis - step 5

Once the records are cleaned, the data is ready for analysis. This is done as follows: first Vantagepoint is used to created lists and matrices. Next, these are exported to a spreadsheet model made with Excel 2003. Using the input of Vantagepoint this model calculates indicator values and ranks research institutes. The following lists and matrices were generated with Vantagepoint: First a co-occurence matrix is constructed displaying which organizations hold which patents F.1.1. In this case the 'DWPI accession number is used as unique identifier for each patent. In this case that was possible since every patent had a unique DWPI accession number (this is not always the case however). Second a co-occurence matrix is constructed to calculate the average number of DWPI classes per patent, issued by a certain organization F.1.1. A third co-occurence matrix is used to determine the average number of

DWPI Accession Number	# Records	Assignee Code - DWPI (individuals sep) (Cleaned)	1	2	3	4	5	6	7	8
		# Records	1	1	1	1	1	1	1	1
		Show Values >= 1 Cooccurrence # of Records	1997272334	2009Q65667	2009Q23078	2009Q12265	2009P81961	2009P56018	2009P27938	2009P21710
1	168	Individuals	0	1	1	0	0	0	0	0
2	55	SIEI|C|SIEMENS AG	0	0	0	0	0	0	0	0
3	23	CANO|C|CANON KK	0	0	0	0	0	0	0	0
4	11	ETRI|C|ELECTRONICS&TELECOM RES INST	0	0	0	0	0	0	0	0
5	11	MICT|C|MICROSOFT CORP	0	0	0	0	0	0	0	0
6	11	VOLS|C|VOLKSWAGEN AG	0	0	0	0	0	0	1	0
7	10	INFO|N|INFORMATION DECISION TECHNOLOGIES LLC	0	0	0	0	0	0	0	0
8	10	GWAN|N|GWANGJU INST SCI&TECHNOLOGY	0	0	0	0	0	0	0	0
9	7	KOEL|N|KOREA ELECTRONICS & TELECOM RES INST	0	0	0	0	0	0	0	0
10	7	BRAC|C|BRACCO IMAGING SPA	0	0	0	0	0	0	0	0
11	7	META|N|METAIO GMBH	0	0	0	0	0	0	0	0

Figure F.1.: Assignee DWPI X DWPI accession number

citations that patents of a certain organization receives F.1.1. A forth matrix is used to determine what fraction of an organization's patents is TRIAD. This forth matric actually requires two matrices as input: a) co-occurence matrix 'DWPI accession number' X 'DWPI family members' and b) A matrix 'assignee DWPI' X DWPI accession number'. Multiplying these matrices yields a new matrix which shows which TRIAD patents are held by which organization. Finally, all of these matrices are used to calculate indicator values, see F.1.1.

Reset		Assignee Code - DWPI (individuals sep) (Cleaned)	1	2	3	4	5	6		
		# Records	416	215	123	106	69	63	Number of DWPI classes	Average amount of DWPI classes per patent
DWPI Class	# Records	Show Values >= 1 Cooccurrence # of Records	T01 E	W04 E	T04 E	P85 N	S05 E	W01 E		
66	1	ACCT|C|ACCENTURE GLOBAL SERVICES GMBH	1			1			3	3
139	1	ACCU|N|ACCUVEIN LLC	1	1			1		12	12
156	1	ACHI|N|ACHILLION PHARM INC				1			3	3
159	1	ADVI|N|ADVANCED VISION TECHNOLOGIES INC							3	3
58	2	ALLM|C|ABB RES LTD	2			1			4	2
85	1	AMBX|N|AMBX UK LTD	1						2	2
138	1	ANON|C|ANONYMOUS							3	3
27	3	ARCS|N|ARC SECOND INC					1		7	2,333333
163	1	ARMU|N|ARMUSEMENT AS	1	1	1				4	4
157	1	ARPA|N|ARPA SOLUTIONS SL	1		1				2	2
154	1	ASAO|C|ASAHI OPTICAL CO LTD	1	1			1		7	7
178	1	ASAO|C|PENTAX CORP	1	1			1		7	7
59	2	ASCE|N|ASCENSION TECH CORP	2		1	1	2		12	6
19	5	AUGM|N|AUGMENTED SOLUTIONS GMBH	5	2	1	1			12	2,4
71	1	AUTO|N|AUTODESK INC	1						1	1
25	3	BAYM|C|BAYERISCHE MOTOREN WERKE AG	3						6	2
131	1	BEIJ|N|BEIJING VR VISION TECH CO LTD	1	1	1				3	3
127	1	BENQ|C|BENQ MOBILE GMBH&CO OHG	1	1				1	3	3
124	1	BIWE|C|BIOSENSE WEBSTER INC	1		1		1		4	4
119	1	BLUE|N|BLUE BELT TECHNOLOGIES INC	1			1	1		3	3
9	7	BRAC|C|BRACCO IMAGING SPA	6	3			7		25	3,571429
112	1	BRBC|C|BRITISH BROADCASTING CORP		1					2	2
107	1	CALA|N|CALABRIAN HIGH TECH SRL					1		5	5
103	1	CANA|C|NAT RES COUNCIL CANADA	1	1	1			1	5	5
2	23	CANO|C|CANON KK	23	11	5	4	1		55	2,391304
149	1	CNDR|C|CONSIGLIO NAZ DELLE RICERCHE	1	1					2	2

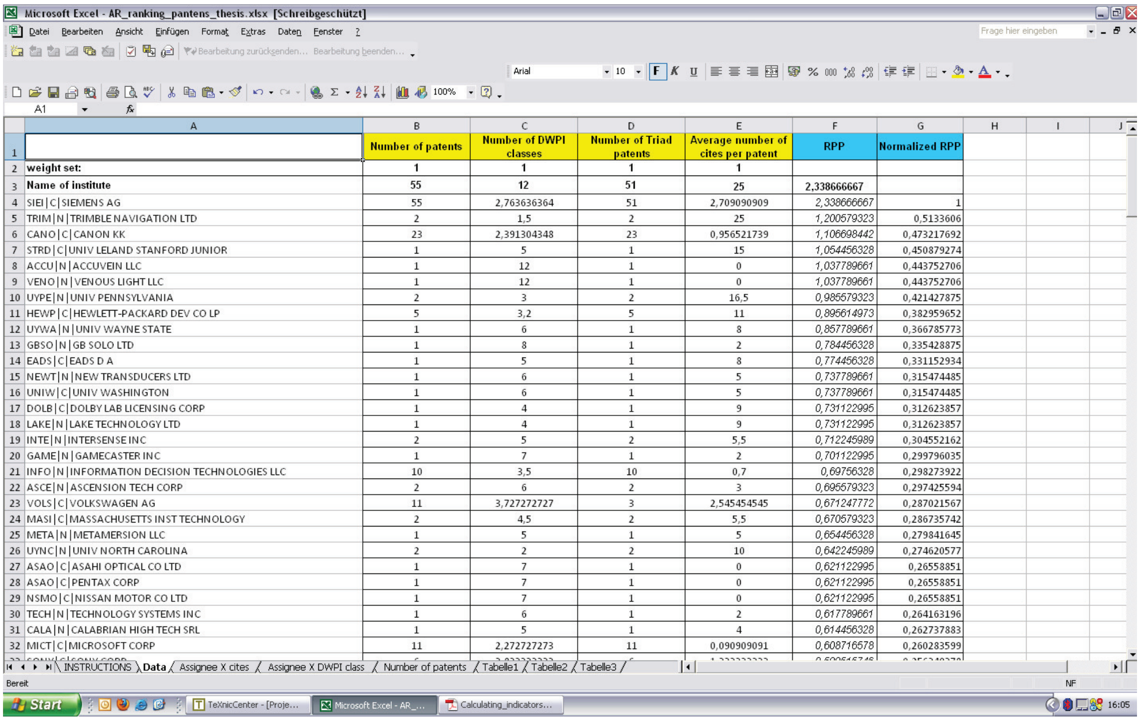
Figure F.2.: Average number of DWPI classes per organization

Reset		Assignee Code - DWPI (individuals sep) (Cleaned)	1	2	3	4	21	22		
		# Records	129	68	33	25	1	1	Total cites	Average number of cites
Count of Citing Patents	# Records	Show Values >= 1 Cooccurrence # of Records	0	1	2	3	18	47		
1	55	SIEI|C|SIEMENS AG	18	10	3	6	1		52	0,9454545
8	7	KOEL|N|KOREA ELECTRONICS & TELECOM RES INST		1	2	1			8	1,1428571
5	11	VOLS|C|VOLKSWAGEN AG	3	3	2				7	0,6363636
9	7	BRAC|C|BRACCO IMAGING SPA	4	1	1	1			6	0,8571429
3	11	ETRI|C|ELECTRONICS&TELECOM RES INST	4	3		1			6	0,5454545
21	4	UYFL|N|UNIV CENT FLORIDA		1	1	1			6	1,5
2	23	CANO|C|CANON KK	4	5					5	0,2173913
14	5	INTT|C|ITT MFG ENTERPRISES INC	1	2	1				4	0,8
23	4	OYNO|C|NOKIA CORP		2	1				4	1
156	1	ACHI|N|ACHILLION PHARM INC				1			3	3
58	2	ALLM|C|ABB RES LTD				1			3	1,5
19	5	AUGM|N|AUGMENTED SOLUTIONS GMBH	2	1	1				3	0,6
41	2	INTE|N|INTERSENSE INC				1			3	1,5
166	1	LOCK|C|LOCKHEED MARTIN MS2				1			3	3
52	2	MIOC|C|MINOLTA CAMERA KK		1	1				3	1,5
13	6	NITE|C|NIPPON TELEGRAPH & TELEPHONE CORP				1			3	0,5
79	1	REAC|N|REACTRIX SYSTEMS				1			3	3
68	1	SILV|N|SILVERBROOK RES PTY LTD				1			3	3
193	1	TRIS|N|TRISEN SYSTEMS INC				1			3	3
44	2	ZENI|N|ZENITH ENTERTAINMENT COMPUTING INC				1			3	1,5
119	1	BLUE|N|BLUE BELT TECHNOLOGIES INC			1				2	2
190	1	DISN|N|DISNEY ENTERPRISES INC			1				2	2
161	1	ENER|N|ENERGID TECHNOLOGIES			1				2	2
101	1	FTWT|N|FTW FORSCHUNGSZENTRUM TELEKOMMUNIKATION			1				2	2
152	1	GAME|N|GAMECASTER INC			1				2	2
151	1	GBSO|N|GB SOLO LTD			1				2	2
62	2	HRLH|N|HRL LAB LLC		2					2	1
6	10	INFO|N|INFORMATION DECISION TECHNOLOGIES LLC	7	2					2	0,2
10	7	META|N|METAIO GMBH	5	2					2	0,2857143
53	2	MITQ|C|MITSUBISHI ELECTRIC CORP	1		1				2	1
17	5	OLYU|C|OLYMPUS OPTICAL CO LTD			1				2	0,4

Figure F.3.: Calculating cites

DWPI Family Members (1)	# Records	DWPI Accession Number Show Values >= 1 Cooccurrence # of Records	USA	WIPO (PCT)	Japan	European Patent Office	WIPO	Triad?	Triad patent? (1=yes, 0=no)
1	1	1997272334	1	1			1	0	1
2	1	2009Q65667	1				0	0	0
3	1	2009Q23078	1	1			1	0	1
4	1	2009Q12265					0	0	0
5	1	2009P81961			1		0	0	0
6	1	2009P56018	1	1			1	0	1
7	1	2009P27938					0	0	0
8	1	2009P21710					0	0	0
9	1	2009P21062		1	1		1	0	1
10	1	2009P16742	1				0	0	0
11	1	2009N90453	1	1			1	0	1
12	1	2009N73154					0	0	0
13	1	2009N71617		1			1	0	1
14	1	2009N70185	1	1			1	0	1
15	1	2009N62860			1		0	0	0
16	1	2009N55230					0	0	0

Figure F.4.: Number of triad patents



	A	B	C	D	E	F	G
1		Number of patents	Number of DWPI classes	Number of Triad patents	Average number of cites per patent	RPP	Normalized RPP
2	weight set:	1	1	1	1		
3	Name of institute	55	12	51	25	2,338666667	
4	SIEI|C|SIEMENS AG	55	2,763636364	51	2,709090909	2,338666667	1
5	TRIM|N|TRIMBLE NAVIGATION LTD	2	1,5	2	25	1,200579323	0,5133606
6	CANO|C|CANON KK	23	2,391304348	23	0,956521739	1,106698442	0,473217692
7	STRD|C|UNIV LELAND STANFORD JUNIOR	1	5	1	15	1,054456328	0,450879274
8	ACCU|N|ACCUVEIN LLC	1	12	1	0	1,037789661	0,443752706
9	VENO|N|VENOUS LIGHT LLC	1	12	1	0	1,037789661	0,443752706
10	UYPE|N|UNIV PENNSYLVANIA	2	3	2	16,5	0,985579323	0,421427875
11	HEWP|C|HEWLETT-PACKARD DEV CO LP	5	3,2	5	11	0,895614973	0,382959652
12	UYWA|N|UNIV WAYNE STATE	1	6	1	8	0,857789661	0,366785773
13	GBSO|N|GB SOLO LTD	1	8	1	2	0,784456328	0,335428875
14	EADS|C|EADS D A	1	5	1	8	0,774456328	0,331152934
15	NEWT|N|NEW TRANSDUCERS LTD	1	6	1	5	0,737789661	0,315474485
16	UNIW|C|UNIV WASHINGTON	1	6	1	5	0,737789661	0,315474485
17	DOLB|C|DOLBY LAB LICENSING CORP	1	4	1	9	0,731122995	0,312623857
18	LAKE|N|LAKE TECHNOLOGY LTD	1	4	1	9	0,731122995	0,312623857
19	INTE|N|INTERSENSE INC	2	5	2	5,5	0,712245989	0,304552162
20	GAME|N|GAMECASTER INC	1	7	1	2	0,701122995	0,299796035
21	INFO|N|INFORMATION DECISION TECHNOLOGIES LLC	10	3,5	10	0,7	0,69756328	0,298273922
22	ASCE|N|ASCENSION TECH CORP	2	6	2	3	0,695579323	0,297425594
23	VOLS|C|VOLKSWAGEN AG	11	3,727272727	3	2,545454545	0,671247772	0,287021567
24	MASI|C|MASSACHUSETTS INST TECHNOLOGY	2	4,5	2	5,5	0,670579323	0,286735742
25	META|N|METAMERSION LLC	1	5	1	5	0,654456328	0,279841645
26	UYNC|N|UNIV NORTH CAROLINA	2	2	2	10	0,642245989	0,274620577
27	ASAO|C|ASAHI OPTICAL CO LTD	1	7	1	0	0,621122995	0,26558851
28	ASAO|C|PENTAX CORP	1	7	1	0	0,621122995	0,26558851
29	NSMO|C|NISSAN MOTOR CO LTD	1	7	1	0	0,621122995	0,26558851
30	TECH|N|TECHNOLOGY SYSTEMS INC	1	6	1	2	0,617789661	0,264163196
31	CALA|N|CALABRIAN HIGH TECH SRL	1	5	1	4	0,614456328	0,262737883
32	MICT|C|MICROSOFT CORP	11	2,272727273	11	0,090909091	0,608716578	0,260283599

Figure F.5.: Screenshot of model to calculate indicator values and rank research institutes

DWPI Accession Number	2009P21710
Title - DWPI	Maneuver assistant for detecting and preventing collision to park e.g. automobile, has monitor or screen for displaying augmented reality image formed by superposition of image of ego-vehicle on selected anterior image
Inventor - DWPI	ABAD F,,,, | BENDAHAN R,,,, | BOUGNOUX S,,,, | VESTRI C,,,, | WYBO S,,,,
Assignee - DWPI	IMRA EURO SAS,,,,
Assignee Code - DWPI	IMRA|N|IMRA EURO SAS
DWPI Class	T01 E | X22 E
DWPI Family Members	FR2929196A1
Priority Date	31.03.2008
Priority Number	FR20081770A
Count of Citing Patents	0
Count of Cited Refs - Patent	3
Abstract - DWPI	The assistant has a selection unit selecting an anterior image e.g. departure anterior image, taken by a camera (3), stored in a memory. Positioning units position an image of ego-vehicle obtained from a pre-stored model with respect to the anterior image selected by comparing an actual position of a vehicle e.g. motor vehicle (1), provided by an odometric device (4) with determined position of the vehicle when taking the selected anterior image. A monitor or screen (6) displays an augmented reality image formed by superposition of the image of the ego-vehicle on the selected anterior image. An INDEPENDENT CLAIM is also included for a maneuver assistant method for a vehicle. Maneuver assistant for detecting and preventing collision to park a vehicle or ego-vehicle e.g. motor vehicle i.e. automobile. The monitor displays the augmented reality image formed by superposition of the image of the ego-vehicle on the selected anterior image, thus displaying the non-visual information directly accessible for the driver in a manner to allow the driver to view all the visible and invisible obstacles with respect to the vehic
DWPI Manual Codes	T01-J07D1 | T01-J40C | X22-E09A | X22-J05
IPC - Current	B60Q000126 | B60Q000148
ECLA	B60R000100 | B62D001502H2
US Class	

Figure F.6.: Example patent record

G. Stakeholders

Based on interviews held in Februari 2010 with analysts at Technological Foresight: Wehringer (2010), Kucz (2010), Uertz (2010) and Walde (2010).

Table G.1.: Stakeholder goals, interests and perceptions

Stakeholder	Goal	Interest	Perception
Principal	N.A.	Initiator of TI; client	Future research can answer those question that traditional research methods cannot [3]
Future research department (K-EFZ)	Provide foresight for successful automotive R&D and thus to stimulate innovations' (internal document)	Executer of TI	T.I. is an essential part of foresight
Research departments	Perform technology foresight by their own means. [1]	Are the main clients, customers for TI [1] [2]	Perception varies strongly from very positive to very negative. [1]
	Reassure own research approach (e.g. wind tunnelling of project design) [2]	Role of technology expert [2]	Stakeholders are specialized in their own field, not always positive about interference by non topic experts. [1]
	Detect potential weaknesses in own projects [2]	May be affected by the outcomes of TI [2][3][4]	'Not invented here', analyst know nothing about 'drive trains' , no technology experts [2]
	Strengthen argumentation line (towards superiors and other stakeholders) [2]		Fear of being measured; quantified in numbers [2]
	Invest minimum time and money on TI [2]		TI is in-house expertise, therefore attractive [2] Some find that TI is irrelevant, useless to them [2]
Individual technology specialists	*same as research departments*	*same as research departments*	*same as research departments*
	To develop knowledge monopoly to strengthen own position within organization [1]		Cooperating in the TI process allows specialists to learn new tools and techniques; allows for networking opportunities with other organizational member [3]

Table G.2.: Stakeholder goals, interests and perceptions (continued)

Stakeholder	Goal	Interest	Perception
Individual technology specialists (continued)	Limit the amount of additional work (organizational structure does not offer incentives to expand work task) [1]		Unwilling to cooperate, because this is not rewarded by superiors [1][2]
Head of research	To make more informed decision based on facts	Client	TI is an important asset in strategic decision making
			TI is a nice tool, but not the only the interesting tool
Head of department	Expand own influence within organization	Responsible for quality of output TI	TI is a useful asset for future research, how it is executed is of less concern
	Controlling budget (limiting personnel being hired)	Active role in transfer of TI to other departments	
		Responsible for project acquisition [2][3][4]	
External information providers	Collect and store information and sell access to this information	Information brokers	Support text- and data mining of databases
	Maintain competitive position as information providers		Uncertain what their perception is towards reselling information
External technology specialists	Customer satisfaction	Provide on-demand technology analyses	Compete with internal analysts
	Continuity of business		
Other potential clients: i.e. Auto-Uni, Marketing department, Development department	May want to use TI in the future	Potential clients	Not aware of what TI is, no clear expectations

Table G.3.: Stakeholder resources, replaceability, dependency, criticality

Stakeholder	Major resources	Replaceability	Dependency	Criticality
Principal	Client Can affect reputation	No	High	Yes
Future research department (K-EFZ)	Personal networks Methodological expertise Experience in multidisciplinary engagement Close lines to research leader, senior management High impact of work	No	High	Yes
Research departments	Technical know-how; expertise [1][2] Choice to use technology intelligence or not (in case of push) [1] Can help achieve bigger impact on other units through own network [2] Have networks, access to other experts, decision makers, external suppliers [2] Gain knowledge in TF [2]	No	High	Yes
Individual technology specialists	*Same as research departments*	No	High	Yes

Table G.4.: Stakeholder resources, replaceability, dependency, criticality (continued)

Stakeholder	Major resources	Replaceability	Dependency	Criticality
Head of research	Formal decision making power Important client of TI Strong influence on research departments, technology specialists	No	High	Yes
Head of department	Formal decision making power Brings in new projects	No	High	Yes
External information providers	Provide commercial access to information databases, which TI exploits	Yes	No	Low
External technology specialists	Provide know-how to specific questions	Yes	No	Low
Other potential clients: i.e. Auto-Uni, Marketing department, Development department	Potential clients	Yes	Low	Yes

H. Verification

Table H.1.: Verification of requirements

Requirement identified for the TI process:	*Satisfied?* (☑☐☒)	*Motivation*
STIPs address predefined MOT questions	☑	The control of the first activity (A1) specifies (a) predefined MOT question(s).
One STIP addresses one or several predefined MOT question(s)	☑	idem
STIPs use fixed information sources to answer the MOT question(s)	☑	The control of activity two (A2) specifies predefined information sources
STIP use predefined record types (e.g. patents or publications) and fields (part of a record)	☑	The control of activity two (A2) specifies predefined record types and fields.
STIPs are created through a systematic process	☑	The entire process and the activities are specified and can be followed according to procedure.
The activities in this process are specified and defined	☑	All necessary activities have been specified
The process defines *when* interaction takes place with actors	☑	Interaction with technology specialists and clients is indicated
The process states *who* this interaction is with, and *what* it is about	☑	The actor is specified and it is indicated during what activity they interact
STIPs are created through standardized procedures and (partial) automation of tasks.	☑	Procedures are developed. Automation plays an important role, especially during data cleaning
The activities *issue identification* and *selection of information sources* are predefined	☑	The first two activities are considered 'fixed'
The procedure for defining search queries is predefined	☑	Search queries are defined using a TI-platform at Volkswagen: DI.ANA
Data cleaning is standardized	☑	Because of predefined questions, information sources, and specification of types and fields, the data cleaning process is standardized and automated.
The process minimizes the number of large feedback loops, especially those from the *analysis* and *choice* phases back to *problem definition*	☑☐	Because of predefined issues and standardization of the other activities, the process is more linear. An exception is 'search query definition'.
The TI process for STIPs uses the TI platform (DI.ANA) for the purpose of search query definition	☑	DI.ANA is used for the definition of search queries

Table H.2.: Verification of requirements (2)

Requirements identified for the methods and general requirements	*Satisfied?* (☑☐☒)	*Motivation*
Basic and advanced analysis is standardized	☑	Analysis is conducted using the models. The output, input, procedures and tools are standardized
The methods are normative	☑	The perceived goal is clear at the start
The methods can be classified as 'hard' and dealing with quantitative data	☑	The methods deal with purely quantitative data as input. The method itself — the model — can be classified as hard
The methods involve no additional actors besides the TI analyst	☑	The method to not require additional involvement of actors
The methods can be executed within the time, personnel and financial restrictions	☑	The models are developed in–house, using available software packages, information sources and tools. The methods can be executed significantly faster than other forms of TI
The indicators are suitable for analysis of the question(s)	☑	The indicators address the question
The calculation of the indicators can be standardized and to large extent automated	☑	The indicators are incorporated into the models
The indicators are unbiased	☑	The indicators do not (dis)favor particular institutes
The indicators are transparent to those that use them	☑	The model which includes the indicators is developed for the purpose of this research project. The model is fully transparent (white box)
There are multiple indicators	☑	Four indicators are used for patent and publications
The data resources to calculate the indicator values are available	☑	The data resources are available through a company license with Thomson Innovation
Presentation of outcomes is standardized	☑	The presentation of outcomes is done using a standardized *one pager design*
The STIP is in line with the general mission of strategic foresight and technological forecasting	☑	The STIP contributes to foresight. This particular STIP is used for the assessment of research partners. Others STIPs can address issues of foresight
Technology specialists are the main actors	☑	Technology specialists are the only actors —besides the initial problem definition by the client— who are involved in the STIP
TI analysts should recognize the challenges that arise while coordinating technology specialists	☑	These issue have been discussed
The coordination mechanisms may not negatively impact the quality of the input provided	☐	Several recommendations have been formulated, but it is still uncertain whether these have the intended effect

I. Validation of models

Setup
This section aims to investigate the sensitivity of the model by making changes to critical model parameters. Three types of critical model parameters can be distinguished;

1. The formulas that are used to calculate the indicator values
2. The set of indicators
3. The relative importance that has been assigned to the indicators (weights)

The first type addresses the calculation of the indicators that have been retrieved from literature on patent and publication analyses. These indicators have been widely discussed in literature and are widely adopted. It is not the aim of this research to validate these indicators. The second type of model parameters refers to the set of indicators that has been selected in chapter 2, based on the requirements for the STIP. Literature provides no indications on the perfect set of indicators to 'measure science' but does point towards several requirements (see section 2.7.2). The third type of parameters refers to the relative importance of indicators. The relative importance is expressed with weights.

I.1. Patents

This section explores the sensitivity of the model to systematic variation of the weights.
The sensitivity analysis is carried out in two parts: In the first part the weight sets are varied and the effect on the institutes' rank is studied by examining changes in the composition of the top-10 institutes. In the second part the focus is on two major indicators; the number of publications and the CPP/FCS (van Raan's crown indicator). In this part the weights of one indicator are systematically varied, while all other indicators remain constant.

Methods
The sensitivity analysis uses the actual data that is also used to construct the rankings. The sensitivity of the model is tested by making changes to the weight parameters. The Excel add-in RiskSim 2.30 is used to study the effect on the *rank* when changing the values of two non-random inputs (the weights).

This chapter is organized as follows. First the sensitivity of the model involving patents will be studied. In the following section the same will be done for the model based on scientific publication. Then in the final section conclusions are formulated regarding the validity of both models.

The model for patents uses four indicators with and a corresponding weight set $w = [w_1,w_2,w_3,w_4]$.

- w_1 = weight for *number of patents*
- w_2 = weight for *average number of DWPI classes*
- w_3 = weight for *number of triad patents*
- w_4 = weight for *the average number of citations received*

I.1.1. Part 1: varying weight sets

Before varying the weights the current rank consists off the list displayed in figure I.1 (w = [1,1,1,1]). The majority of institutes that are listed appear to score high on one or two of the indicators, and relatively low on the two other indicators. An extreme example is Accuvein, which has published just one patent in 12 different patent classes but is listed in the top–10 anyway.
In the next step the weight set is changed to w = [2,1,1,1]. Some new institutes are added which benefit from the increased importance of the number of publications, see figure I.2. Weight set [1,1,1,2] adds three new institutes to the list and results in changes in ranks (figure I.3) (as compared to figure I.1). Finally, increasing the importance of citations, the weight set w = [1,2,1,1] results in a new list, different than the results in figure I.1) and again with changes in ranks, see figure I.4.

Conclusion
The changes in weights result in significant changes in the composition of the top 10 institutes, and cause changes in ranks. This can be explained by the large relative differences in indicator values of the different companies, i.e. looking at figure I.2: certain institutes score very high on certain indicators (e.g. Trimble Navigation, Accuvein), and very low on others. As a consequence, changes in weights quickly lead to changes in ranks.

Organization name	Rank	RPP	Number of patents	Average citations per patent	Average number of DWPI classes	Number of Triad Patents
Siemens Ag	*1*	1,00	55	2,7	2,8	51
Trimble Navigation Ltd	*2*	0,51	2	25,0	1,5	2
Canon Kk	*3*	0,47	23	1,0	2,4	23
Univ Leland Stanford Junior	*4*	0,45	1	15,0	5,0	1
Accuvein Llc	*5*	0,44	1	0,0	12,0	1
Venous Light Llc	*6*	0,44	1	0,0	12,0	1
Univ Pennsylvania	*7*	0,42	2	16,5	3,0	2
Hewlett-Packard Dev Co Lp	*8*	0,38	5	11,0	3,2	5
Univ Wayne State	*9*	0,37	1	8,0	6,0	1
Gb Solo Ltd	*10*	0,34	1	2,0	8,0	1

Figure I.1.: Augmented reality; patents; weight set 1,1,1,1

Organization name	Rank	RPP	Number of patents	Average citations per patent	Average number of DWPI classes	Number of Triad Patents
Siemens Ag	*1*	1,00	55	2,7	2,8	51
Accuvein Llc	*2*	0,79	1	0,0	12,0	1
Venous Light Llc	*3*	0,79	1	0,0	12,0	1
Univ Leland Stanford Junior	*4*	0,57	1	15,0	5,0	1
Gb Solo Ltd	*5*	0,56	1	2,0	8,0	1
Univ Wayne State	*6*	0,53	1	8,0	6,0	1
Trimble Navigation Ltd	*7*	0,52	2	25,0	1,5	2
Canon Kk	*8*	0,51	23	1,0	2,4	23
Gamecaster Inc	*9*	0,50	1	2,0	7,0	1
New Transducers Ltd	*10*	0,48	1	5,0	6,0	1

Figure I.2.: Augmented reality; patents; weight set 1,1,1,2

Organization name	Rank	RPP	Number of patents	Average citations per patent	Average number of DWPI classes	Number of Triad Patents
Siemens Ag	*1*	1,00	55	2,7	2,8	51
Trimble Navigation Ltd	*2*	0,90	2	25,0	1,5	2
Univ Leland Stanford Junior	*3*	0,68	1	15,0	5,0	1
Univ Pennsylvania	*4*	0,67	2	16,5	3,0	2
Hewlett-Packard Dev Co Lp	*5*	0,55	5	11,0	3,2	5
Univ Wayne State	*6*	0,48	1	8,0	6,0	1
Canon Kk	*7*	0,47	23	1,0	2,4	23
Eads D A	*8*	0,45	1	8,0	5,0	1
Dolby Lab Licensing Corp	*9*	0,45	1	9,0	4,0	1
Lake Technology Ltd	*10*	0,45	1	9,0	4,0	1

Figure I.3.: Augmented reality; patents; weight set 1,2,1,1

Organization name	Rank	RPP	Number of patents	Average citations per patent	Average number of DWPI classes	Number of Triad Patents
Siemens Ag	*1*	1,00	55	2,7	2,8	51
Canon Kk	*2*	0,46	23	1,0	2,4	23
Trimble Navigation Ltd	*3*	0,37	2	25,0	1,5	2
Univ Leland Stanford Junior	*4*	0,32	1	15,0	5,0	1
Accuvein Llc	*5*	0,32	1	0,0	12,0	1
Venous Light Llc	*6*	0,32	1	0,0	12,0	1
Univ Pennsylvania	*7*	0,31	2	16,5	3,0	2
Hewlett-Packard Dev Co Lp	*8*	0,30	5	11,0	3,2	5
Information Decision Technologies Llc	*9*	0,26	10	0,7	3,5	10
Univ Wayne State	*10*	0,26	1	8,0	6,0	1

Figure I.4.: Augmented reality; patents; weight set 2,1,1,1

I.1.2. Part 2: gradual changes of weights

The first part shows that changes in the weights result in changes in the top 10. This part examines the sensitivity of the model, by systematically changing the weights of one indicator, while all other weight values remain constant. The first analysis is conducted to see what happens to the rank of an institute when changes are made to two of the four indicators. Siemens AG is taken as an example. Two weights (w_1 and w_4) are changed gradually to produce table I.5. The rank of Siemens AG changes only when w_4 had three times the value of all other indicators. This is expected since institutes with high citation rates benefit from the large relative importance of this indicator.

SIEMENS AG		Weight: Average number of cites per patent								
		1,00	1,50	2,00	2,5	3,00	3,5	4,00	4,5	5,00
Weight: Number of patents	1,00	1	1	1	2	2	3	4	4	4
	1,5	1	1	1	1	2	2	2	3	4
	2,00	1	1	1	1	1	2	2	2	2
	2,5	1	1	1	1	1	1	2	2	2
	3,00	1	1	1	1	1	1	1	2	2
	3,5	1	1	1	1	1	1	1	1	2
	4,00	1	1	1	1	1	1	1	1	1
	4,5	1	1	1	1	1	1	1	1	1
	5,00	1	1	1	1	1	1	1	1	1

Figure I.5.: Augmented reality; effects of weight changes on rank Siemens AG

The second sensitivity analysis examines the ranks of the eight leading institutes, displayed in figure I.1, when gradual changes are made to one weight while keeping all other weights equal. The first

The model is starts off with weights set [1,1,1,1] (bottom left corner). Then w_4 is increased with steps of 0,5 unit, while all other weights remain constant. Figure I.6 displays the developments of the ranks, as the w_4 is varied from 1-5, while keeping all other weights constant. Figure I.7 displays the development of the ranks, as the w_1 is increased from 1-5, while keeping all other weights constant.

Conclusions
A ranking model insensitive to changes in weights would show 8 parallel lines, with no points exceeding the 8th rank. When changing the weight of citations, the model is relatively robust with the exception of 3 institutes; Venous, Accuvein and Siemens. When changing w_1, lines begin to intersect which means that the 8 institutes' relative positions are changing. The explanation for the model's sensitivity to changes in weights can be found in their heterogeneity[1]: the institutes score very different on the different 4 indicators, see figures I.1–I.4. Introducing a threshold value for say, number of patents would be a first step towards getting more robust results since this would reduce part of the heterogeneity.

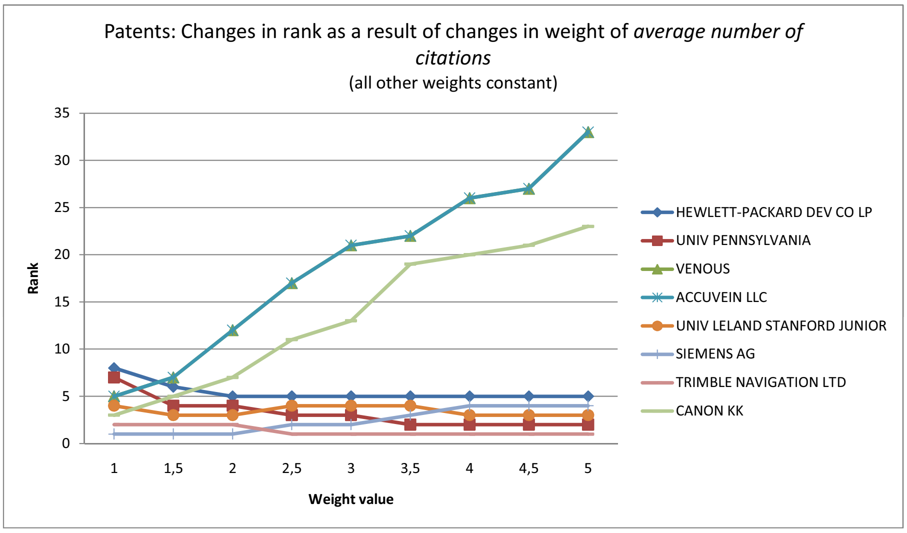


Figure I.6.: Augmented reality; effects of gradual weight increase for citations on rank

[1]heterogeneity expresses that objects or systems that have multiple attributes, have a large number of structural variations

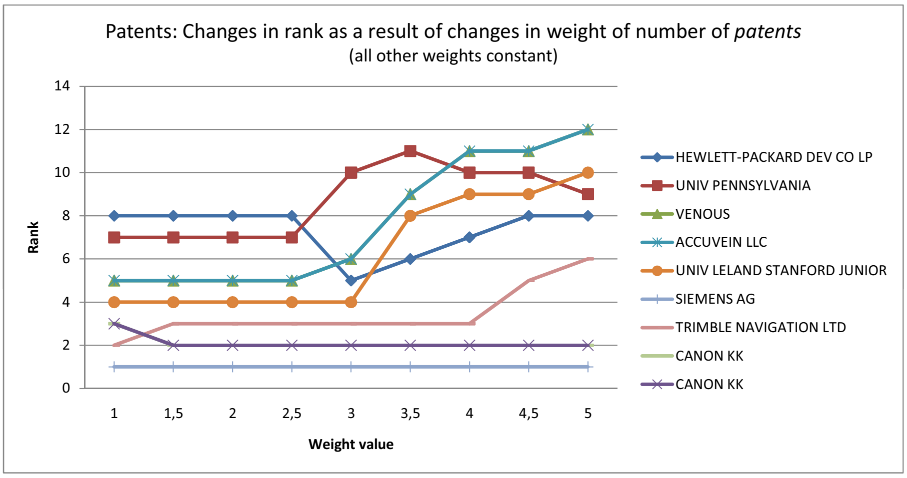


Figure I.7.: Augmented reality; effects of gradual weight increase for publication on rank

I.2. Publications

Setup
This section aims to investigate the sensitivity of the model which uses publication data as input. The sensitivity analyses is carried out in the same way as the model using patent data.
The sensitivity analysis is carried out in two parts. In the first part the weight sets are varied and the effect on the institutes' rank is studied by examining changes in the composition of the top-10 institutes. In the second part the focus is on two major indicators; the number of publications and the CPP/FCS (van Raan's crown indicator). In this part the weights of one indicator are systematically varied, while all other indicators remain constant.

Methods
The sensitivity analyses uses the actual data that is also used to construct the rankings. The sensitivity of the model is tested by making changes to the weight parameters. The Excel add-in RiskSim 2.30 is used to study the effect on the *rank* when changing the values of two non-random inputs (the weights).

The model for publications uses four indicators with and a corresponding weight set $w = [w_1, w_2, w_3, w_4]$.

- w_1 = weight for *number of articles*
- w_2 = weight for *CPP*
- w_3 = weight for *CPP/JCS*
- w_4 = weight for *CPP/FCS*

I.2.1. Part 1: varying weight sets

Similar as for patents, the weight sets are varied and the effect on the situations in the top 10 list is studied. The weight sets used: [1,1,1,1], [1,1,1,2], [2,1,1,1], [1,0,0,1].

Before varying the weights the current rank consists off the list displayed in I.8 (weight set w=[1,1,1,1]. The CPP is not displayed because this is not depicted on the one-pager design either. Institutes appear to score relatively high on one or two indicators, and relatively low on the other indicators. In the next model the threshold is removed and the weight set is changed to [1,1,1,2]. Some new institutes are added with high CPP/FCS values which benefit from this increase of importance of this indicator (see fig.I.10. Then the set of weight is changed to [2,1,1,1]. The result is that more universities end up in the list I.11. No major changes in the rankings list appear.

The weight set [1,0,0,1] however, results in more significant changes (see figure I.11. This weight set implies that the model uses one indicator for *quality* and one for *citations*. The effect is that nearly all institutes with a few publications are removed from the list, with the exception of Imagineer Systems, which has an unexceptionally high number citations but just one publication. Introducing a threshold value will remove this institute from the list.

Organization name	Rank	Relative Position	Number of Publications	CPP/JCS	CPP/FCS
Imagineer Syst Ltd	*1*	1,00	1	8,3	87,1
Tech Univ Munich	*2*	0,34	30	0,0	1,1
Commissariat Energie Atom	*3*	0,28	1	6,2	2,6
Renault Sas	*4*	0,28	1	6,2	2,6
Univ Paris 05	*5*	0,28	1	6,2	2,6
Cnrs	*6*	0,27	4	1,4	22,4
Univ Oxford	*7*	0,26	4	1,3	21,8
Univ Med Ctr	*8*	0,24	1	3,4	11,9
Univ London Imperial Coll Sci Technol & Med	*9*	0,21	6	0,7	15,6
Natl Univ Singapore	*10*	0,20	18	0,0	0,6

Figure I.8.: Augmented reality; publications; weight set 1,1,1,1

Organization name	Rank	Relative Position	Number of Publications	CPP/JCS	CPP/FCS
Imagineer Syst Ltd	*1*	1,00	1	8,3	87,1
Cnrs	*2*	0,27	4	1,4	22,4
Tech Univ Munich	*3*	0,26	30	0,0	1,1
Univ Oxford	*4*	0,26	4	1,3	21,8
Commissariat Energie Atom	*5*	0,22	1	6,2	2,6
Renault Sas	*6*	0,22	1	6,2	2,6
Univ Paris 05	*7*	0,22	1	6,2	2,6
Univ Med Ctr	*8*	0,21	1	3,4	11,9
Univ London Imperial Coll Sci Technol & Med	*9*	0,20	6	0,7	15,6
Coll William & Mary	*10*	0,18	1	1,6	14,5

Figure I.9.: Augmented reality; publications; weight set 1,1,1,2

Organization name	Rank	Relative Position	Number of Publications	CPP/JCS	CPP/FCS
Imagineer Syst Ltd	*1*	1,00	1	8,3	87,1
Tech Univ Munich	*2*	0,66	30	0,0	1,1
Natl Univ Singapore	*3*	0,40	18	0,0	0,6
Graz Univ Technol	*4*	0,40	18	0,0	0,4
Fraunhofer	*5*	0,39	18	0,0	0,3
Cnrs	*6*	0,31	4	1,4	22,4
Univ Sydney	*7*	0,31	14	0,0	0,4
Univ Oxford	*8*	0,30	4	1,3	21,8
Commissariat Energie Atom	*9*	0,28	1	6,2	2,6
Renault Sas	*10*	0,28	1	6,2	2,6

Figure I.10.: Augmented reality; publications; weight set 2,1,1,1

Organization name	Rank	Relative Position	Number of Publications	CPP/JCS	CPP/FCS
Imagineer Syst Ltd	*1*	1,00	1	8,3	87,1
Tech Univ Munich	*2*	0,98	30	0,0	1,1
Natl Univ Singapore	*3*	0,59	18	0,0	0,6
Graz Univ Technol	*4*	0,59	18	0,0	0,4
Fraunhofer	*5*	0,58	18	0,0	0,3
Univ Sydney	*6*	0,46	14	0,0	0,4
Beijing Inst Technol	*7*	0,42	13	0,0	0,1
Keio Univ	*8*	0,42	13	0,0	0,1
Delft Univ Technol	*9*	0,40	12	0,0	1,2
Huazhong Univ Sci & Technol	*10*	0,39	12	0,0	0,0

Figure I.11.: Augmented reality; publications; weight set 1,0,0,1

I.2.2. Part 2: gradual changes of weights

This part examines the sensitivity of the model, by systematically changing the weights of one indicator, while all other weight values remain constant. The model is starts off with weight set w = [1,0,0,1] (bottom left corner). Then the weight of the fourth indicator is increased with steps of 0,5 unit, while all other weights remain constant. This test includes the top 8 companies listed. Figure I.12 depicts the results. The TU-Munich is performing best. Figure I.13 displays the developments of the ranks, as the weights of indicator CPP/FCS is varied from 1-5, while keeping the value the indicator *number of publications* constant.

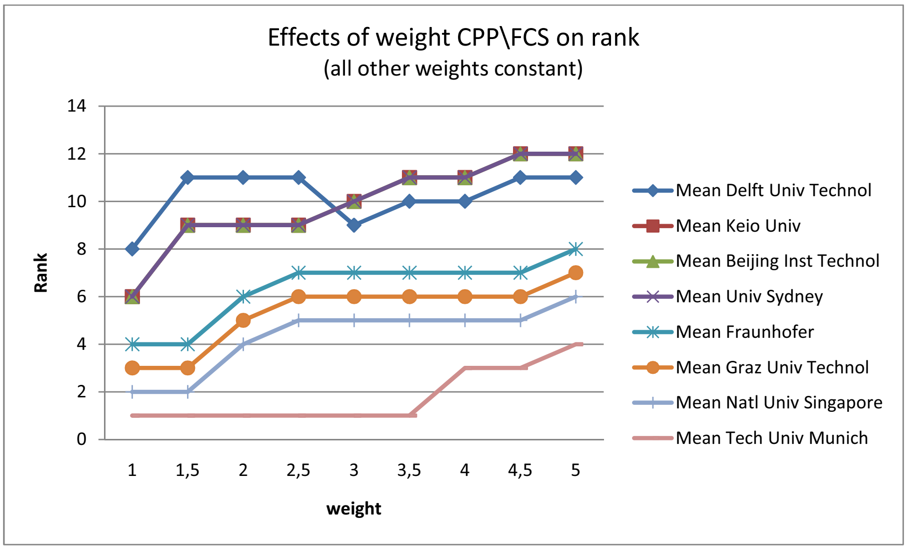


Figure I.12.: Augmented reality; effects of weight CPP/FCS on rank

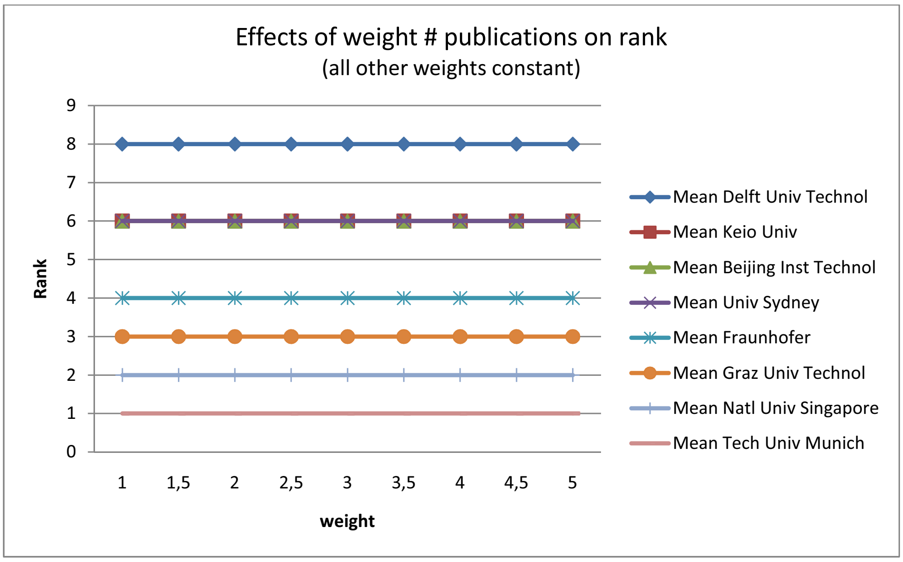


Figure I.13.: Augmented reality; effects of weight # publications on rank

I.3. Conclusions validation

Both models, based on patent and based on publication data, have proven sensitive to changes in model parameters. The model which deals with patent data is slightly more sensitive than the model which deals with publication data (i.e. larger effect on outcomes as a result of changes in weights). However the changes in ranks as a result of changes in weights was expected and does not lead to unexpected (extreme) behavior of the model.

The information that served as input to the model is heterogeneous, which means the ranks are relatively easy changed when the relative importance of the indicators changes. This is clearly illustrated by the institutes with only one publication and very high citation rates and institutes with many publications and average citation rates. The heterogeneity can be partly reduced by introducing threshold values (e.g. institutes must have a minimum number of articles). It also raises the question of whether *institutes* can effectively be compared, because of their significant differences in attribute values. One way to deal with the incomparability is to assign institutes with similar characteristics to groups, and then compare the member with each group (Pruyt 2008).

One further point that came to light in this chapter is whether different indicators are *incommensurable*. Commensurable indicators allow for trade offs to be made between them (e.g. cost versus quality of a system or product), for incommensurable indicators this is more difficult (Pruyt 2008) (e.g. number of fatalities versus additional production costs for a car designer). With respect to the model this would mean that it may not be possible to make trade offs between certain indicators. As a result it may not be possible to determine one ranking value.