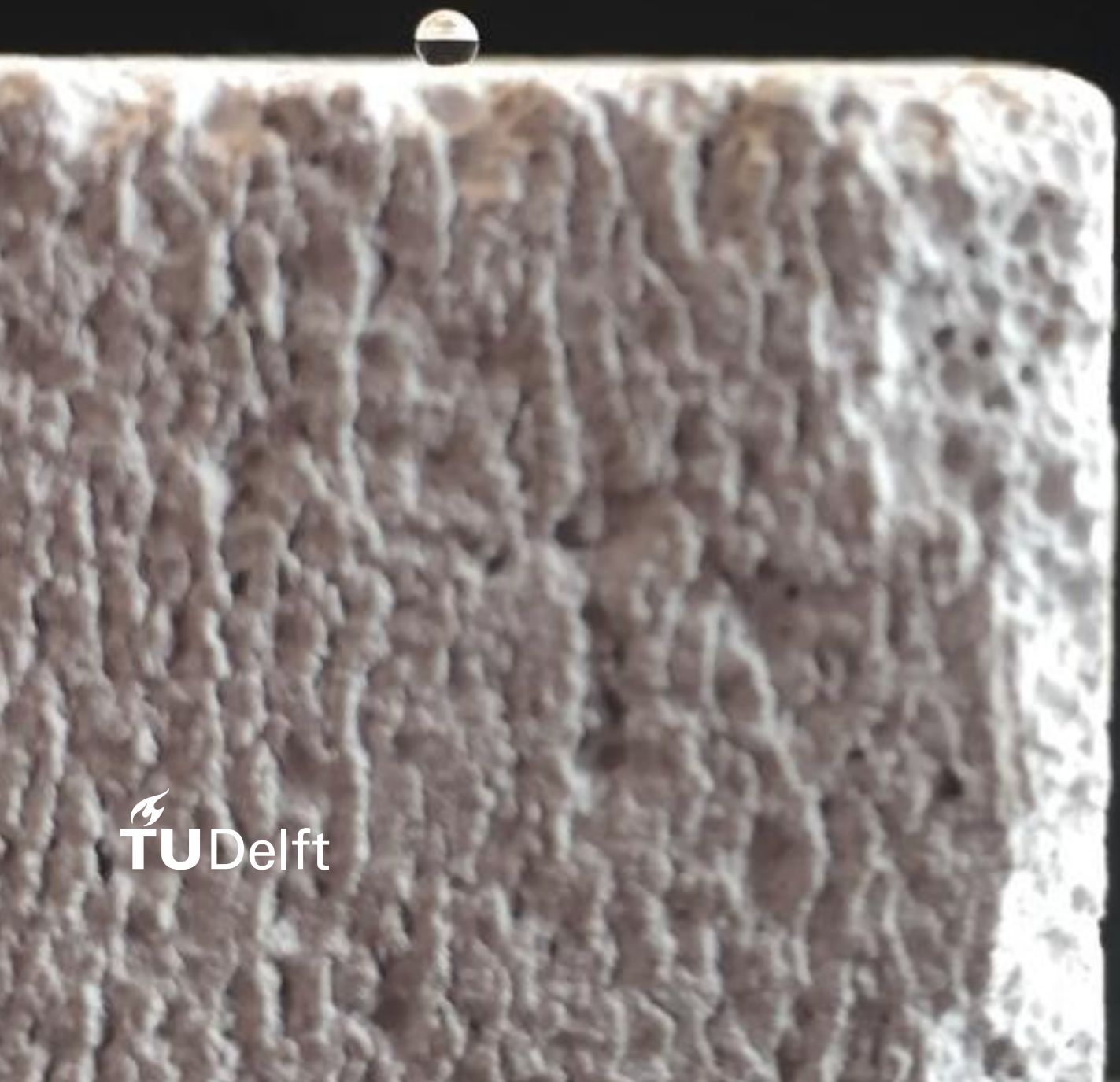
R.C. Boekel

Exploring the nanotechnology landscape for competitive advantage

A Subject-Action-Object based text mining methodology for finding, selecting and evaluating nanotechnologies for innovation problem solving.



TU Delft

Exploring the nanotechnology landscape for competitive advantage

A Subject-Action-Object based text mining methodology for finding, selecting and evaluating nanotechnologies for innovation problem solving.

By

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The appendix of this thesis is confidential and cannot be made public until October 2019

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"Nobody ever figures out what life is all about, and it doesn't matter. Explore the world. Nearly everything is really interesting if you go into it deeply enough."
– Richard Feynman

Preface

Amsterdam, October 30, 2016

Eleven months ago I emailed Scott with the question if he could help me with the first steps of my graduation project. At that time, I read an article by him and Claudia on the influence of proximity and collaboration in nanotechnology development. I was thrilled to find the connection between the faculty and nanotechnology. Nanotechnology is such an amazing development, just imagine, with nanotechnology we can manipulate atoms and molecules which are so small that we can hardly obtain them with the most advanced measuring equipment. Until now we have only been able to understand its behavior based on mathematical calculations some smart people designed from the 30s to the 50s. Yet everything in the world is constructed by atoms and molecules. Humans itself are a unique, and amazingly advanced composition of molecules.

With nanotechnology we are able to understand this more and more and we are not only able to understand, we are also able to manipulate, design and produce nanotechnologies. This is all very scary but also extremely exciting! With the development of the field new social challenges will lie ahead. The risks of nanotechnology are certainly there and everything we do not understand that may be harmful must be thoroughly assessed. But imagine, understanding nanoscale interactions will enable people to learn from nature and back trace billions of years of advanced nanotechnology to think of systems like DNA, photosynthesis and life in general. I believe that we can make the most beautiful solutions by understanding nature better, solutions that could definitely help solving challenges in energy, sustainability and life quality that are ahead of us.

Therefore, I wanted to integrate nanotechnology and SEPAM skills, and if possible, innovation in my graduation project. The paper by Scott and Claudia were the start of making this possible. I found out quite quickly that bibliometrics would be a perfect match of combining these three fields. And here I am, eleven months later, I deliver a methodology that allows to find, select and evaluate nanotechnologies for innovation purposes. Secretly I am very proud at what I present, but without others I would never have been able to present what I have written today. That is definitely something I have learned during this thesis process, that without any help, without reflection, without interaction it is pretty damn hard to create and realize your ideas. I therefore want to take some space to thank the people that helped me realize the thesis and helped me through the project.

First of all, I want to thank Scott Cunningham for being helpful from day one in guiding me in the process from a student to a Master of Science (if everything goes well ;-)). He helped me with understanding the content in all the fields I used; nanotechnology, innovation management, text mining and systems engineering. I can assure you, that is quite a bunch of knowledge. Furthermore, I really liked the talks, from the philosophical talks about innovation to the talks about US elections.

I am very thankful to Lina Rambausek who brought me onboard to DESSO and was able to use both her PhD and business skills in supervising. This was really a blessing because it enabled a seamless fit between the needs of DESSO and the requirements the University has for a research. We also had some good laughs, and I'm really thankful despite being called a character from "despicable me" sometimes. Furthermore, in DESSO I want to thank Ruben de Reu and Hans Roelandt for taking the time for explaining the technical processes and answering all my questions.

I also want to thank Marina van Geenhuizen and Claudia Werker for their comments and guidance in the graduation project. I want to thank Vincent Franken, Jeffrey Kruijswijk and Lise Leijtens for taking the time to understand my research, editing and listening to all the ideas I had for my research. I want to thank Eva van Loon and my family for supporting me throughout the project. I want to thank Michiel van Daal for his reflections and smart ideas for the research validation. That really is something for a lawyer. Finally, I want to thank my co-students and friends for thinking along and for their recommendations on the research design. I'm feeling honored that you all wanted to help me!

Sincerely,

Roel Boekel
MSc. Student Systems Engineering, Policy Analysis and Management.

II Executive summary

Nanotechnology is an emerging technology field that will influence many industries. It can be seen as a toolbox of technologies that obtain their function based on their nanoscale activity. On the macro scale, this results in special functionalities of materials and products. Examples include lightweight materials, increased chemical performance, electro-conductivity and morphology improvement. Because these functionalities are multi-applicable, nanotechnology has been proposed often as a general purpose technology. For this reason, the expectations of nanotechnology are high and for years, it is hoped that nanotechnology would turn into a mass-market industry. This industry has not yet been observed. Three reasons are discussed; first, the nanotechnology industry is diverged and fragmented because nanotechnologies emerge from many traditional industries. There is no entity that integrates and organizes the nanotechnology industry. Second, the health- and environmental risks of nanotechnologies are unclear. Companies therefore wait with adopting nanotechnology until the risks are clearer. Third, nanotechnology faces similar challenges like every new, emerging and science based industry in which the transfer from science to market needs to be bridged.

To overcome these gaps for mass-market adoption of nanotechnology more understanding is necessary about why companies innovate, how this is organized and what tasks companies perform to innovate. The reason innovation occurs can be explained from the macro (societal) perspective and the micro (firm) perspective. On the macro level innovation is one of the three cornerstones in realizing societal growth. On the micro level companies innovate to stay competitive, adapt to technological developments, fulfil market needs and because of the shortening of product life cycles.

The way innovation is organized differs per sector. Especially production intensive industries can benefit from general purpose and multi-applicable technology, because they control their own technical process and are in a continuous process of improving their activities to stay competitive. Fundamental parts of this process are; technology scouting and technical problem solving. Technology scouting is the process of finding technologies from external sources to solve technical problems or for new product development. Technical problem solving is a process that uses (engineering design) methods to structure a problem in a set of requirements and **functions**[1]. This problem can be solved by finding **means**[2] that execute the function. Technology scouting together with technical problem solving are an iterative process of information retrieval and conceptualization.

To retrieve information, companies use many sources. Patents and scientific literature are used to gain insight in the newest developments in science, technology and what competitors are doing. Due to the large amount and complex substance of these information sources, gaining insight is a time-consuming and costly process that not always renders useful results. To gain better insight in these large amounts of texts faster natural language processing (NLP) can be applied. This is a text-mining technique. Specifically, the SAO-based parsing method is an interesting NLP technique. SAO-parsing extracts the grammatical relation of the Subject (S), Action (A) and Object (O) from a sentence. This technique enables to extract functional technical relations from sentences because the Subject (S) acts as a means and the Action-Object (AO) acts as the function.

The toolbox of nanotechnology possesses great innovation potential for firms, especially firms that are in a continuous need of technical developments and innovations. Firms should therefore efficiently

[1] Functions are minimalistic (verb-noun) descriptions of what a certain system needs to do.
[2] Means are technologies or components that execute the function.

find, select and evaluate the potential that the science based nanotechnology toolbox has to offer for innovation purposes. An activity that currently cannot be performed because such a methodology has never been designed. In this research it will be investigated what kind of methodology can be designed to find, select and evaluate nanotechnologies.

The methodology integrates existing concepts of engineering design and SAO based text mining to extract nanotechnologies from scientific article abstracts. Engineering design methods are used to structure an innovation problem within the firm and to develop requirements and functions of a potential solution. Because minimalistic functions in engineering design are described by an action-verb (A) and an object-noun (O), the minimalistic function can be used as input to find SAO-relations that have a (semantically) similar action and object. For this research over 1.2 million nanotechnology related articles are downloaded from Web of Science and indexed based on SAO-parsing of the title and abstract. A computer program with a user interface is developed that allows the user to browse the SAO-relations that are extracted from the scientific abstracts. This computer program is called *Nanotech scout*. To browse technologies there is an input field for both action (A) and object (O) of the function that, when searched, returns the corresponding subject (S). By interpreting the subject, the user can determine if the subject is a potential means that can be a nanotechnology based solution to the design problem. Relevant means can be evaluated by scoring based on their relative performance to the requirements and other means. Based on those outcomes decisions can be made regarding the potential application of nanotechnology for innovation problem solving. A scheme of the designed methodology is pictured in **Figure 1**.

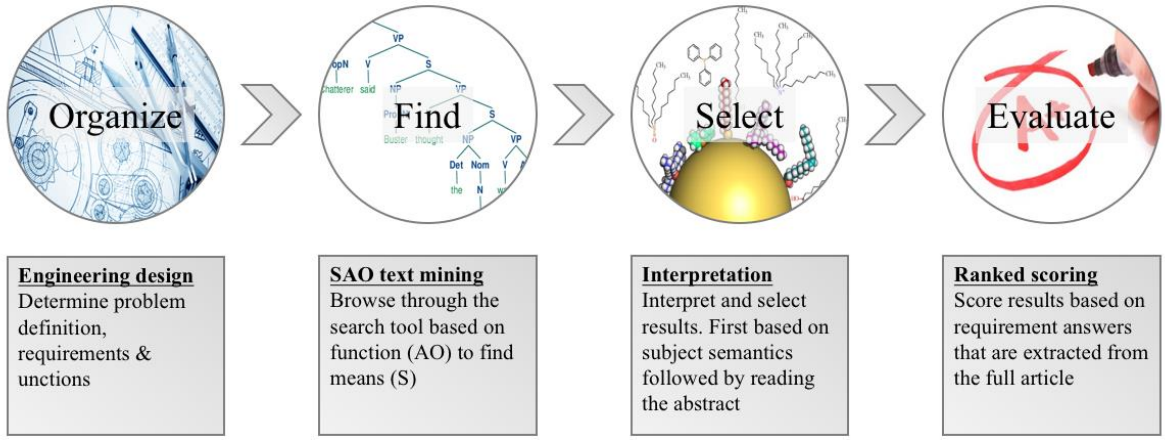

Figure 1 Parts of the methodology

To evaluate the methodology two case studies within a production intensive firm are presented. This firm produces textile products for the flooring industry. The first case is to scout for technologies that optimize the textile dyeing process. The second case is to scout for technologies that increase the flame retardancy of textile products. The cases are structured according to the engineering design methodology resulting in a total of 10 functions and therefore 10 action-object (AO) queries. The queries are executed in the Nanotech scout program. For the 10 queries, 266 results (SAO-relations) were generated. Selection based on subject scoped the set down to 139 results that were all individually assessed by interpreting title and abstract within the Nanotech scout. Of those 139 results, 95 articles were regarded relevant and could be narrowed down to 44 means. These means represented the scouted technologies and are individually assessed by measuring the requirements and scored based on their relative performance on the requirements and to other means. Multiple interesting technologies for the innovation problems have been generated by the methodology.

To validate the methodology three types of analyses were executed: The Nanotech scout was internally verified by testing the SAO-parsing algorithm. This showed that 66% of information is lost because 66% of the sentences do not have an SAO-relation. The Nanotech scout was validated by comparing its performance with the conventional search engines Web of Science and Google

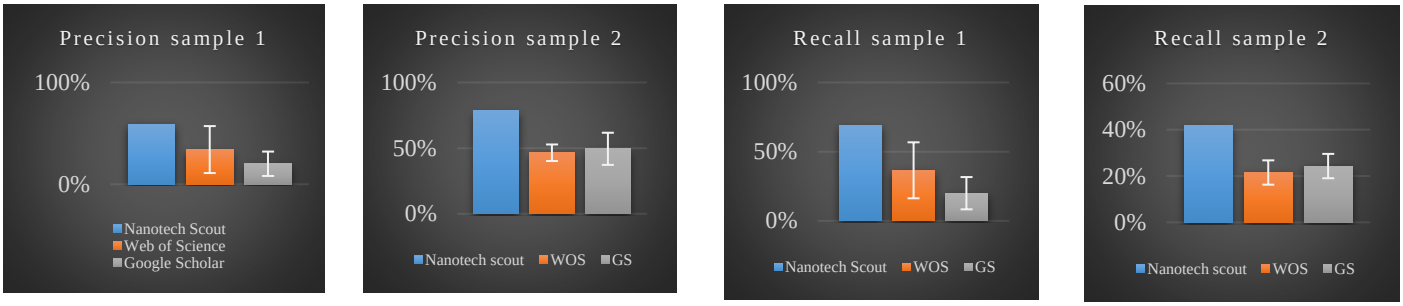

Figure 2 Precision and recall results of the methodology

Scholar. The performance was measured based on precision and recall. Precision shows the rate of relevancy of the retrieved results. Recall shows how many of the relevant results were retrieved in relation to the total relevant results. The outcomes of the measurements are presented in **Figure 2**. The measurements show that the average precision and recall increase is respectively 91% and 114%[3]. The methodology itself was verified using a structured interview conducted with two engineering managers. The interview showed that new useful insights were generated for problem solving and that the scouting time can be reduced while the quality of knowledge extraction is improved. Improvements were also suggested as the methodology heavily depends on the input of word formulation and has only the ability to search for nanotechnological concepts. The flexibility of the engineering design methods and SAO-text mining technique however allows that the methodology is generalizable and transferable to other scale intensive production firms and can be adapted to scout for different kinds of technologies. The rules for applying the methodology are presented in **Table 1**.

Table 1 Rules for applying the methodology in other companies	**Rule No.**
The company controls its own technical process and is in a continuous process of improving their activities	1
The company is searching for technologies in which small scale physical, chemical or biological interactions determine the outcome.	2
The user is able to reason that the knowledge base he is searching in could logically lead to a solution.	3
The user has an innovation approach for finding technologies to solve, replace or improve processes in the company.	4

The methodology for finding selecting and evaluating nanotechnologies using an SAO-based approach has been designed and demonstrated. Promising results have been obtained, both from the methodology demonstration as from performance evaluation. However, there are plenty of challenges ahead in which the knowledge loss due to SAO-parsing and information stickiness are influencing the performance and viability of the methodology. There are also new opportunities to explore the field of nanotechnology more carefully to gain more understanding about its nature and multi-applicable character by means of SAO. Furthermore, SAO-based indexing could be explored for other applications like abstract indexing and general search engine technology.

[3] Relative values. This is the combined average of both samples for the relative precision and recall increase of the Nanotech Scout in comparison to the combined performance of Web of Science and Google Scholar.

III list of abbreviations

SAO	:	Subject Action Object
NLP	:	Natural Language Processing
TRL	:	Technology readiness level
PPP	:	Public Private Partnership
NNI	:	National Nanotechnology Initiative (US)
GPT	:	General Purpose Technology
C2C	:	Cradle to Cradle
R&D	:	Research and Development
PET	:	Poly Ethylene Terephthalate
WOS	:	Web of Science
GS	:	Google Scholar
Stanford DP	:	Stanford Dependency Parser
PCC	:	Pairwise Comparison Chart

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1 Introduction

Nanotechnology is a ground breaking field of science that enable materials to behave like never seen before [1], [2]. The discovery of special features at the nanoscale meant the start of a research field where almost every natural science field meets. Knowledge of nanoparticle behavior, materials, surfaces, molecular motors and sensors resulted in a large crossover of knowledge between research fields that never would have been brought together [3]. Nanotechnology, viewed as a toolbox with technologies, is regarded as a general purpose and multipurpose technology [4], [5]. However, the uncertainty of application areas and health aspects have slowed the adoption of nanotechnology. This, combined with the specific resources required for commercialization (knowledge, skilled people, measurement equipment) and the complexity of the science and application fields, have inhibited the mass commercialization of nanotechnology [6]–[8]. The low adoption is interesting, as the possibilities are present and companies are continuously seeking to improve their activities and follow the latest technology trends [9]–[11]. Companies like to be aware of the implications of emergent technologies like nanotechnologies, for the sake of innovation and competitive advantage.

In bulk manufacturing industries the innovation strategy is organized based on multiple drivers within the firm [12]. First, there is the ongoing task of continuous product and process improvement to increase the efficiency of the production line and the quality of the product. This is often driven by costs, but can also be driven by regulations and sustainability. Management and the innovation team thinks of new products and possibilities to increase the market size and for outsmarting competition. Furthermore, companies follow technologies that are outside their own knowledge field, these are technologies that are new with unknown implications. These technologies are put on the timeline and implemented into the company when their implications become clearer.

Nanotechnology is an excellent example of a science driven emerging technology that has many uncertainties regarding its implications. It is a field of technology that companies in bulk manufacturing would like to evaluate for their continuous need to improve and innovate. But how do they do that? Although nanotechnology innovation possibilities might be on their radar, its direct implications are often unknown. This is supported by the fact that nanotechnology is a toolbox of multipurpose applications, that can come from various technology fields. A methodology is necessary that allows companies to bridge the gaps in to science based knowledge and structure the diverged and fragmented nanotechnology industry. Furthermore, this would also help the actors in the nanotechnology field understand how nanotechnology can be commercialized to bulk manufacturing companies. To find how companies in bulk manufacturing can make use of nanotechnology the following research question needs to be answered:

> *“What kind of methodology can be designed that provides an innovation manager clear steps on how nanotechnology related scientific knowledge can be identified, selected and evaluated to support decision making in innovation strategy?”*

Browsing the field of nanotechnologies based on its multi applicable character would greatly enhance the exploitation and dissemination of nanotechnology from a business perspective. That would allow technology scouts and innovation managers to select nanotechnologies, identify their scientific results and make decisions based on their functions and applicability. This function based process is similar to the methods used in engineering design. An innovation project has the same structure compared to when a company is searching for technologies that could solve a problem or should have a specific

function. Based on this, companies can determine the function that the technology should do. Functions can be used to scout for emerging technologies that can act as a means for executing this function. The directed approach for scouting technologies based on functions can be valuable for exploring the multipurpose character of nanotechnologies. The approach enables innovation managers to scout for technologies that could be directly beneficial to existing innovative goals. The challenge is what kind of methodology can be constructed that provides an innovation manager the right tools to define functions from innovative goals and use these functions as input for searching nanotechnologies. In the past, there have been studies to computationally identify functions from large datasets such as patent databases. This approach for extracting functions from text is called text mining [13], [14]. Text mining tools can be redesigned and used for determining other nanotechnology related datasets like research literature or patent information. This research proposes a new methodology for scouting nanotechnologies based on their functions by means of a unique function based search method.

In the following chapters, the research will be structured and executed to answer the research question. Before the research problem and question are thoroughly described in chapter 4, multiple theories and practices will be introduced. The thesis is organized as such because the research problem will cover and integrate many theories. Therefore, all these theories and will be introduced first. This will be done in the **theoretical framework in chapters 2 and 3**. Chapter 2 will describe the field of nanotechnology, its unique possibilities, its knowledge character and the pitfalls in technology transfer.

The pitfalls are the foundation of the research problem because the lack of commercialization of nanotechnologies influence the innovativeness of firms. Chapter 3 covers the multiple stages of innovation from the drivers at the societal level to the execution in bulk manufacturing companies. First, it will be described **why** innovation is necessary for society and the firm. This is followed by a section that introduces theories and models **how** firms organize innovation. The third section will discuss **what** bulk manufacturing companies do to innovate at an operational level. We will then look at a specific type of task in that process that is used to find new technologies like science based nanotechnologies. Based on this task the field of text mining and natural language processing will be introduced. Research in text mining will show how the process of finding science based technologies can be simplified.

Based on the theoretical framework the **research design** will be described in **chapters 4, 5 and 6.** In chapter 4, the research problem will be described, the research question will be constructed and the research approach will be explained. Chapter 5 will introduce the case study and how the innovation strategy of the company relates to the theory described in chapter 3. Chapter 6 the requirements will be defined that the methodology needs to have.

Based on the requirements the research questions will be answered by **executing the research in chapters 7 and 8**. In Chapter 7, the methodology will be designed and in Chapter 8 the methodology will be demonstrated in two case studies from a company. **Chapters 9, 10 and 11 comprise the research validation**. After demonstrating the methodology, the outcomes of both the methodology execution as the performance will be validated and evaluated in Chapter 9. Chapter 10 will reflect on the research findings regarding the character of nanotechnology, the innovation problem solving process and the application of the text mining technology. In chapter 11, the findings will be presented with a conclusion. A schematic representation of the research structure is shown in **Figure 3**.

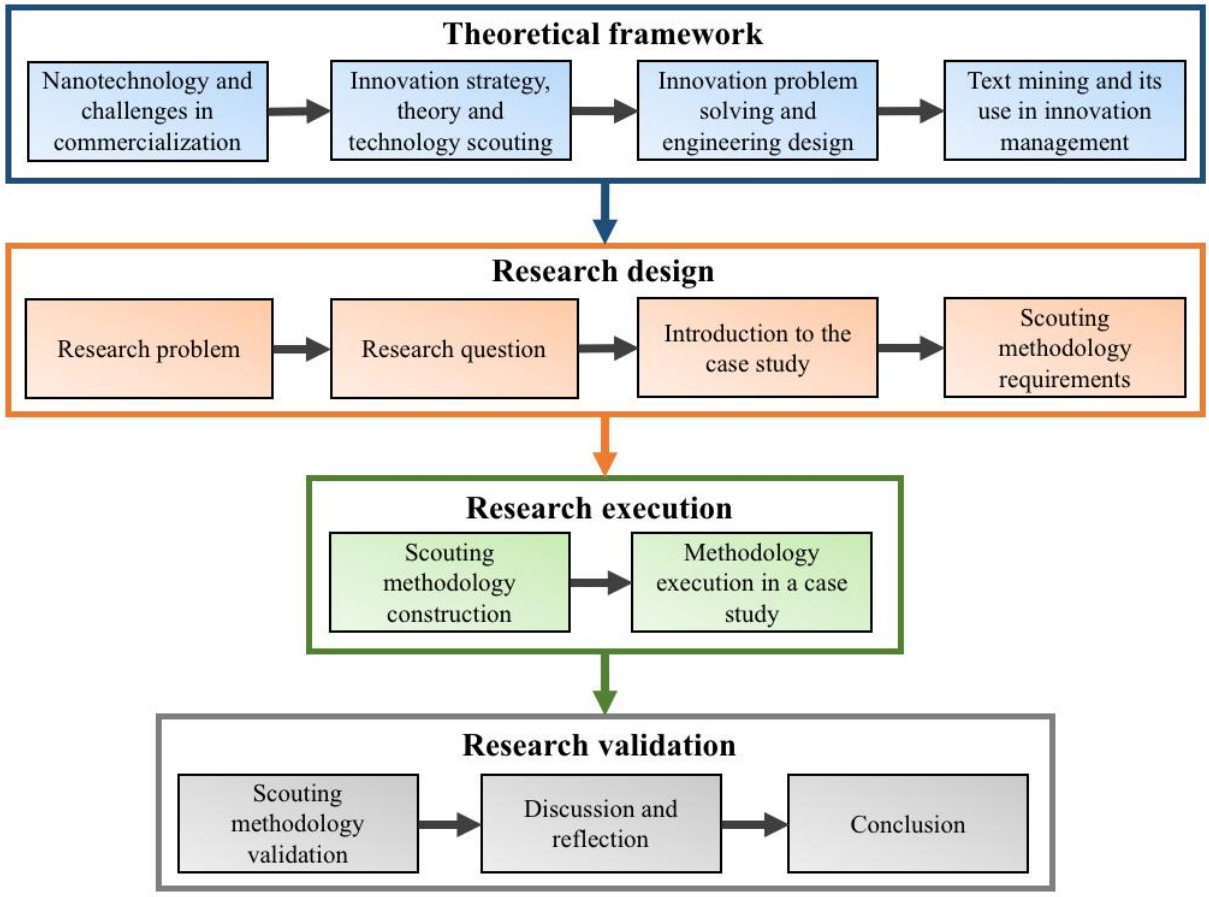
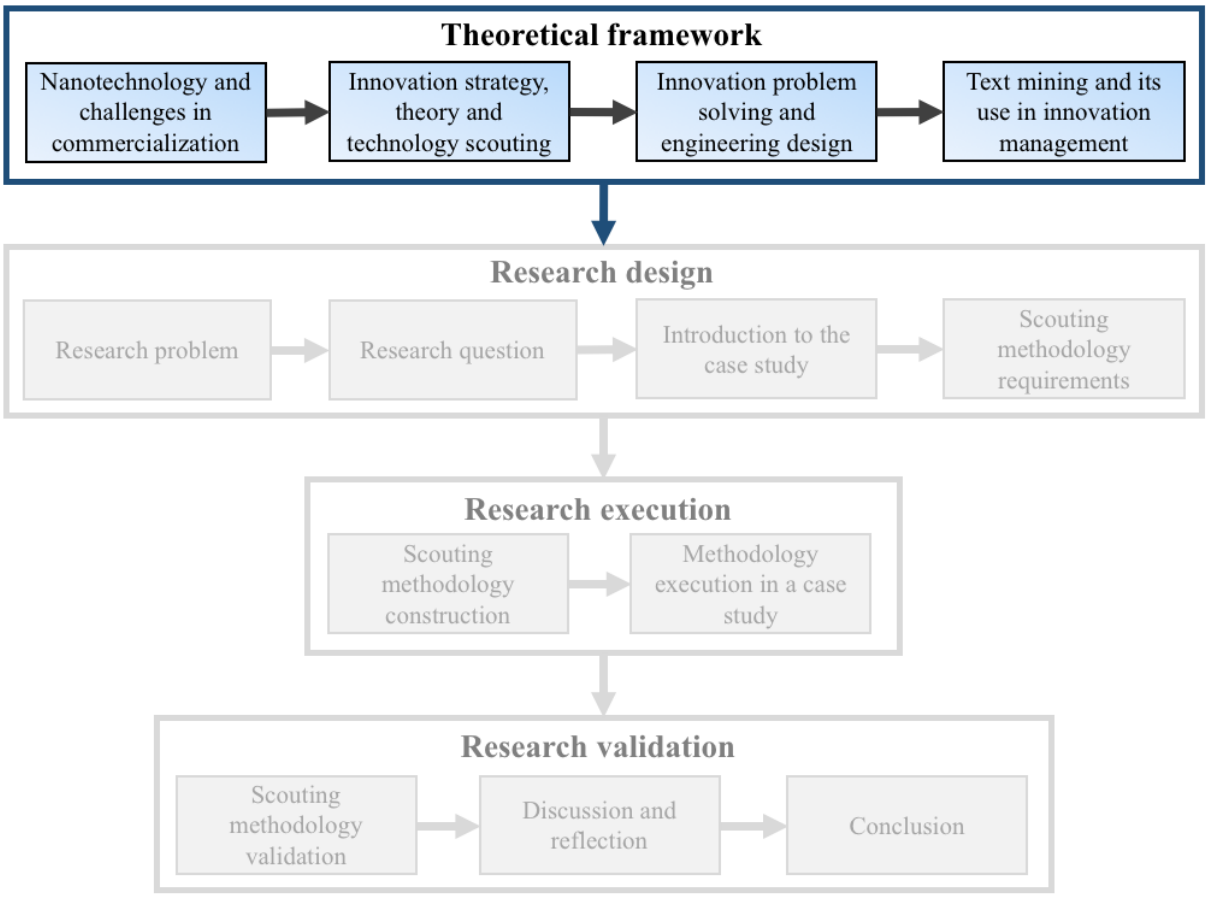


Figure 3 Schematic representation of the research (own figure)

Part 1

Theoretical framework



2 Nanotechnology and nanotechnology commercialization

Nanotechnology shows tremendous possibilities for many industries, which in itself is an important argument to underwrite the innovation opportunities for companies. This chapter aims to explain what nanotechnology is, why it has tremendous possibilities and why this would be interesting for companies. Additionally, more background on the "emerging" and "general purpose" character of nanotechnology will be provided. This character supports the claims that nanotechnology can be embedded in many products or processes. This claim must be validated in order to investigate how the field of nanotechnology can be analyzed to show its broad range of functionalities. The reasoning regarding the possibilities and GPT character of nanotechnology raises the question why mass implementation of nanotechnology has not occurred yet. One may think that companies will heavily invest in the field to render its capabilities when a technology is this promising. Nonetheless, there is an apparent lack of nanotechnology commercialization. Arguments must be explored that explain this unexpected behavior. In the following section the topics of nanotechnology, its character and commercialization deficits will be discussed. At the end of the chapter conclusions will be drawn about the multi-applicability of nanotechnology in relation to the commercialization deficits. A valuable conclusion for chapter 3, where innovation strategies in bulk manufacturing will be introduced.

2.1 What is nanotechnology?

Nanotechnology is a broad field of technology that is related to chemistry, physics and biology on the scale of 1 to 100 nanometer. It describes the quantum physical properties of materials on the nanoscale and the application of this technology within industries like medicine, materials and electronics [15]. The development of nanotechnology goes back three decades, and since then the application of nanotechnology in society has always been promising [16]–[19]. The field was introduced by Nobel Prize winner Richard Feynman in his speech "there is plenty of room at the bottom" in 1959 [20]. Despite this the term nanotechnology was first mentioned in the seventies and eighties by Drexler and Taniguchi [21], [22], [23]. Thereby providing a solid foundation for the new emerging scientific field that nanotechnology is today. This field has been described as a toolbox of amazing possibilities stretching to almost any imaginable technical field [7]. This raises the question how nanotechnology is embedded and can be embedded in society. It is especially interesting to view the embedding from the perspective of businesses as they adopt new scientific fields into their products and processes for technical change that fosters economic growth and prosperity [24].

2.2 Characteristics and applications of nanotechnology

As described above, nanotechnology is a broad field of technology on the nanoscale that is related to chemistry, physics and biology. Nanotechnology follows from the special behavior of molecules on the nanoscale. The foundation of this behavior can be found in quantum mechanics. Quantum mechanics is a field within physics that describes the behavior of particles as small as electrons, atoms and molecules. The existence of quantum mechanics follows from the failure of classical mechanics to describe the behavior of matter with a very small mass like electrons, protons, atoms and molecules [25]. In nanotechnology the

knowledge of the specific behavior of matter with a very small mass is used and manipulated to exploit it for specific applications on both the nano- and macro-scale. Köhler et al gives an overview of what kind of behavior materials execute if they are enhanced on the nanoscale. This behavior is depicted in **Table 2**.

Table 2 Properties and effects on nanoscale and related (possible) applications [26]

Properties and effects on the nanoscale	***Examples of possible applications***
Higher surface to volume ratio - enhanced reactivity	Catalysis, solar cells and batteries
Lower percolation threshold	Conductivity of materials
Increased hardness with decreasing grain size	Hard coatings and thin protection layers
Narrower band-gap with decreasing grain size	Opto-electronics
Higher resistivity with decreasing grain size	Electronics
Increased wear resistance	Hard coatings and tools
Lower melting and sintering temperature	Processing of materials and low sintering materials
Improved transport kinetics	Batteries and hydrogen storage

The properties and effects on the nanoscale enable certain materials and products to exhibit properties that provide useful applications like batteries, gas storage and stronger materials. An example of a single nanotechnology that has multiple properties is the carbon nanotube. Carbon nanotubes have a strength that is over 100 times stronger than steel and can be produced in such a way that they could have conducting capabilities or semiconductor properties [27]. These specific properties have the potential for a tremendous number of applications in the advanced material, and electronics industry. Therefore, nanotechnology is often referred to as an enabling technology or a general purpose technology (GPT) in the literature [28]–[30]. This means that nanotechnology does not serve a single application, product or process but instead can be explored for multiple purposes for which the enhanced properties can be useful. A nanotechnology designed for a specific application could therefore be used in multiple industries, increasing the commercial value of the single technology. Rafols describes this as “flexibility in applications”. They state that nanomaterials are generally not mass market commercial products but rather functional components for intermediary products or for the functionalization of end-user products. A parallel can be drawn with other general purpose industries like chemicals or ICT. Chemicals and ICT are embedded in many products and processes. The same trajectory is envisioned for nanotechnology. Take for example a house; in the future nanotechnology will be embedded in solar cells that are located on the roof of the house, nanotechnology will be found in the battery in the garage that stores the excess electricity, nanotechnology will be in the isolation material that reduces the energy required for heating the house. A water filter will be stationed under the house, which uses nanotechnology to purify used water and preparing it for immediate reuse. The bricks of the house will be supported with nanomaterials that lower the carbon footprint and are impregnated with a coating that enables a self-cleaning effect. These are just a few examples of how nanotechnology will change many existing products and could improve the way of life.

In addition to the amazing market opportunities nanotechnology could offer, there are also critiques and concerns about the developments of nanotechnology. This concern can be described as the “asbestos effect”. It has been known for years that the inhalation of small particles may cause health concerns. The same is true for nano-materials [31], as they are small enough to enter the bloodstream and cells. This has many benefits, for example, it makes the use of biological motors possible in medicine and drug delivery that can move through the veins to specific locations in the body to deliver drugs [32]. Alternatively, it may also damage cells and inhibit cell growth. The potential toxicity and health effects in the long run cause reluctance to use nanotechnologies.

2.3 Knowledge character

The characteristics and application of nanotechnology underwrite the mass market potential of nanotechnology. The house example in the previous section shows a future in which many technologies will be embedded in many applications and products of everyday life. The word “future” also unveils that nanotechnology is still regarded as a “potential” technology, while it has existed for more than four decades. In the past 40 years the many potential opportunities have created high expectations and interest in the impact of nanotechnology in industry and society. In order to translate the nanotechnology knowledge into usable products, governments, companies and universities bundled their resources to obtain new knowledge and to commercialize nanotechnology [1]. To organize the cooperative goal, the formation of public, private partnerships (PPP) with research funding was necessary as nanotechnology research and development is cost-intensive. This is a result of the required research instruments, measuring equipment, cleanrooms, production complexity and specific knowledge [33]. The nanotechnology innovation system is therefore characterized as science-driven. From which field nanotechnology emerges is heavily debated in literature. On the one hand it is discussed that nanotechnology is an interdisciplinary field, in which scientists work together exchanging knowledge from multiple scientific fields to synthesize solutions for real world problems. An analysis by Huang showed that the debate remains because there is a lack of consensus on how interdisciplinary is obtained. Although many studies confirm the interdisciplinarity by using bibliometric analysis of patents and literature [34]. Nanotechnology is not a stand-alone science field. Instead it is comprised of knowledge from many other traditional science fields like chemistry, physics, material science and electrical engineering. All these traditional fields study the behavior of very small particles and interactions and use the concept of quantum mechanics to understand the behavior. Knowledge therefore crosses multiple fields and nanoscale functionalities are exploited within several applications in the traditional fields of medicine, chemistry and physics.

The science driven interdisciplinary character of nanotechnology allows for collaborative research that can generate new products and materials to solve societal problems. It also means that that the majority of new knowledge and technology results from collaborative research with larger corporations or by university spin-offs. Hence, commercialization of nanotechnology stems from (fundamental) university research or from R&D activities of larger, high-tech corporations [1]. The way of nanoscience and -technology transfer is also discussed. Research programs are government funded and a lot of emphasis has already been placed on increasing the commercialization of nanotechnology output. Examples of country based research programs are the US National Nanotechnology Initiative (NNI) and the Dutch NanoNextNL program. These programs do not focus primarily on the transfer of knowledge,

they are designed to increase the fundamental understanding of nanotechnologies and for technology assessment and risk analysis [35].

In the Netherlands there have been multiple programs to boost research and innovation in Nanotechnology. The first official program was the NanoNed program that started in 2005. 235 million was invested in the NanoNed program that was distributed into three sub-programs; to create a nanotechnology infrastructure (80 million), boost research over 11 themes in science (150 million) and for program management and knowledge valorization (5 million) [36]. Its successor, launched in 2011, was the NanoNextNL program. This program was designed to put more emphasis on the industrial application of the generated knowledge. Although the budget was raised to 250 million, half of the money was contributed by 130 industrial partners to safeguard industrial application and commercialization of the knowledge [36]–[38]. To increase societal impact, the research program was divided in 10 themes to ensure that the research findings would contribute to society. Themes like medicine, food technology and sustainable energy were designed. The themes are shown in **Table 3** and show interesting insight the broad application of nanotechnology and the societal challenges in the Netherlands.

Table 3 Themes in NanoNextNL [39]

Theme
Risk analysis an technology assessment
Energy
Nanomedicine
Clean water
Food
Nano-electronics
Nano-materials
Nano-biology
Nano-fabrication
Sensors and Actuators

The collaborative research program rendered, besides marketable outcomes for contributing industries, all kinds of new startup companies like VSParticle, Lumicks and Lipocoat. In total 8 startup companies were realized through the program and 4 startups benefited from the program [39]. These companies emerged from the program and are currently high tech niche players. The Dutch NanoNextNL program shows, like any governmental program, that governments are actively trying to advance technical development and boost the nanotechnology industry forward to aim for societal growth.

2.4 Gap in technology transfer

To date nanotechnology has not yet shown that it can fulfill its promises and expectations. Researchers in policy have argued that the industry is still too young and more research and development is necessary [40]. Others state that nanotechnology should be divided in more subfields and the impact of those fields should be measured independently [3]. Alternatively, it has been proposed that the focus of nanotechnology industry development should be on knowledge dissemination and market formation rather than knowledge generation [41]. An interesting line of reasoning is proposed by Rafols. He states that governance frameworks are too focused on governing risk and instead they should focus more on governing innovation [7]. The enabling GPT character of nanotechnology proves to have potential for many different industries, in which the applications are quite general. However, there seems to be a gap in the transfer of technologies. There are multiple reasons that could support this statement, three of those reasons will be described below.

2.4.1 fragmented and divergent networks

As described earlier, nanotechnology stems from various traditional science fields and is regarded as interdisciplinary. Through this interdisciplinary field many industries and science fields share the same technological concepts, which is very favorable for cross-border knowledge transfer. It also means that fields and industries are connected through the terminology of nanotechnology that have nothing in common, like biomedicine and geosciences. **Figure 4** shows the fields of science that are often cited in nanotechnology

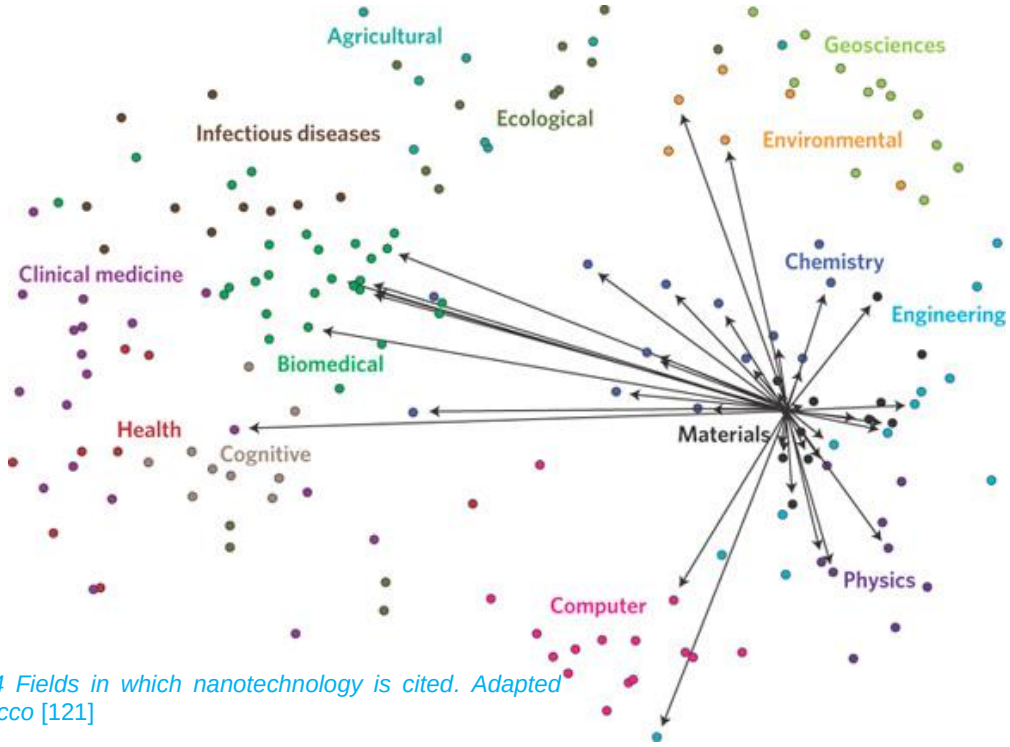


Figure 4 Fields in which nanotechnology is cited. Adapted from Rocco [121]

research papers. Only the scientific fields are shown, even though application areas are even more diverse. Materials range from airplanes to electronics and chemistry to geosciences, resulting in a diverse set of applications. Networks within the field of nanotechnology are divergent and fragmented. Pharmaceuticals and telecommunications are also very distributed industries. However, these industries have large corporations that act as system integrators. Although in the nanotechnology industry also large corporations like Bayer and BASF can be identified, they do not act as system integrators because they do not shape the complete value chain. Instead, they receive and deliver to small specialized firms or user firms. This results in a highly distributed market structure which is almost impossible to govern and explore [7]. The fragmented and multidisciplinary field complicates the acquisition of nanotechnology. How does a company know in what scientific or industrial field an enabling technology should be searched? For this information companies have to rely on their suppliers. However, we have explained that these suppliers are not system integrators. Hence, currently there is no entity or organization yet that enables firms to help firms acquire the right enabling technologies.

2.4.2 Health and safety

The small particles and functional characteristics of nanotechnology have resulted in health concerns and toxicity of nanomaterials. This concern is well grounded as many studies show that nanomaterials may have negative health effects or are toxic to the environment [31], [42], [43]. With the development of many nanomaterials and an endless amount of molecular confirmations, it is almost impossible to be aware of all the possible health effects. A negative

image may have been created around nanotechnology, even though many technology assessment roadmaps exist and health and safety are an important part of governing nanotechnology. However, companies may prefer to wait until all the possible health risks are identified rather than taking the risk of incorporating risky materials in their products. Governments are aware of this risk and has the task to balance between sustaining technological development while assessing the risks for society. For that reason the Dutch NanoNextNL program included a theme specifically to investigate the risks of nanotechnologies for health and environment [39].

2.4.3 Technology transfer

Another reason for the gap in the transfer of nanotechnologies is its science driven character, as it is a relatively new field and knowledge is young [1]. This results in a lack of application and implementation knowledge. The upside is that nanotechnologies have a high competitive potential because of the low adoption rate. Competitive companies may not be aware of its implications or they may prefer to wait until the technology is further developed. The downside is that the technologies are not completely developed yet and implementation requires specific knowledge, measuring equipment and other production barriers. This means that the application of nanotechnology in products or processes is not an activity of simply buying a technology and adding it to the production line. This limits the application possibility for (smaller) firms that do not have the knowledge and resources at hand. In these cases, external knowledge and systems are required, resulting in a research project with external partners such as research institutes or universities. This reduces the adoptability of nanotechnologies, as resources for a project are required and high transaction costs are incurred.

Nanotechnology balances in a level playing field constituted by universities, research institutes, large technological companies, startups and early adopters [40]. Rafols and Huang have discussed that nanotechnology is not a product in itself but needs to be added to an existing product or process [7], [34]. This makes the commercialization of nanotechnology even more complicated as it must show its value in a process [44]. The actual applications are not in a phase of mass adoption yet, instead the technologies are still in a development phase. For companies, individually commercializing nanotechnology can be too risky or does not align with their core business [6]. Furthermore, for a company in bulk manufacturing this technology push principle is not a regular innovation path. Bulk manufacturing rather focuses on scale, cost reduction or new product development. These companies would rather acquire knowledge that strengthens their existing activities. Although the discussed GPT-character of nanotechnology enable product and process optimization, there is a missing link between this GPT-character and application within the companies.

2.5 Chapter conclusions and key findings

The goals of this chapter were to introduce nanotechnology, explore its character and to determine what is holding back mass adoption of nanotechnology. It is now clear that nanotechnology stems from the manipulation of nanoscale matter and that its special behavior can be explained by quantum mechanics. Manipulation in this scale results in the special characteristics that could be exploited for various purposes. This is where the terms general- and multi-purpose technologies come from. It also became clear that this nanoscale understanding of materials is described in almost any natural science field, making the nanotechnology field wide and interdisciplinary. The broad nature of nanotechnology makes it

complicated to construct one general commercialization strategy. Health and safety concerns inhibit the transfer because commercialization is slowed down by risk analysis and a negative image is created around nanotechnology. The field also suffers from general commercialization barriers. Furthermore, companies would rather wait until a technology is further developed and understood than implement it themselves while they are unsure of its implications. However, the implications are for general purpose and can be widely implemented. For example; weight reduction, increased strength, catalysis (improved reaction rate) and conductivity are multi-applicable concepts. These findings show that there is a gap in accessing nanotechnology knowledge and for reviewing its implications. This claim is supported by the broad nature of the nanotechnology field, which crosses multiple scientific areas. In the next chapter we will therefore explore why companies innovate, how they organize innovation and what tasks they execute to establish new products. The aim is to identify the needs of the company for innovation and how those needs can be fulfilled with nanotechnology. We then can design strategies to enable the technology and knowledge process.

3 Theoretical framework: Innovation

In the previous chapter nanotechnology and its innovation possibilities for companies have been outlined. Nanotechnology is an interdisciplinary field of technologies that emerges from many natural science fields. Among other things, it increases the performance of materials, reaction rates and enables electronic functions. To assess what type of companies benefit from nanotechnologies we will find out in section 3.1 why companies innovate and how sectoral patterns influence the innovation process. We will see that the differences in type of company determines what knowledge sources companies use to innovate. It will also show that the innovation potential of nanotechnology can be very useful for companies in bulk manufacturing. In section 3.2 it is discussed how those companies innovate and what innovation model describes this process best. After presenting why and how companies innovate in bulk manufacturing it will be described what tasks companies execute to realize innovation. First the process of technology scouting will be introduced in section 3.3 followed by the operational task of engineering problem solving and engineering design which is motivated in section 3.4. Both in technology scouting as in engineering problem solving there is a need for information. However, the continuous increasing amount of information asks for new tools that enable to organize the information. Therefore, in section 3.5, text mining techniques and its applications in innovation management are discussed. Once all the theories have been presented a full discussion will be provided which motivates the research design in chapter 4.

3.1 The organization of Innovation in bulk manufacturing

Within the manufacturing industry the role of innovation is indisputable, but where does the essence of innovation come from and why is it so important? On the highest level, innovation is discussed from a societal point of view. The role of innovation in society is important to foster societal growth. This has already been pointed out in 1956 by Robert Solow [24] who developed a model providing three main sources that foster economic growth:

1. Capital accumulation,
2. Population growth and
3. Technical development.

Within this theory, technical development relates to innovation and the generation of new knowledge to be applied in society. Solow's theory is supported by many other respected researchers such as Lundvall, Freeman & Soete and Sundbo who also argue that innovation is a socio-economic driver for economic growth [45]–[47]. Thus, innovation brings society and companies forward. A brilliant example often used to explain the impact of innovation on society is the development of the T-Ford. The T-Ford revolutionized the mobility sector by making mobility available for millions, simply by reinventing production [48]. Companies are not alone in their innovation journey. To keep up with competition, companies are continuously searching for improvements to increase their competitive advantage [9]–[12]. A company that does not innovate and does not listen to its customers can be easily surpassed by competitors that do. A company needs to be dynamic and able to adapt to its surroundings. The drivers for innovation have been discussed in innovation literature multiple times. Cooper explains that innovation is driven by four drivers: technological development, increasing customer needs, shorter product life cycles and increased world competition [49]. Utterback argues that innovation is essential for company survival and that two types of innovations constantly need

to be executed, namely, incremental and radical innovations. Incremental innovations are essential for short term survival while radical innovations ensure long term existence. In his five forces model Porter explains a set of five imaginary forces continuously acting on the space a company is operating in. This space is determined by customers' bargaining power (1), suppliers (2), the threats from substitutes (3), new entrants (4), as well as the rivalry from its direct competitors (5) [50]. Innovation is a way of staying in position by using supplier input, creating market demand, being aware of the competition and ensuring that the product remains interesting for customers. Based on the innovation literature Utterback has a generalized and theoretical approach to innovation types within firms instead of providing actual drivers. The approach is useful to understand the process of innovation in firms but is not directly applicable to them. Both Porter and Cooper provide more pragmatic and useful drivers for firms, which can be applied to understand the threats to the company and which drivers can be mapped by the firms themselves.

The driving force for innovation varies per industry type. Pavitt has researched and described this in his multi-cited article "sectoral patterns of innovation" [12]. Although the article has been cited many times, there is recent criticism on the use of Pavitt as a source for sectoral pattern analysis. Pavitt's theory on sectoral patterns dates back to 1984 and therefore is not up to date. It has been argued that the sectors described by Pavitt focus mainly on manufacturing companies, while in recent years the business landscape has been enriched with service providers [51]. However, to explore nanotechnology for competitive advantage, manufacturing and production driven companies are particularly interesting. In this study we will extensively use the advances of technical change, a process that is thoroughly described by Pavitt. Within his theory he identified three types of firms: supplier-dominated firms (agriculture, housing, private services), production-intensive firms (bulk materials, specialized machinery) and science-based firms (electronics, medicine, chemical). Science based firms incorporate the newest science fields and it is well known that sectors like electronics and medicine are at the forefront of innovation with nanotechnology [1], [40]. Supplier dominated firms rely heavily on their suppliers, as the name indicates, and therefore do not have much innovative freedom [12]. In between these two firm types we find production intensive firms. These types of firms are an interesting sector in which to explore the implications of nanotechnology as they have the freedom to innovate because of their product- and process driven activities. Pavitt delineates the production intensive industry further into two types of firms, namely, bulk manufacturing and specialized suppliers. As specialized suppliers are relatively small and focus on a functional product, the main interest of this study will point towards bulk manufacturing. The rationale for this choice will be further discussed. Within the production intensive industry, where scale is of importance, the main sources of technology are suppliers, R&D and the production engineering departments [12]. These companies innovate based on improvements in their raw materials or have their own research, development and engineering activities. As the production is continuous and concerns large amounts, failures have high impact on the output. These companies work actively to decrease failure, increase capacity in an act of continuous troubleshooting. This results in good understanding of the process and being aware of the bottlenecks within the production process. This continuous need aligns well with the enabling character of nanotechnology for process improvement, economies of scale and new functionalities for products. This combination is only found in bulk manufacturing.

3.2 The innovation model

Developments in the business landscape in the past decades have influenced the way companies manage innovation. The internet, fast communication and immense databases have resulted in a tremendous growth in information and information accessibility [52]. This enabled companies to continuously be aware of the newest inventions and knowledge, thereby making it possible to continuously improve their products and services. Innovation is the development of existing or new products based on drivers that push the status quo into new directions. The process of optimizing and developing these products and services is the assumed "innovation process". An innovation process can be a complex, ill-structured process involving many stakeholders, and a lot of knowledge and resources [53]. Companies face a real challenge in managing the innovation process. Innovation is a resource intensive process correlated with high uncertainty of the outcomes [54], [55]. Therefore, companies take risk-based decisions about what kind of innovations they would like to invest in. The risk and the amount of the investment must not outweigh the potential benefit of the innovation. If this is the case, the investment is still a good investment from a financial perspective. In section **3.1 The organization of Innovation in bulk manufacturing** companies is described. It is outlined that these companies determine their innovation potential based on competitor influence, technological development, shortening product lifecycles and customer needs.

The innovation project can be structured according to many models that have been explained thoroughly in literature. Well-known innovation models are the linear model of technology push, the market pull model, open innovation model of Chesbrough and the chain linked model by Kline and Rosenberg [56]–[58]. The models will be briefly explained: The **technology push model** (**Figure 5**) can be viewed as a linear model in which scientific findings result in new technologies that are "pushed" into the market. The **Market pull model** (**Figure 5**) is somewhat similar except that it reasons the other way around. New technologies are developed as a result of a certain market need**.** The **Open innovation model** (**Figure 8**) reasons from the premise that knowledge is everywhere and that this knowledge can also be applied within the firm and internal knowledge can be shared outside the firm [57]. An open innovation strategy within the firm can still be market pull or technology push, it merely describes a differing strategy of how to organize the innovation process. The last model is the **Chain-linked innovation model** (**Figure 7**). This model distinguishes itself from the linear model of technology push and market pull. From the company perspective an innovation project is a continuous flow of knowledge that supports a certain project/process design. This means that when reasoning based on a scientific finding, feedback loops from the market environment are necessary to test whether there is a market for the finding [56], [59]. The same is true for market need -- there must be some technology out there to construct a hypothesis on. The theory on the chain-linked model argues that there are multiple continuous loops throughout the innovation process supporting the successful realization of the information.

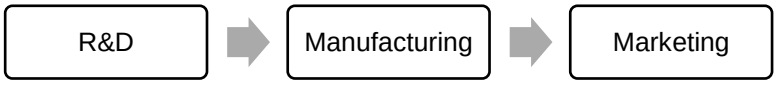


Figure 5 Technology push innovation model (own figure)

Figure 6 Market pull innovation model (own figure)

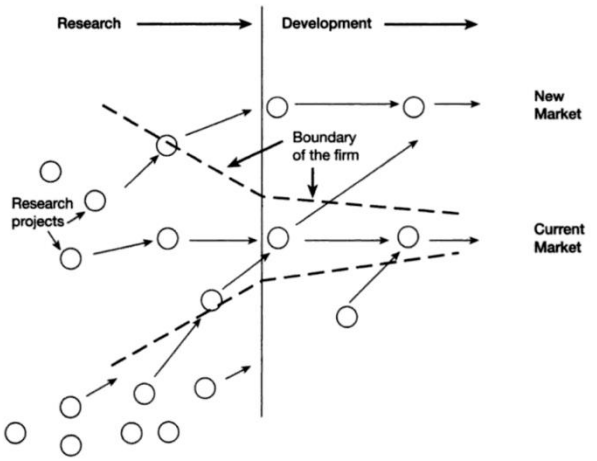


Figure 8 The open innovation model adapted from Chesbrough [57]

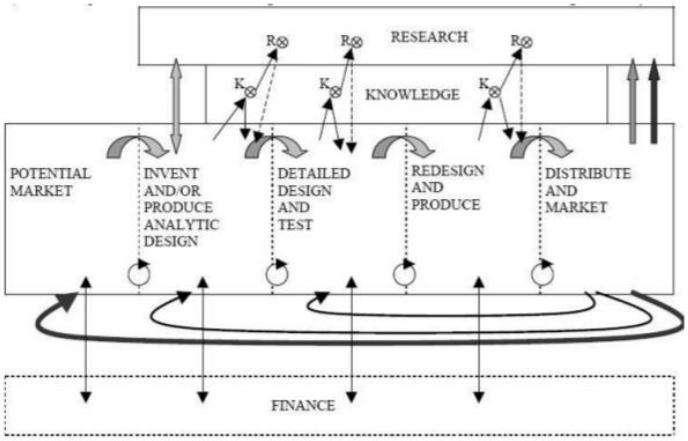


Figure 7 The chain linked innovation model adapted from Kline *[56]*

3.3 Technology scouting

Before a preliminary innovation project is designed, as described in section **3.2 The innovation** model, the process of technology scouting takes place. In previous literature, the process of technology scouting has been described using names such as technology intelligence or technology sourcing [60]–[62]. During the technology scouting process the firm defines the problems and challenges that need to be solved or what kind of new products need to be developed. This process results in identifying, evaluating and selecting technologies that suit the company's goals. According to Porter, this process is arranged by the corporate strategist [50]. Phaal et al determines this phase as the project level at the start of innovation. In this phase the company determines its innovation strategy. These future strategies and goals can be based on cost reduction, new product development and customer needs. The project level is where new technologies and products are controlled and evaluated [63] and where innovation goals are identified. Setting up goals at the project level requires information from inside and outside of the company. This can be driven by suppliers, customers, individuals or universities [57], [64]. For example, increased raw material cost or price reduction of competitors may pressure the company to innovate for cost reduction [65]. These technical challenges and potential opportunities can be organized using a technology roadmap. A technology roadmap is an innovation management tool to structure the innovation process within a company. There are multiple interpretations of technology roadmaps, in Moehrle et al a technology roadmap is summarized as *"a graphical representation of technologies, often relating objects like products or competencies and the connections that have evolved between them in the course of time"* (Moehrle et al, 2013 p.4). Moehrle essentially state that a technology roadmap shows the technical reality and its possible developmental path in the line of the company. The existence of a technology roadmap and its role in innovation management supports the companies' statements in following the technological developments. It supports the validity of the chain-linked innovation model and the continuous activity to scout and evaluate new technologies. The technology scouting process is a mixture of activities. It is a process of systematically gathering information in science and technology with the aim of acquiring technology. Technology scouting can be executed by employees in the firm (technology scouts, innovation managers) or by external consultants. There are two main aspects in technology scouting. One is the identification,

evaluation and communication of information (technology intelligence). The second is the technology acquisition (technology-sourcing) [61] [66].

Table 4. Sources for Innovation and information [67]–[69].

Clients
Competitors
Universities
Suppliers
Other divisions within the same firm.
Consultants
Industrial fairs and exhibitions
Professional conferences
On-line databases
Patent analysis

The firm scouts for technologies based on internal problems and follows the developments of potential technologies. Technology scouts or innovation managers in the firm scout for technologies based on internal problems and follows the developments of potential technologies by using various information sources organized though an existing network. **Table 4** summarizes the sources for information on innovation. Based on literature regarding technology scouting it remains unclear how the firm organizes the problem in order to find technologies. In other words: how an innovation manager structures the identification of technology. It is interesting to note that the technology identification process is not clearly discussed in the literature, even though it is such an important step. Rohrbeck explains that the identification "*relies on weak signals and aims at the detection of technical discontinuities*" (Rohrbeck, 2007, p.2), and thus, is an unorganized approach. This identification method is only suitable for observing technology trends, while an innovation manager in the previously described situation is also looking at a particular technical problem or a specific functionality. The technology identification method in the innovation management process is more thoroughly described by Lichtenthaler who suggests that identification should be a selective search based on needs of the company (inside out) combined with interest in technology trends (outside in) [10]. This organization makes sure that there is no blind spot for discontinuous technologies while serving the company goals. A schematic summary of the technology scouting process is provided in **Figure 9**.

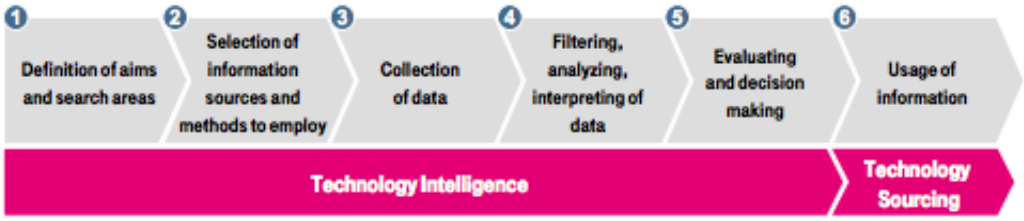


Figure 9 Figure showing the technology scouting process. Adapted from Rohrbeck [72]

The summarized knowledge sources for technology scouting provided in **Table 4** shows many possible sources of innovation and information that can be used for technology scouting. When exploring science based technologies it is assumed that sources such as universities and patents are key information databases. However, technology scouting based on literature and patent analysis (citation analysis) has been valued as complex and costly [60]. Thus, these scouting methodologies are mainly used for strategic issues, competitor analysis and open scanning for technologies. Nevertheless, they are used in corporates because there is a need to find real new opportunities. Simply using competitor development and developing the same products as developed by the competitor does not support the competitive advantage enough. Furthermore, there is an increasing pressure within firms to improve effectiveness of R&D project selection, pressuring teams to discover and validate new technologies as quickly as possible [70]. The identification of technologies from an engineering point of view is more

specifically discussed by Mavris et al. They constructed a methodology for decision making in the early phases of aircraft design [71]. This methodology is a step by step approach for the early design of a new product, and relates to the engineering design approach. There is a distinct difference between technology sourcing and an engineering design project approach. Technology sourcing focuses on the initial phase of innovation (T-1), where there is hardly any information and a lot of uncertainty about the function. Contrarily, an engineering design is a process of new product/process generation. However, both the methodologies cover the activities of technology identification, evaluation and selection [71], [72].This overlap can be found in one process that is nicely illustrated in a figure by Rohrbeck (**Figure 10**). In this figure the horizontal process describes the process of innovation management that is also described by Mavris, while the vertical process describes the previously outlined innovation process. Both processes overlap in product specification and development. This means that the selection criteria for innovation management for a product or process uses the same systematic design as the selection of a new technology that is sourced from outside the company. The next section will provide more information about the engineering design, its nature and the methods that accompany this approach. The process itself, and how it relates to the process of innovation management needs to be thoroughly examined'

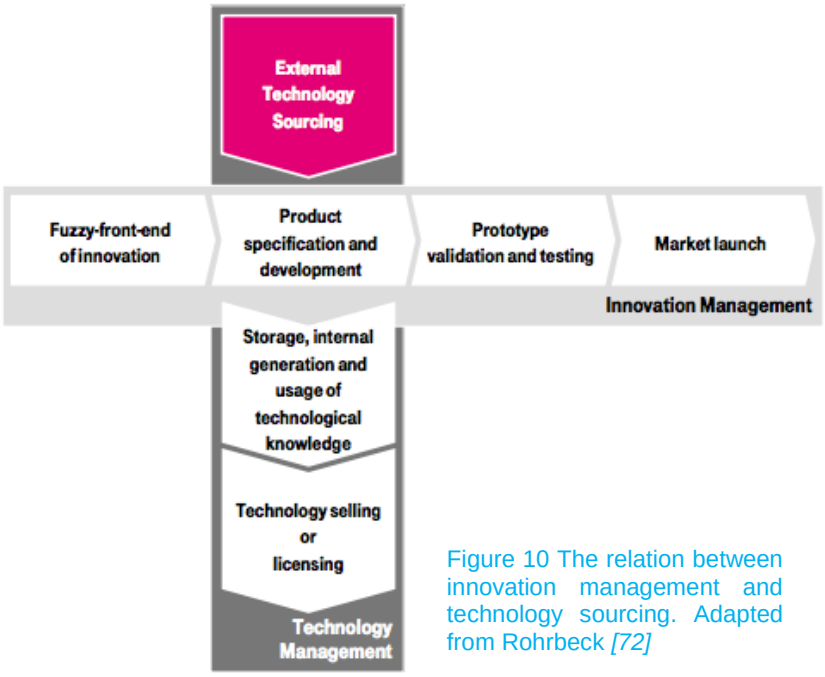


Figure 10 The relation between innovation management and technology sourcing. Adapted from Rohrbeck *[72]*

3.4 Systems and functions in engineering design

The previous section explored the theory on technology scouting and ended with a figure by Rohrbeck showing the interaction between technology scouting and innovation management. In this section more information will be gathered on the innovation management process within engineering design, focusing specifically on the innovation process for problem solving with the engineering design approach. First, the nature of solving problems in an engineering context will be described. The theory on systems engineering will be introduced and the role of functions in technology. In the next section engineering design and technology scouting will be linked to text mining techniques. We will discuss how these techniques are currently applied for technology scouting and how this together with engineering design can be elevated to a new unique approach. Throughout the text we will make use of the terms; engineering problem, technical problem, technical challenge and innovation problem. All the terms describe the same process within the context of this thesis. We define these terms as: "*the challenge that the company needs or wants to overcome by using technology for improving processes or products and for designing new processes or products.*"

Engineers in the industry face many problems during their work. Continuous pressure to innovate and external forces on the systems require them to come up with knew technological ideas to keep up with the pace of development. To do so, engineers have to gather knowledge continuously. Most of the (basic) knowledge gathered by engineers during their studies has been further developed throughout their careers by sharing and creating new knowledge. This process has been outlined by Henriksen [73], who described the complex activities of engineers in gathering knowledge to solve problems. An important argument made by Henriksen is that this problem solving process is not linear:

Problem – knowledge – Solution

In a more realist approach Henriksen argues that it is an iterative process:

Symptom – Problem
Knowledge – Conceptualization
Knowledge – Conceptualization
– Solutions

The problem starts with a symptom, a deficit in the process, a business opportunity or a threat from the market. When this symptom is identified the first step is to understand why this symptom occurred and constructing a problem statement. From this moment on, the iterative problem solving process begins. A problem goes through a continuous cycle of being conceptualized, being partly solved, and being conceptualized again until the symptoms have disappeared and the problem is solved. Knowledge plays a vital role in this process, both to generate solutions to the problem as well as in understanding the symptoms and the solution. Engineers have many different sources for knowledge of which the most important one is the dialogue with other people. Other sources are previous projects, customers, suppliers, research programs, literature, electronic media, knowledge centers, consultants or fairs and conferences. It is interesting that problem solving is not simply about finding a solution for a problem, it is also about designing the problem solving process, asking the right questions and continuous feedback from the symptom. Knowledge must be structured according to the problems and systems that evolve throughout the process.

Apart from the iterative process in engineering design there are more challenges the engineer faces in solving an engineering problem. In engineering design the problem is larger than the problem-solution relation. Regardless of whether the design is linear or iterative, the innovation problem is part of a larger system. Especially in bulk manufacturing technical problems or innovative goals can be regarded as part of a larger system. It is important to understand that the goal is not only to solve a problem but also to make sure that the obtained solutions can be embedded into the larger system. This system can be open or closed, can contain multiple elements and can be comprised of multiple functions. This means that considering the problem solving design process described above, from the moment that a part of a system, in which the problem occurs, is retrieved from the real world and ends up on the design table, the connection with the real world needs to be safeguarded. The level of the problem in the system determines on what level the problem should be organized and what kind of technology is necessary. The higher the level of the problem in the system the more functions the technology is comprised of. The same is true for finding a component that needs to execute a single function and is part of a larger technology or system [74]. We can therefore not claim that a

solution to a problem executes a single function and therefore not say that a technology that is scouted is only comprised of one function. We however can say the technologies/solutions are comprised of (multiple) functions and that the amount of functions depend on the level of embeddedness and linkages within a system.

The theory of systems engineering provides a solid and well-founded ground on which complex problem solving processes can be organized. Systems engineering is a theory in science and practice that focuses on the design and organization of complex systems. Systems engineering incorporates all the possible influences that act on the system and reasons that a system is more than the sum of its parts. Within systems engineering, methodologies are provided that organize a complex problem in order to solve it within the frame it operates in, taking into account soft (persons) and hard elements (technology) and making sure all the requirements in this field are met. A frequently used methodology to organize a process according to systems engineering is the SIMILAR method [75]. Which breaks the process down into seven tasks:

1. **S**tate of the problem
2. **I**nvestigate alternatives
3. **M**odel the system
4. **I**ntegrate
5. **L**aunch the system
6. **A**ssess performance
7. **R**e-evaluate

These tasks can be related to the problem solving process in engineering that has been previously described. This problem solving process is even more elaborate as it starts with a symptom. The SIMILAR method can be a means for structuring the problem solving process in an engineering project. A problem solving project in engineering is a good example of a complex project as it must be executed within the organization that will continue its daily process and activities simultaneously. Furthermore, it needs a problem solving structure to define requirements, and forces the engineer to understand and conceptualize the problem. The first step is a problem statement that will define how the symptoms translate into the problem. To go from task 1 to task 2 of the SIMILAR method the problem must be formalized creating requirements and by defining how the alternatives will be evaluated. During these steps the engineers need to convert the symptom into a problem and approach the answer towards a solution. Knowledge is required for both constructing the requirements as well as for the generation of alternatives. The engineer's general or external knowledge is initially required to understand the symptoms, define the problems and generate the requirements. The same is true for generating alternatives, when the problem is clear it is still unknown how the problem could be solved. The engineer can turn to its knowledge channels to acquire the knowledge, but generating of alternatives for a problem that needs to be solved is quite complex. Within engineering design a few tools are available that could help to generate alternatives: brainstorming techniques, literature reviews, patent searches, reverse engineering and benchmarking. Within patent searching the theory of inventive problem solving (TRIZ) and text mining techniques are already introduced. These techniques have not yet been used to directly generate means for functions.

In this theoretical background it is important to understand what the nature of problem solving within companies is. Although it looks simple, the company has a technical problem and the task is to find a solution, it is more complex in real life. A lot of reasoning and knowledge is required to detect a symptom, structure a problem, and connect this to knowledge that could help solve the problem. It would be unwise to construct a methodology that reasons in this linear fashion, especially when iterative methods are already widely accepted and available. Systems engineering methods can be adopted to help companies structure the innovation problem.

3.5 Computer aided techniques for innovation

Along with many types of computation and information systems the field of natural language processing emerged. This field of information science is all about letting computers understand language and part of speech [76]. Thereby allowing a computer to interpret texts like a human interprets texts and language. Human beings' language must be learned in order to understand speech, conversation and text. To read, a human is taught what letters are, how they sound, how they can be put together to create words and how words make up sentences and stories. If humans can learn to interpret text and use it based on rules than a computer can be programmed to interpret text and use it based on these same rules. This has led to the field of Natural Language Processing (NLP).

The field of natural language processing has led to interesting applications in science and industry. Take for example a computer's email software. When a person receives an email from a friend about an event later that week the software understands the connection between the date and location and proposes to add this to this person's calendar. Furthermore, NLP can be used for sentiment analysis of online newsfeeds. Using NLP algorithms, the sentiment of a text can be deducted and show whether the article is positive or negative about the topic it describes. For example, if a stockbroker wants to conduct a study about the sentiment of a certain company, it could search for recent articles and establish the weighted sentiment of the company. This way the stock broker could choose to invest or not to invest in the company [77], [78].

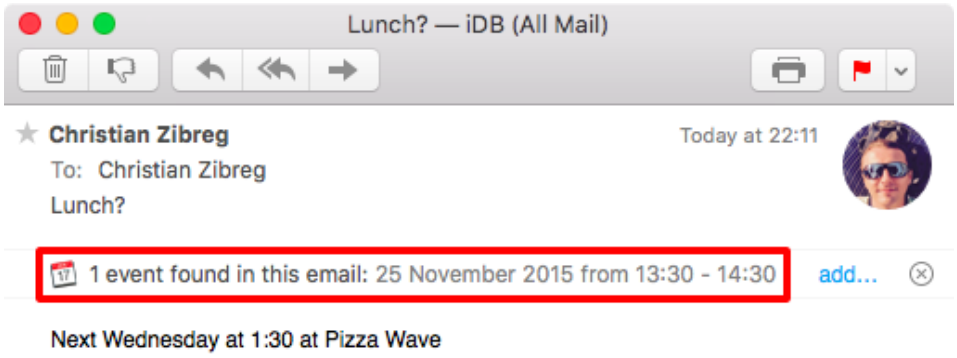


Figure 11 Suggested events tool example using NLP.

Natural language processing and the tools that can be developed with the knowledge in this field appear to be very useful. NLP tools can be used for information extraction in large amounts of structured or unstructured texts. When one searches for specific types of information in large amounts of text, data mining techniques can be applied [79]. This specific field of data mining using NLP tools is called text mining. Text mining has already found many applications in innovation management and technical knowledge generation. One of the key applications of NLP is the processing of patents for knowledge extraction. Patents harbor a

great deal of technical information that can be used in a problem solving process [80], [81]. Therefore, they are an interesting source for information extraction that could contribute to the strategic and innovation processes. This can be useful to obtain prior-art when filing a new patent or to obtain technologies from competitors that can contribute to the innovation strategy [82]–[84]. In science, patents are analyzed by social scientists to measure innovation activities in industries, and regions. Scientists also investigate the scientific developments based on bibliometrics and citation analyses. This information can be used to contribute to policy making, measuring research activity and to observe new emerging patterns in science [85], [86].

There are several ways to mine text, one of which is NLP. Abbas et al have reviewed different text mining approaches for patent analyses. **Figure 12** shows the taxonomy of the text mining techniques. ***NLP techniques*** are used for: technology roadmapping, novelty detection, identification of promising patents, technology intelligence, technology trees, competitor analysis etc. The use of NLP for innovation is often executed by incorporating patent studies with a TRIZ based approach to generate novel and innovative technology [49], [87]–[89]. Within NLP techniques there are two main strategies for mining and structuring text. The first is the keyword based approach, in which text is analyzed based on keywords, and texts containing the keywords are displayed. Keyword analysis is useful to obtain the frequency with which certain words are found in text data. For example, this method can be used to ascertain how many articles in a dataset contain the word nanotechnology. The downside of keyword-based text mining is that it does not show any relational information between other words in a sentence or text. This is not the case for the second main NLP strategy, which is an SAO based NLP technique and looks at Subject-Action-Object (SAO) triplets. SAO triplets can be formed based on the grammatical structure of sentences that consist of an object, a subject and a relation between those two: the "action". These are noun-verb-noun relations, and can contain a problem-solution relation which is an interesting property for problem solving [90]. The second text mining technique is the ***Property functions based approach***. This technique allows the extraction of properties and functions from the text using grammatical analysis. The property is related to the characteristic of the system while the function is related to the action of the system. NLP tools are used to establish the grammatical connections between function and property. The benefit of this technique is that it does not require keyword input. Instead, the Property-functions relations can be explored to interpret the technological findings of a patent or other technical text. ***Rule based***

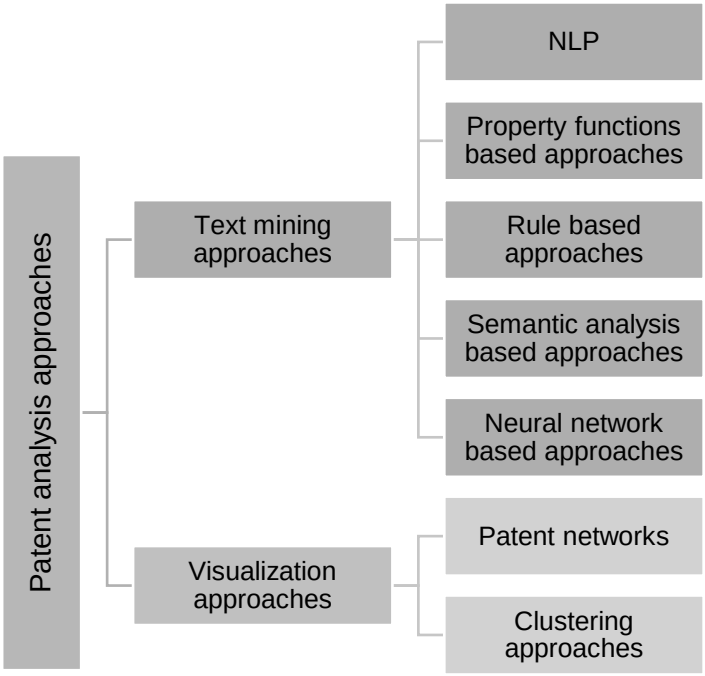


Figure 12 Taxonomy of techniques for patent analysis. Adapted from Abbas et al *[13]*

approaches make use of if-then terminology to mine data from the texts. This technique has been used to mine changes in metadata of patent trends. ***Semantic analysis based approaches*** in patent analysis require more domain knowledge for the context of the patents. With semantic analysis the mining is focused on word meaning rather than word frequency [84]. Patents can be mapped based on the context of the words. Studies have been conducted using semantic analysis to extract the key concepts of patents and identify relationships with patents [91]. ***Neural network based approaches*** use training of the network (of patents). This training is executed by using input from multiple users which is used to train the search algorithm and optimize the outcomes based on this knowledge. Training of the network has been used to evaluate the quality of patents, but also to obtain optimized searching for prior-art, patent infringement and IP [92].

There are pros and cons of using each technique, and choosing the most appropriate one depends on the purpose for text mining and the type of dataset. **Table 5** shows which text-mining approach is used in which situation and is based on the reviews by Abbas and Mattas [13], [93].

Table 5 Text mining approaches, their purpose, advantages and disadvantages [13], [93].

Technique	Purpose	Dataset	Pro's	Con's
NLP keyword based	Determining frequency of words.	Structured and unstructured	Fast, easy and efficient.	Does not give the information about relations in technologies.
NLP SAO based	Structuring the subject, action and object of a sentence. Extract the functionality of a technology in text, the tree structuring of technologies, roadmapping, trend analysis and novelty detection.	Structured and unstructured	Extracts information of a technology even in large amounts of text. Shows the dependencies of relationships between words.	Is dependent on the sentence grammatical structure. Grammatical ambiguities.
Property-function based approach	Technology trend analysis allowing the inclusion of new patents.	Unstructured	Does not require a predefined set of keywords and phrases.	Grammatical ambiguities. Unable to distinguish technological importance as it looks at the functionality. Manual categorization of properties and functions.
Rule based approaches	Grouping of patents based on if-then rule.	Structured and unstructured	Also works with partial information.	Requires domain knowledge and system learning.
Semantic analysis	Text based similarity. Based on string similarity, semantic	Unstructured	Extract key concepts and	Inefficient, corpus length is limited.

based approaches	similarity and common-word order similarity. To find claims made in text.		identify relationships.	
Neural network based approaches	Improving the search outcomes for patent searching based on annotator input.	Structured	Improves the precision of the results, reduces time.	Complex algorithms, requires training and therefore annotator interaction.

The NLP field is extensively applied in patent analysis. The reviews executed by Mattas and Abbas are based on 16 and 19 studies respectively. Roughly 40-50% of these studies are a NLP-based studies using SAO-based text mining techniques. In addition to the advantages of SAO described in **Table 5** there are many NLP tools available to construct SAO-structures. Furthermore, many studies exist on the use of SAO-structures for mapping technology fields or to execute innovation policy analysis. Furthermore, the SAO structuring of texts can be used to extract problem-solution relations from texts. An interesting study that uses SAO for product innovation was conducted by Yoon et al. In this study patents and their functions have been compared to explore potential crossover of functionalities to improve products and existing functions [94]. This study is an interesting example of how SAO-relations can be applied in product innovation. It shows how SAO-relations can be applied for innovation management and function structuring.

SAO-parsing is an interesting text mining technique, mainly because of its ability to extract functions from sentences and as a result it enhances the extraction of concepts from large amounts of text compared to keyword based approaches. Previous research with SAO-parsing has demonstrated its capabilities for innovation management, technology roadmapping and product development. These capabilities support its potential to be applied in all kinds of technical texts.

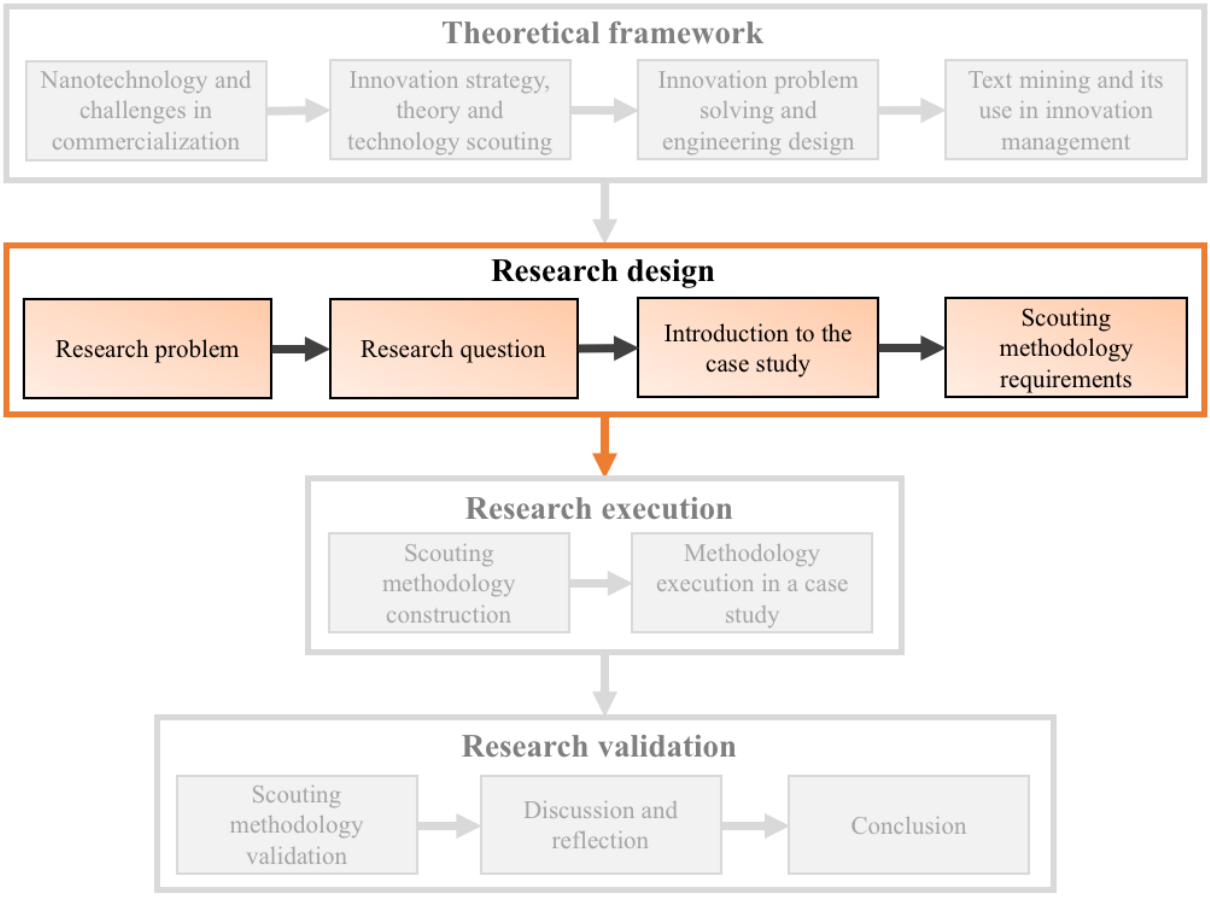
3.6 Chapter conclusions

In this chapter, theories on innovation management, technology scouting, engineering design and text mining techniques have been introduced. The aim of this chapter was to show how innovation management, technology scouting and engineering design are founded in the literature. It has been determined that innovation management is a continuous and iterative process in which both the technology scout and engineer are involved. It has been observed that the process of innovation management is similar to that of engineering design. Merging the two practices together results in the innovation problem solving process. Technology scouting can be applied within this process as a potential source for information and knowledge. As technology scouting is a time and knowledge intensive process, computational practices for text based technology scouting have been reviewed. To automate the technology scouting practices of reading and interpreting from textual data, computational text mining techniques can be applied. Text mining approaches are currently applied for bibliometric analysis and patent analysis. SAO-based text mining approaches are extensively used to extract functions from technical texts. Further exploration of its capabilities in innovation management is interesting when they can be combined with nanotechnology based information. In the next chapters, chapters 2, an 3 are used as a theoretical background to construct the research problem of the current study. 'The aim is to define a general approach

for production intensive companies to support their innovation problem solving process through implementing the toolbox of nanotechnologies in their current technology scouting practices.

Part 2

Research design



4 Research problem

The theories and practices described in the previous chapters have created an interesting background in nanotechnology, its adoption pitfalls, innovation problem solving, technology scouting and the use of NLP text mining techniques to extract functions from texts. The next step is to formulate a research question that structures the process of setting up a methodology that supports the firm in evaluating nanotechnologies for competitive advantage. To do so, a short summary of the past chapters will be provided in section 4.1. Based on these chapters the problem statement and knowledge gaps (section 4.2 and 4.3) are determined, which describes the problem that results from the status quo. Consequently, these result in the synthesis of a research approach and generation of objectives, deliverables and the research question. In the last sections the research question is split into multiple sub questions, each of which will individually contribute to answering the main research question.

4.1 Problem introduction

Nanotechnology has been a popular field for years, promising ground breaking and world changing technologies [19], [95], [96]. Although great things are possible with the technology, the commercialization of nanotechnologies has only shown to be fruitful for a specific type of company thus far. These companies are often large hi-tech companies with suitable knowledge bases, financial resources and skillful personnel [97]–[99]. However, the general purpose character of nanotechnology seems to have value for many more industries. Lightweight materials, specialty coatings, soft matter and catalysis might be opportunities for many other industries that use a lot of materials in products and processes. We have discussed that on the macro level (societal) there is a lack of technology transfer of nanotechnology. The main drivers for this lack of transfer is; first, the complexity of the nanotechnology industry itself, broadly defined without an integrator that organizes the information and possibilities of nanotechnologies. Second, the health and safety risks that limit the adoption of nanotechnology because firms would rather wait until risk-analyses show that the technologies are safe for society. Third, the field of nanotechnology faces the general pitfalls of market adoption, such as uncertainty of technologies, long lead times and costly research based innovation.

In addition to the adoption challenges of nanotechnology on the macro level, there is the need for companies to innovate in order to sustain the business on the micro (firm) level. The described production intensive industry is an industry that strongly depends on innovation, has an engineering department and sets strategic innovation goals. Problem solving, efficiency improvement, cost reduction and new product development are all part of that strategy. However, a production intensive industry is not a knowledge institute and therefore relies heavily on external knowledge. This knowledge can come from many sources such as suppliers, universities and patents. The main sources for production intensive firms are suppliers, their own production engineering and R&D departments. Knowledge about new technologies can be an important new information source to diversify from other companies or to find solutions for problems that where previously not possible. Firms hire innovation managers to apply strategies, and to scout and implement new technologies. The firm defines innovation goals based on drivers such as (global) competition, customer needs, shortening product life cycles and technical development. If nanotechnologies have the potential to achieve these goals, incorporating them in this process is particularly interesting.

Unfortunately, no framework, database or methodology exists for firms or innovation managers to explore the toolbox of nanotechnologies to support innovation problem solving. This results from the very fragmented and diverged nanotechnology industry. Furthermore, nanotechnology is mainly science based, and is represented by small spin off companies that explore the nanotechnology potential or by big firms that already apply the concepts in their products. To address the challenges in commercialization, the nature of engineering and technologies have been assessed. This has shown that technologies are comprised of functions, and techniques exist to index technologies based on these functions. These Subject-Action-Object based text mining techniques have already been extensively applied in patent analysis. As nanotechnology is well founded in scientific literature these techniques could be applied for indexing nanotechnological concepts from scientific literature. This would create a unique knowledge base comprised of vast amounts of nanotechnology technology-function relations that can be browsed for problem solving.

4.2 Problem statement

Nanotechnology, like any other enabling, research driven technology, faces challenges in commercialization. Despite all the efforts in research, innovation programs and technology transfer, the requirements for applying nanotechnology are only met by (small) specialized nanotechnology companies or large high-tech companies. There are three main uncertainties that inhibit the adoption of nanotechnology to a broader audience. First, the access to nanotechnologies is complicated due to its diverged and fragmented network structure. Therefore, companies are unable to determine whether nanotechnologies are available and in which processes they can be applied. Second, the health implications of nanotechnology are uncertain, and as a result companies rather wait to adopt nanotechnologies until the risks are more clear. Third, the field of nanotechnology is science driven and the market adoption is subject to the challenging transfer of knowledge from science to business (1). However, the application of nanotechnologies remains very promising because of its unique and enabling characteristics. Moreover, companies in bulk manufacturing are in a continuous need for innovation to secure firm survival. They include technology scouting and engineering design practices to scout new technologies and develop new products. Although these companies may be aware of the existence of nanotechnology, the nanotechnology industry is lacking proper nanotechnology opportunity identification and evaluation possibilities for those companies. As a result, the companies are inhibited in innovating with nano science and technology (2).

4.3 Knowledge gap

Following from the problem statement the knowledge gap is the inability of technology driven companies in bulk manufacturing, that could benefit from nanotechnologies**, to find, select and evaluate nanotechnologies** because:

(1) Commercialization of nanotechnology is complex due to the organization of the nanotechnology industry.

(2) Bulk manufacturing companies are unfamiliar with the possibilities of nanotechnology, or have imperfect access to information **that reduces uncertainty** (diverged market, health risks and science driven technology transfer) about nanotechnology application and therefore they are unable to innovate using nano science and technology.

4.4 Approach

The key actor or problem owner is two-fold in this situation. On the one hand we have the policy makers for transferring nanotechnology into the market (read: governments, universities, knowledge institutes). And on the other hand we have technology driven companies that are unaware or have imperfect access to the nanotechnology knowledge (stored in scientific papers). As the goal of this research is to increase the adoption and transfer of nanotechnology in the latter, the research will be written based on the firm level perspective.

In order to find out if a company has no or imperfect access to nanotechnology this research will be conducted within a company that is taken as representative for bulk manufacturing companies. This company does not have the conditions for nanotechnology application that are described earlier but does have the drive to innovate. The innovation strategy and practices of the firm will be described in chapter 5. To execute the process of exploring nanotechnologies and nanotechnology knowledge, a methodology must be constructed. This methodology will be a generic tool to structure the process of a step by step plan to identify, select and evaluate possible nanotechnologies based on publications from an online scientific repository. The methodology must be designed for people within the company that execute the task of strategic innovation management.

4.5 Objective and deliverable

The objective is the design of a methodology that can support the scientific transfer and application process of nanotechnology in companies. The second objective is the application and evaluation of the methodology at the representative company and explain to what extent it can be a valuable tool for nanotechnology scouting. Based on this the following objective and deliverable will be defined:

I. The objective: Is to increase the use and transfer of nanotechnology knowledge that can be applied by companies in their technology scouting strategy.
II. The deliverables is a methodology with clear steps for a company innovation executive to obtain nanotechnology applications for ideation & product/process innovation. Validated within a representative company.

4.6 Research question

Based on the problem statement and the following research question is designed:

“What kind of methodology can be designed that provides an innovation manager clear steps on how nanotechnology related scientific knowledge can be identified, selected and evaluated to support decision making in innovation strategy?“

Based on this research question 5 sub-questions are designed that, by answering them, will constitute the answer to the research question. For answering the sub-questions, a designed based approach is used.

4.6.1 Sub-questions

1. What requirements are needed for the methodology to overcome the gaps given in "*4.3 Knowledge gap*"?
2. How can the technological challenges, stated as functions, provided by the company be transferred into a natural language processing model (that is part of the methodology) that can link them to scientific knowledge?
3. How can the scientific knowledge be acquired, analyzed and structured?
4. What method can be used to evaluate the technology outcomes and use them in the company's innovation strategy?
5. Do the outcomes of the case-study meet the requirements obtained in sub question 1?

In the following chapters the sub-questions will be answered by **designing, applying and validating a nanotechnology scouting methodology**. In chapter 5 we will first determine the prerequisites of a reference company and how the company of study aligns with these prerequisites. We will also compare the innovation practices of the company to the innovation theories and models in chapter 2. Based on the prerequisites and the description of the case study company requirements will be constructed in chapter 6 for the design of the methodology in chapter 6. Measurable requirements need to be constructed to verify the methodology at the end of this research. Question 2 to 4 will be answered in Chapter 7. In this chapter the complete methodology will be designed that covers the process from input generation towards result assessment. In chapter 8 the methodology will be applied in the case study company. Two cases cases of innovation problems will be organized to find nanotechnologies that can be used to (partly) solve the innovation problem. In chapter 9 The results of the methodology and its performance will be assessed on multiple validation points. The chapter closes with reflecting on the requirements given in Chapter 6. In chapter 10 we will reflect on the methodology outcomes and discuss the findings and future challenges of the outcomes. The research is finished with a conclusion in chapter 11.

5 Introduction to the case study

In the previous chapters we have described the theory on innovation, how this is organized within the firm and what tasks firms execute to realize innovation. We then found that there is a gap in the possibility of bulk manufacturing companies to evaluate the innovation potential of nanotechnologies. A research question is proposed and a research design approach to bridge the gap is provided. Until now the view into the innovation process has been mainly theoretical. This chapter aims at determining the conditions companies need to have in order to benefit from a methodology for finding, selecting and evaluating nanotechnologies. This is described in section 5.1. In section 5.2 We will then introduce the company and outline in what way the company organize innovation to ensure firm survival. In section 5.3 we will determine how the practices in the company relate to the innovation theory in chapter 2.

5.1 Conditions for a representative company

In section 2.1 of chapter 2 it was described how sectoral patterns determine the innovation practices of the firm. It was argued that bulk manufacturing company can benefit from nanotechnologies because of its organizational characteristics such as economies of scale, having an engineering department and the continuous need to improve the process and and new product development. Based on this we will create a general argument that bulk manufacturing companies;

- Require innovation for firm growth and survival;
- Manage the innovation process themselves based on sectoral specific innovation drivers and sources;
- That those drivers match the unique enabling character of nanotechnology as an innovation source.

Based on this argument we can further construct conditions that a company in (bulk) manufacturing needs to have in order to benefit from the multi-purpose character of nanotechnology. Five conditions are constructed based on the description of bulk manufacturing and the implications of nanotechnology in chapter 2. The first straightforward condition explains the need for the representative company to be product or technology driven. The second condition relates to the drivers for innovation and describes the need for innovation by having constructed innovative goals. Part of this is also the condition to have an organization in place that could manage an innovation process. This is described by Pavitt as an engineering department. The fourth condition relates to the means of acquiring technology outside the firms' boundaries and to have an open strategy towards external knowledge. The last condition, and the most important one for this study, is that the implications of nanotechnology have not been assessed before. This means that companies are still unaware of the potential influence this technology field can have on their activities. These requirements construct the framework for whom this study and the outcomes of this research are applicable.

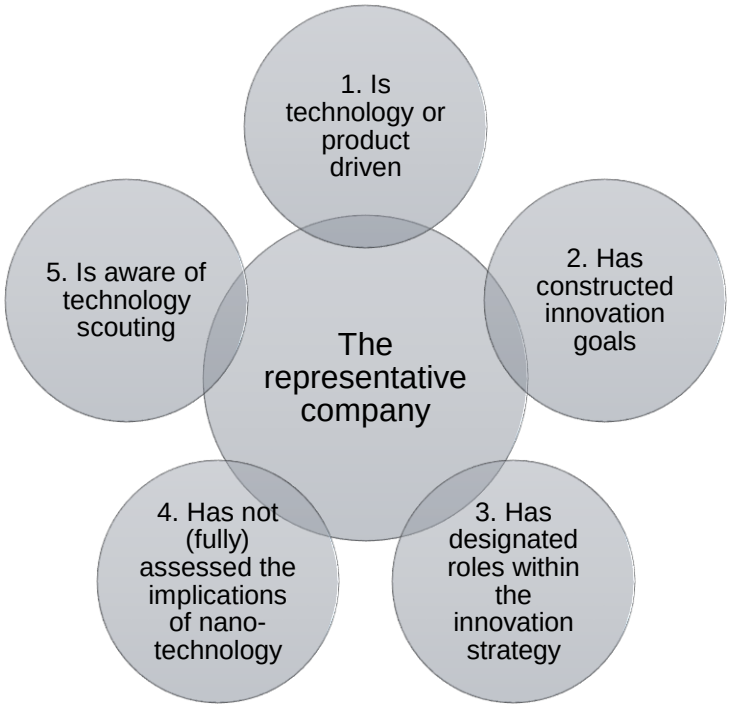


Figure 13 Requirements of a representative company

Based on the previously described conditions we can say that a representative company is one that has a driver to actively search for technological innovations in production intensive firms and is unaware of the potential of nanotechnologies. Thus a company sets strategic innovation goals and the innovation manager has a vital role in gathering ideas, knowledge and information to achieve those goals.

5.2 Introduction to the case study in bulk manufacturing

The case study is executed at DESSO and will be used as a representative for an industry that can benefit from nanotechnologies. This company is a Dutch company in the textile industry operating in a highly competitive market. In this section the company will be assessed based on the requirements described above.

DESSO produces textile products for commercial, residential, and hospitality housing. The company has multiple production facilities in which most of the (semi-)completed textile products are created. The production facilities are all located in European countries. The company has existed for many decades and has been owned by various parties. In the early 2000s the product and the company brand had an old-fashioned image. In those years the company invested to improve the brand and to create a better product image. Clients are decision makers in the field of design and architecture. These people make decisions based on design, sustainability and innovativeness (such as new functionalities). This means that DESSO changed their proposition to better target the decision makers. Consequently, DESSO has the aim to be the most innovative company in their field.

In the past years, DESSO has invested in creating new products to increase their competitiveness. The company has generated many products with special functionalities for health, feel and design. To break the status quo in the industry it teamed up with other

companies to create joint venture products. In doing so, it caught the attention of many designers, architects and other decision makers in real-estate. In addition to the investment in innovation capital, the company puts great emphasis on sustainability and Cradle 2 Cradle (C2C). Both the innovation and C2C strategy made the company a leader in their industry and allowed them to serve as an example for sustainable business.

DESSO needs to keep improving the product line and operations. In order to structure this process several people are working on product improvement, process improvement and innovation in general. Within the company multiple projects have been established that could reach the following goals:

- **Cost reduction**: This is a general goal to reduce the resources required in the operations department. The department deals with the production of the product. Cost savings can be achieved by re-engineering technical processes, decreasing raw material costs, reducing the amount of materials used, substitution of materials and organizational improvements such as Lean Six Sigma.
- **Cradle 2 Cradle 2020**: The company's goal is to produce and deliver products that are completely C2C certified. Cradle 2 Cradle means that materials used in production and in products do no harm to society, the environment and are renewable and reusable. As a result, all the company's products and by-products suit the C2C guidelines.
- **Innovative products**: The company operates in a highly competitive market. Therefore, the production of innovative and functional products is necessary to increase the competitive advantage. Continuous scouting for new product functionalities and seizing creative opportunities can lead to the development of new products. With these products the company can increase its market share and as a result, strengthen its market position.

These are the three main drivers for the DESSO to retain their innovative image and to stay competitive. To be an innovative leader the company is continuously monitoring the newest technologies and trends in science through innovation management in the operations department and the design and technical development department. The scouting of (cross industry) technological opportunities is a major part of this exercise.

To facilitate the continuous search of innovative solutions with focus on the three drivers, DESSO has constructed a working environment in which knowledge sharing is facilitated and ties between departments are strengthened. The innovation organogram is shown in **Figure 14**.

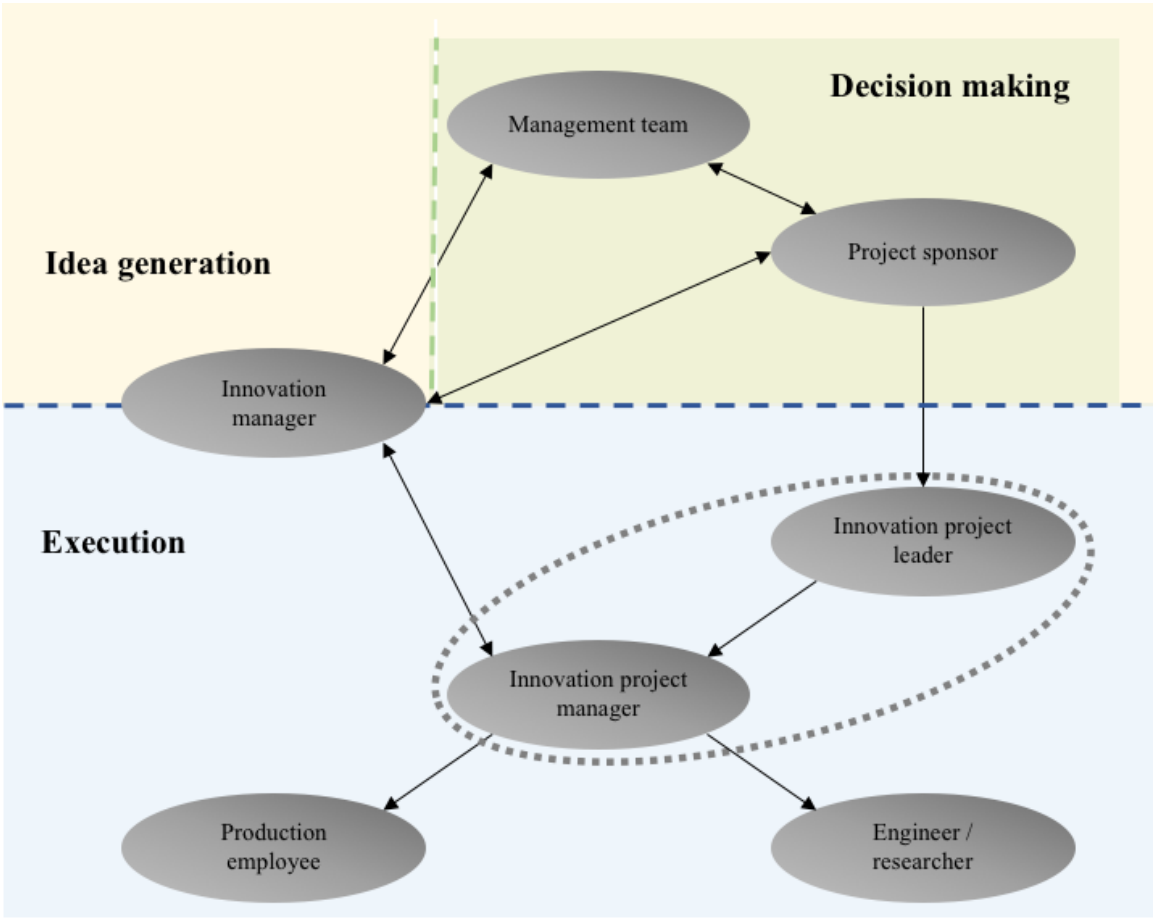


Figure 14 Innovation management organogram at DESSO (Own figure)

The first innovative activity is the idea generation. In this activity both the management team and innovation manager play a vital role. The management team defines the company's future goals and appoints tasks that needs to be addressed by the innovation manager. The company's future goals are driven by many sources such as customer needs, sustainability and technological developments. To generate new ideas DESSO also uses co-creation mechanisms where it uses input by architects to define new product ideas. It also works together with other companies to create joint venture products. During idea generation the innovation manager operates as a technology scout. The innovation manager searches for technologies that can fulfil the future goals in the production and product field. When an innovation manager scouts' technologies that fulfil the defined goals, the technologies will be evaluated by the management team. The innovation manager will have collected all the necessary information that could support the feasibility of the technology. If the technology is positively evaluated by the management team, money and resources are allocated by the project sponsor. In cooperation with the innovation manager, the project sponsor determines a project management team. This team will be executing the next phase which entails project execution. Depending on the size of the project, a project leader will be assigned to split the project into multiple subprojects. Each of these projects will be managed by an individual project manager that is in direct contact with researchers and executing personnel. The distinction between a project leader and project manager depends on the size of the innovation project. At DESSO, the innovation manager balances between idea generation and execution of the project. As the project "initiator" the innovation manager has the most information in the

project. This information is initially generated to make investment decisions when designing the project. When a project is constructed the information must be transferred to the project team, the innovation manager therefore is, at least at the start, part of the innovation project. Eventually, when all the information is transferred, the innovation manager is disconnected from the project.

The innovation manager, balancing between idea generation and execution within the company, has an important role in gathering the right information and knowledge. This knowledge is used to make decisions and as general project information for the execution of the project. There is a challenge for the innovation managers to continuously generate new ideas and find solutions for bottlenecks in operations or technical development. Therefore, the innovation manager has to monitor all kinds of technological fields and emerging technologies that could influence their product landscape. The innovation manager is, however, not only bound to the company goals defined by the management team. As the link to the outside world, the innovation manager also has to monitor competitors' behavior as well as follow the newest technology developments.

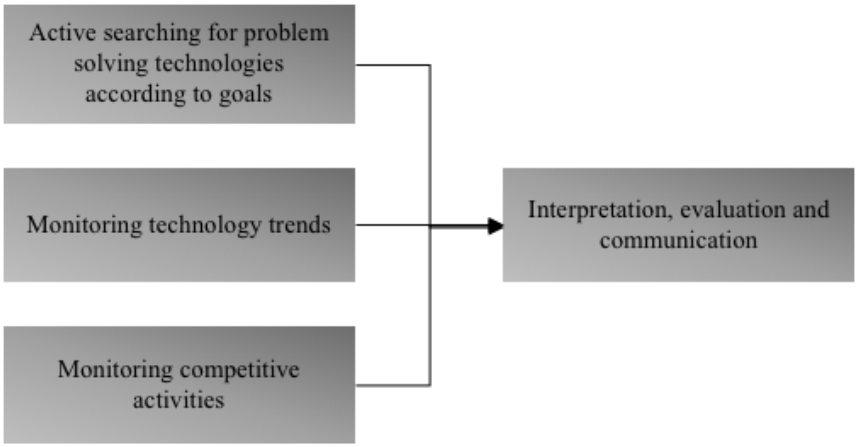


Figure 15 Technology scouting activities of innovation manager (Own figure)

It is important for DESSO to keep an eye on nanotechnology. The exact opportunities in nanotechnology have not been investigated yet and only a few application areas are known within the company. To keep up the pace with scientific developments in nanotechnology, it is crucial to increase the knowledge level in order to investigate the full potential of nanotechnology in reaching company goals. Initially, it is not important to determine in which particular production step or design this knowledge will be useful. For example, the knowledge can be useful to support cost reduction, reaching the Cradle to Cradle 2020 goal or to find new product opportunities. As the innovation manager looks at all kinds of innovative solutions there is no distinction in high impact or low impact technologies. The company has multiple goals and is open for disruptive change if they are in congruence with the goals or contribute to the competitive advantage. The path to nanotechnologies is currently underexplored. In the past there have been some attempts by third parties to supply nanotechnology related products but due to internal regulations they have never been applied. There is a challenge in reviewing the possibilities of nanotechnology from the perspective of the company. The company is aware of nanotechnology but its exact implications concerning material performance, product improvement and production speed are unknown. Knowing the implications of nanotechnology for the company would greatly help them to make decisions for future innovation projects.

Although nanotechnology has not been thoroughly explored, its existence is known and part of the innovation strategy is to follow scientific trends. The implications of nanotechnology for the company are not well understood. The company is interested in identifying the implications

of nanotechnology in relation to their products and processes as they benefit from improved materials, more efficient processes and the creation of new product functionalities. However, it is still unclear how this company could assess nanotechnologies for their current processes.

5.2.1 Generalizability of DESSO as reference company

There is a clear link between the proposed requirements of the representative company and the case study company. It has become clear that this company is a production intensive bulk manufacturing company, that it operates in a competitive market and therefore has constructed many innovative goals to secure its position in the market. To foster this there is a well-organized organizational innovation structure. Within this structure it is the innovation manager's task to scout technologies that support the innovative goals. Thus a company sets strategic innovation goals and the innovation manager has a vital role in gathering ideas, knowledge and information to achieve those goals. It is, however, still unclear where technology needs come from within the company. Sources of knowledge are known, for instance, suppliers, universities, individuals and customers. From Pavitt we know that within the production intensive industry the main sources of technology are suppliers, R&D and the production engineering departments [12]. These companies innovate based on improvements in their raw materials or have their own research, development and engineering activities. As the production is continuous and concerns large amounts of products, failures have high impact on the output. These companies work actively to decrease failure and to increase the capacity of the production line in an act of continuous troubleshooting. This results in good understanding of the process and increases awareness of the bottlenecks within the production process. These bottlenecks result in process improvement projects and, when the engineering department is not able to develop a solution right away, the bottlenecks are communicated to the management team. As a result, the bottlenecks are placed on the agenda of the corporate strategist and in the technology scouting loop.

5.3 Relation of the case to innovation theory

By exploring the practical execution of innovation management in DESSO it is interesting to find out how the innovation theories described in chapter 3 compares to the practical execution within the firm. A comparison can be made between the innovation process used by the organization described in section **5.2** and the innovation models discussed in section **3.2 The innovation model**. Within the representative company there is a driver based search to solutions (the C2C goals, functions and cost reduction). There is also an interest in investigating disruptive technologies, cross industry opportunities and new developments in science. The company therefore has both a market driven innovation need as being open to scientific developments. Confirming the existence of the market pull and technology models for technology development. Moreover, the innovation manager plays a vital role in organizing this process. An innovation manager acts as a technology scout to find new opportunities, as well as a problem solver who searches for and evaluates ideas. It is essential that prior to introducing the idea to the decision makers, the innovation manager gathers information to place the idea within the organization, and executes market studies and technical feasibility studies. The innovation manager plays a major role in the distribution of information to multiple levels within the firm. This role of information sharing starts even before an innovation project is executed and remains when a project is started. There is a link with Chesbrough's theory open innovation model as there is an active flow of new information from outside the company. This flow of information enters the company via various routes. One type of route is the process

of technology scouting, a process in which the company actively scouts for technologies and components to contribute to the information and innovation process of the company. The situation in DESSO also conforms with the chain-linked model for innovation by Kline et al. [56] in which the innovation is a continuous process and is adapted when new information is introduced (**Figure 7**). The chain link model describes that there are continuous information flows throughout an innovation project. This project starts with identifying the potential market driven by innovative goals. Within DESSO the innovative goals are determined by drivers within the firm, technology trends or customer needs (co-creation with architects). The process then continuous through the stages of analytic design, detailed design, redesign and production. The innovation manager remains part of the process until all the information is transferred to the development team who is then able to take over the information gathering process. This process obtained within DESSO and described by Kline is similar to the innovation problem solving process described in section **3.4** Systems and functions in engineering design The nature of innovation problem solving is an iterative process of information conceptualization and feedback to the problem with also a continuous need of information gathering. We can therefore confirm that the theories introduced align with the innovation practices within DESSO. Especially the chain link model and innovation problem solving theories cover the interactive process between the innovation manager, the management team and the development team. We also confirmed the existence of the linear innovation models within the company, however, their interpretation is a too simplified representation of the situation obtained within the company.

5.4 Chapter conclusions and key findings

In this chapter conditions were generated for a representative company that can benefit from the methodology that will be constructed. The case study company was introduced and we determined the innovation strategy and management activities that DESSO applies. In the last section the case study was compared to the innovation theories. In the next chapter the understanding of the innovation process and technology scouting activities from both theory and practice will be used to determine the requirements of the methodology for finding selecting and evaluating nanotechnologies.

Key findings

- Conditions a representative company requires to have in order to benefit from a methodology for finding, selecting and evaluating nanotechnologies are that the company:
    - Is technology or product driven;
    - Has constructed innovation goals;
    - Has designated roles within the innovation strategy;
    - Has not (fully) assessed the implications of nano-technology;
    - Is aware of technology scouting.
- DESSO fits the requirements and shows that the innovation manager plays an important role in organizing and transferring information at multiple stages in the innovation process.
- The innovation process can be best compared to the chain-linked model of innovation and theories on innovation problem solving.

6 Requirements of the scouting methodology

In order to bridge the gap between innovative bulk manufacturing companies and the application of nanotechnology by the companies we will design a methodology that enables companies to find, select and evaluate nanotechnologies. To design such a methodology, it must first be clear what the methodology should do, which problems it needs to solve and what kind of requirements are necessary. In chapter 5 the representative company is introduced. Three main roles into the innovation process can be distinguished: Idea generation (1), decision making (2) and execution (3). It is described that the innovation manager plays a vital role in both idea generation, communicating the idea for decision making and transferring the knowledge towards execution. A large part of this activity is the scouting for technologies. Therefore, a methodology needs to be constructed that helps the innovation manager to bridge the nanotechnology knowledge gap and enables the innovation manager to directly find nanotechnologies. In this chapter the requirements (section 6.1) will be constructed that the methodology needs to have in order to help the innovation manager find, select and evaluate nanotechnology as an extension of their current activities. To obtain those requirements we use both theory and practice information. Moreover, we will outline how to assess the methodology on face, control and internal validity. At the the end of the chapter a list with requirements will be provided on what the methodology needs to be and how to measure.

6.1 Generation of requirements

In chapter 5 the role of the innovation manager has extensively described and is explained using **Figure 14.** This figure shows that the innovation manager has a balancing role between idea generation and project execution. Ideas result from company goals, goals that have the aim to reduce cost, generate new innovative products or to be more sustainable. Based on the goals the innovation manager scouts for technologies by using his or her network, knowledge and external knowledge sources to determine how the goals can be achieved. In these continuous activities the methodology must be embedded. The methodology aims at making the life of the innovation manager easier in analyzing and interpreting science based technologies like nanotechnologies. However, such technologies have not been assessed before. The methodology should therefore be designed to enable the innovation manager to find nanotechnologies based on the company innovation goals regardless of its knowledge level of nanotechnology. The methodology should also render better outcomes than the innovation manager would have using conventional and known methods of retrieving science based information. Eventually the methodology needs to save time of the innovation manager. This results in three general requirements; time reduction of the scouting process, cost reduction of the process and quality increase of information obtained (**Figure 16**). All three requirements have the aim to reduce risk in the process of innovation management. With risk we mean on the one hand the

Figure 16 Requirements with the aim to reduce risk/uncertainty regarding nanotechnology

necessity of firms to innovate to ensure firm survival. And on the other hand the risk of developing a new product that will return on its investment. Lowering cost, time and increasing quality improves the speed and quality of decision making in the innovation project and therefore decreases risk.

The general requirements (time, budget and quality) can be broken down in multiple sub-requirements. A helpful tool to construct requirements is by using an objective tree [53]. An objective tree displays the objectives of the problem owner and breaks the objectives down in multiple sub-objectives. This organizes the problem and helps to identify ways of measuring the output. The lowest level objective always must be measurable. Based on the three high level requirements several lower level requirements are constructed. The objective tree for the methodology requirements are displayed in **Figure 17**. The lowest level objective is reached if it cannot be split down into multiple objectives and is concluded with a measure. Based on the objectives requirements and constraints can be generated. The lowest level objectives with its measurement are displayed in **Table 6**.

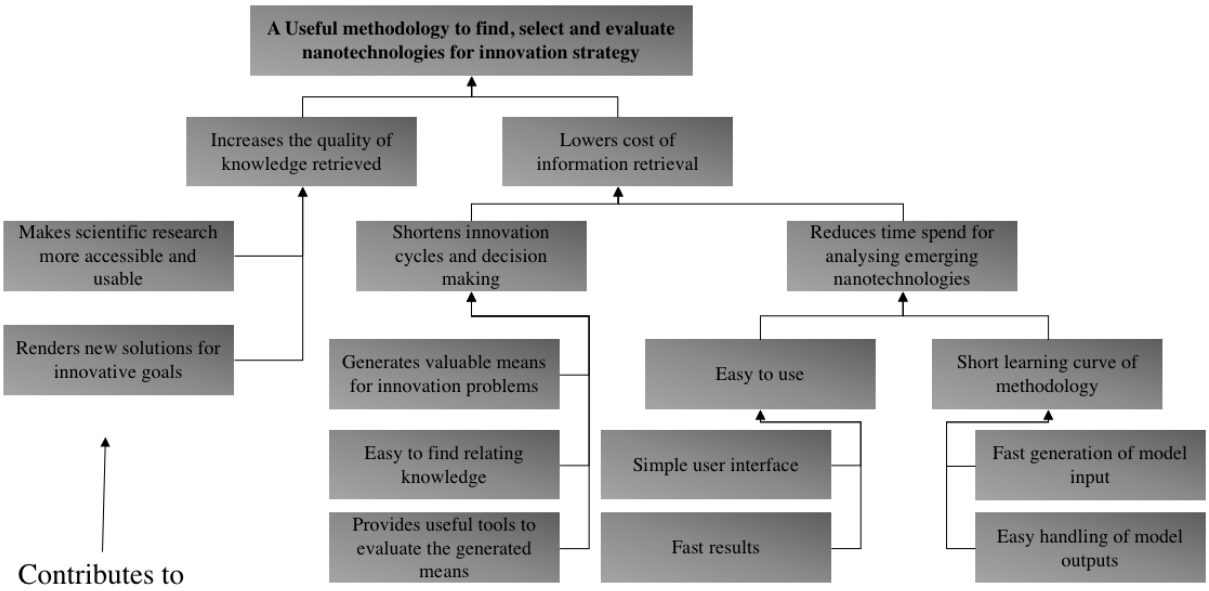


Figure 17 Objective tree for methodology requirements (own figure)

Table 6 Lowest level objectives and their measure

#	Objective	Measure
1	Makes scientific research more accessible and usable	Amount of articles used per innovation objective / amount of articles used without the methodology
2	Produces new solutions for technical goals	Amount of unknown technologies scouted / query
3	Simple user interface	Ease of use compared to other scientific information retrieval systems.
4	Fast results	Effort needed from the problem definition until the evaluation of the means.
5	Easy handling of model outputs	Effort needed to interpret and apply results
6	Fast generation of model input	Effort needed to create input to run an effective search
7	Fast tool for reviewing state of the art research papers	Effort needed to find and understand research papers

8	Generation of valuable means for innovation problems	The sum of the useful means scouted
9	Easy to find relating knowledge	Option to deepen the understanding of a certain technology

Based on the objective tree a total of nine measurable objectives can be constructed. Two lowest level objectives are related to the quality increase of the information. Seven of the objectives relate to the time and thus cost needed to apply the methodology. The lowest level objectives will be the requirements as they are measurable entities of what the methodology needs to be.

After the methodology is designed and applied it in the case study the results and its performance needs to be validated. Requirement 1 is the objective of making scientific information more accessible and usable. It can be measured by qualitatively assessing if the methodology enables the use of scientific research. Within DESSO this task is often skipped as browsing scientific research is time consuming. Something that also has been confirmed by Pearson [54]. Requirements 2 and 8 are related to the technologies that will be extracted by the methodology and can be interpreted by the company. The technologies can be qualitatively validated by experts in the technical departments. Requirements 3 to 7 describe the process of finding, selecting and evaluating (scientific) information. Because no such methodology currently exists and the process of finding, selecting and evaluating technology is a knowledge intensive process we cannot easily measure these requirements. We will therefore measure them based on the qualitative metric of effort needed by the user. Validating this measure can be done by comparing the proposed scouting methodology with conventional methods of scientific knowledge interpretation. Requirement 9 is a measure for improving the speed of knowledge interpretation. We can measure this by the possibility given in the methodology to further investigate further information based on a search result for example to find relating information of the technology retrieved for example to find out if a technology can be applied in a certain environment. This is a binary requirement; the option is given or not.

Part of the methodology will make use of computational text mining techniques that are programmed as software. Because software is used we must verify if the software can be trusted for executing its function. In software this consists of a step of internal verification and external validation [100]. Internal verification represents the step where a software system is demonstrated to be internally consistent and that there are no contradictions in the algorithm, logic or mathematics used. External validation is the process of finding out the correctness of the system, for example by comparing it to a model that mimics the input-output behavior of the real system (functional validation) [100].

To verify the software internally, we will find out if the algorithms used and applied are consistent. We will measure this by comparing the algorithms with two reference algorithms. One algorithm is executed by hand and one algorithm is the same algorithm applied on a smaller part of the dataset. For the second validation step we will look at the concept of input-output transformation for measuring the performance of the software. To measure the performance of the search component of the methodology the search component will be assessed based on methodologies for information retrieval systems. The most basic and often used measures for information retrieval effectiveness are the concepts of precision and recall [101]. The precision (P) is the fraction of retrieved results that are relevant.

$$precision = \frac{|\{relevant\ results\} \cap \{total\ results\}|}{|total\ results|}$$

The recall is the fraction of relevant results based on all the possible relevant results.

$$recall = \frac{|\{returned\ relevant\ results\} \cap \{total\ relevant\ results\}|}{|total\ relevant\ results|}$$

The precision and recall show the performance of the information retrieval part of the methodology. The rates can be compared to the rates of conventional information retrieval systems. This comparison can then be used to calculate the performance of the system. Based on the software verification validation 2 extra requirements are added to the list with requirements. The new list with requirements is shown in **Table 7.**

Table 7 list of requirements

#	**Requirement**	**Measure**
1	Makes scientific research more accessible and usable	Amount of articles used per innovation objective / amount of articles used without the methodology
2	Produces new solutions for technical goals	Amount of unknown technologies scouted / query
3	Simple user interface	Ease of use compared to other scientific information retrieval systems.
4	Fast results	Effort needed from the problem definition until the evaluation of the means.
5	Easy handling of model outputs	Effort needed to interpret and apply results
6	Fast generation of model input	Effort needed to create input to run an effective search
7	Fast tool for reviewing state of the art research papers	Effort needed to find and understand research papers
8	Generation of valuable means for innovation problems	The sum of the useful means scouted
9	Easy to find relating knowledge	Option to deepen the understanding of a certain technology
10	The software part of the methodology is face valid	Yes/No
11	Increases information retrieval performance	Rate of precision and rate of recall

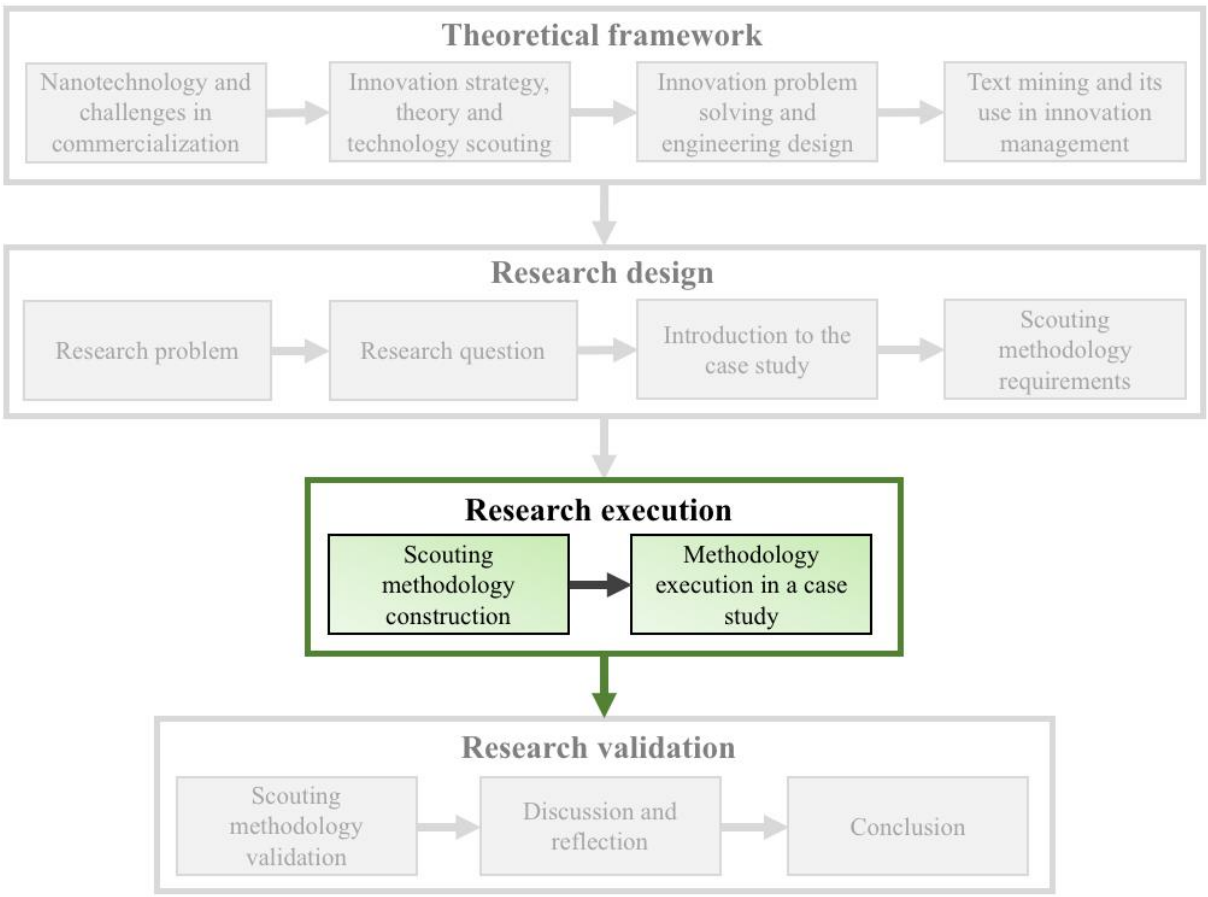
The software validation methods can be applied to measure the functioning and the performance of the software as part of the methodology. The outcomes do not show qualitative information of the results and what these results mean for the organization. The outcomes however do give insight to the performance of the methodology in comparison to other information retrieval systems. This information can be used to contribute to the validation of requirements 1 to 7. For validating the other requirements of the methodology, the results need to be valued by experts. The experts can interpret the methodology and its outcomes and compare this to the current activities that are executed within the company. They can determine if results found are already known, if the methodology itself can be easily applied

and if nanotechnology can make a difference. A common way to get in-depth expert opinion is by means of interviews. Because the outcomes of the interview most be comparable but also requires expert opinion the interviews will be semi-structured [102].

6.2 Chapter conclusions

Requirements have been constructed based on the needs and problems of the company and structured using an objective tree. To safeguard that the methodology designed can be applied appropriately the methodology needs to be validated. First the functioning of software component will be measured using internal verification. When internally verified the methodology is executed in cases to explore nanotechnologies for the cases. To show the performance of the information retrieval system the concepts of precision and recall will be used. The outcomes can be compared to conventional information extraction systems. The results will be qualitatively assessed based on semi-structured expert interviews. Chapter **9 Verification and validation** will discuss all the types of validation applied. After validation, there will be a reflection on each one of the objectives to see if the methodology could deliver what it was designed for. In the next chapter the methodology will be constructed, the objectives provided can already be taken into account in designing the methodology.

Part 3
Research execution



7 Methodology construction

With generating the requirements of the methodology a framework has been constructed that can be used as foundation for the methodology and to assess the outcomes of the case study. But first the methodology needs to be constructed. From the highest level this should be a methodology that enables the innovation manager to find, select and evaluate nanotechnologies based on existing innovative goals in the company. However, on the lower level this means that a methodology needs to be constructed that supplies:

1. *A means for structuring innovation goals in the company;*
2. *A means to scout nanotechnologies using text mining based on the innovation goals;*
3. *A means for evaluating and interpreting the outcomes of the scouted results.*

In this chapter these three components will be developed. First the computational search model will be described, followed by the structuring of the innovation goals in a fashion that they can be used as an input for computational searching. The aim of this search is to generate results. These results however must be communicated to be evaluated and selected. Therefore, the last section discusses how the results can be further explored.

7.1 Construction of the SAO search model

Due to the science driven character of nanotechnology a lot of information relating to technologies and knowledge concepts are stored in scientific literature. This information is readily accessible when having access to scientific databases like Web of Science, Scopus and Google Scholar. These databases provide search tools to browse and analyze the articles from the meta-level to the specific level. The search tools allow the user to search for specific keywords in sections of the article. These sections are i.e. the abstract, title and citations. The pitfall for using these databases for finding potential solutions is the keyword restricted search query. It allows to search for words but it will only search for those words. In chapter **3.5 Computer aided techniques for innovation** it is explained the drawbacks of keyword based search are the inability to grasp actions and specific relations within the search. In that way it is not possible to search for specific relations between words or actions that could be used for problem solving. The specific searching of relations in text is however possible through the use of SAO-based NLP tools. These tools allow a computer to determine the grammatical relations within a sentence. If it is possible for a computer to read through text like a person it is possible for a computer to store the meaning of sentences in its memory and to access this memory like a person is accessing memory. Through the use of a computer and NLP it is possible to mimic this action. To do this the computer must understand how reading works, how words relate to each other and what conclusions can be taken from the text. One way to do this is, is by understanding the subject, action and object of a sentence (SAO). Structuring sentences based on their subject, action and object shows the essential elements and allows to look at the content of the sentence. Knowing the content of the sentence, technical functions can be distinguished. In chapter **3.5** Computer aided techniques for innovation it is described that SAO-structures can have a function-means relation. This relation is very useful to scout for nanotechnologies based on functions in a large SAO nanotechnology database.

A database must be constructed of all the scientific papers that are related to nanotechnology. To gather this data, the record download function of Web of Science (WoS) is used. This function allows to download records with article titles, abstracts and references of 500 at a time. The search in Web of Science's core collection shows that there are 1.2+ million articles available related to nanotechnology. The articles are then downloaded in UTF-8 .txt-format in sets of 500 and stored in a directory.

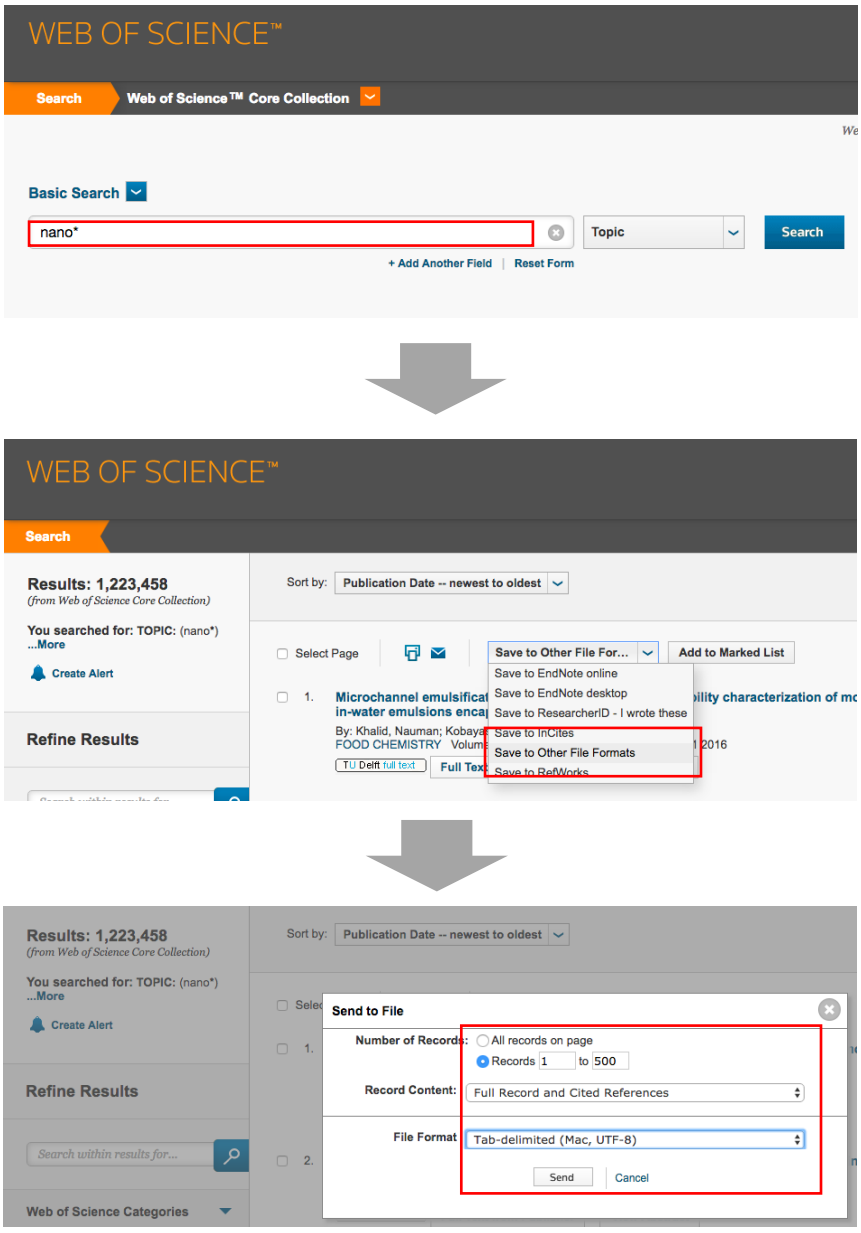


Figure 18 Steps in Web of Science to download a file with 500 records.

Figure 18 shows how the records can be search and downloaded in the WoS online environment. When all the abstracts are downloaded they must be stored in a database. To store the .txt files the programming language Python is used within the Jupyter notebook. Python is a programming language which can be used for a lot of programming activities. Text mining and natural language processing tools like NLTK, SpaCy and Pypi have been developed for years [79], [103], [104]. This allows even untrained programmers to pick up Python programming and build their own algorithms.

In order to construct a dataset with the 2400 .txt files the .txt files must be merged into one file that can be operated in the search algorithm. The merging of this database is done using Python programming and is described by Cunningham and Kwakkel [105] in Tech mining for Engineering Managers. Jupyter notebook is used to run the code provided by Cunningham and Kwakkel. At the same time the merged files must be workable. WoS delivers its files in a tab delimited format showing the abbreviations of the article fields at the beginning of each file. By learning the computer to read those files and let the computer understand which abbreviation is related to what field the .txt file can be structured within the Python environment. In **Figure 19** the structure of a WoS file is shown. On the top the abbreviations are shown; AU corresponds to the authors, AB corresponds to abstracts and TI corresponds to titles etc. By connecting these abbreviations to the contents in the 500 other records in the .txt file the text file can be structured and used for further applications within the model. The linking of

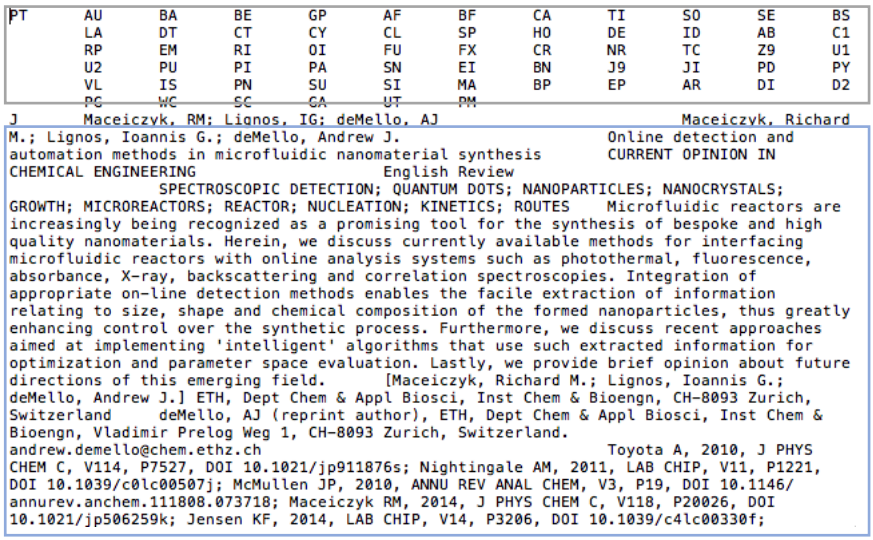


Figure 19 Print screen of the downloaded Web of Science file showing the abbreviations and a single record.

abbreviations to the elements of a scientific paper is done using the functionality of a dictionary within Python. A dictionary connects and stores the relation between the abbreviation and the abbreviation text in its memory. Allowing to retrieve this when necessary. It can also be used to retrieve all the abstracts, titles or references of the dataset. The functionality of the dictionary is useful when SAO-relations must be traced back to their original record. The programming algorithm to merge all the downloaded web of science files into one file and structuring these files into a single library is shown in Algorithm 7.1.

Algorithm 7.1 Construct 1 complete database with all 1.2 million records

1. **Set inputdirectory**
2. **Set outputdirectory**
3. Define **record** structure
4. **Read in all records**
5. **For all records:**
6. **Structure**
7. **End if**
8. **Return all records in dictionary format**
9. **Store all records in JSON as dictionary of records**

The next step in building the SAO-relations from the qualitative texts. Within the records only a few elements can be regarded as qualitative texts. SAOs are grammatical structures that can be deducted from sentences. Therefore, only the sentences with a normal grammatical structure can parsed to extract an SAO-relation. This means that only the title, abstract and titles of references can be used for SAO-parsing. To construct the SAO-relations from the sentences in the title, abstract and/or reference titles a parser is necessary that can determine the subject, object and action of a sentence. NLTK is a powerful toolkit for natural language processing within Python that provides tools to construct dependency trees from sentences. To construct dependency trees the sentence must first be analyzed on word types. This is called a tagger [79]. A tagger determines if a word is a noun, verb, adjective, adverb etc. When the tagger has defined the word types the words must be related to each other in the sentences. Using the Penn Treebank system or dependency Treebank algorithm the computer is able to construct the sentence (S) in types of a noun phrase (NP) and a verb phrase (VP). These phrases can be further decomposed into a prepositional phrase (PP), adverb phrase (ADVP) until the word level is reached. An example of a dependency tree is shown in **Figure 20** for the sentence "*The nanoparticles increased the hydrophobicity of the surface*".

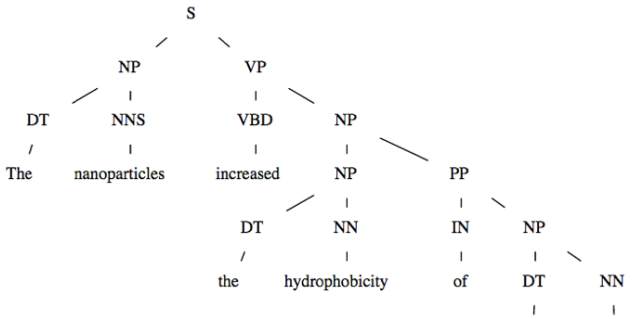


Figure 20 Example of a Penn Treebank

It is necessary to look at more than only the word-tags for constructing the SAO-relations. Although SAO-relations have a noun-verb-noun relation the tagset is not able to distinguish which noun corresponds to which verb. This could lead to noun-verb-noun triplets that do not have an SAO-relation in the sentence. Therefore, dependency parsing is necessary to relate the words to each other. The dependency tree of the sentence is shown in **Figure 21**. This tree shows the relation between the words. The "ROOT" verb shows the action, the "nanoparticles" are the subject and "hydrophobicity" is the object. Resulting in the SAO structure: nanoparticles-increased-hydrophobicity. Within python programming the grammatical dependencies are returned in the following structure.

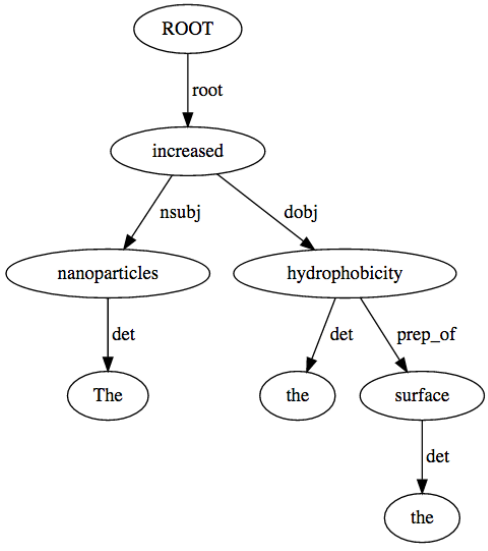


Figure 21 Dependency tree

```
det(nanoparticles-2, The-1)
nsubj(increased-3, nanoparticles-2)
root(ROOT-0, increased-3)
det(hydrophobicity-5, the-4)
dobj(increased-3, hydrophobicity-5)
det(surface-8, the-7)
prep_of(hydrophobicity-5, surface-8)
```

The abbreviations in nsubj, root and dobj of a sentence can construct the SAO-relations of each sentence. By programming the computer to first parse a sentence, construct the

dependencies and to store the subject, action and object in a list, the SAO-relations can be constructed automatically per sentence until the algorithm has parsed all the sentences. To do this the computer must learn some more rules concerning texts. It needs to know where a sentence starts and where a sentence ends. This is not simply when a word begins with a capital letter and ends with a dot. Names for example also start with a capital (e.g. New York) and abbreviations are often abbreviated with a dot (e.g. professor is abbreviated as prof.). The NLTK toolkit described and written by Bird et al. has constructed a sentence tokenizer that is able to see the differences between a name in a sentence and abbreviations. Thereby dramatically increasing the performance of the algorithm and the construction of SAO-relations.

The next step is the automation of the SAO-relation construction. There are two main dependency parsers that enable the construction of SAO-relations in Python; Stanford dependency parser (Stanford DP) and spaCy. NLTK unfortunately does not support the construction of nsubj, root and dobj dependencies in a sentence. Therefore, the choice remains between the Stanford Dependency Parser and spaCy. There are two reasons why spaCy is preferred over the Stanford Dependency parser. The first is the language, Stanford DP is written in Java. Although there are enough options to bridge the package to the Python script the performance radically decreases. When long complex sentences are analyzed, which is often the case in densely written abstracts, it takes a lot of time to transfer the dataset through a bridge structure (like Jpype or by running java-script inside Python) into java and back into Python. Furthermore, the parser needs to handle a lot of data (tens of GBs) resulting in a performance problem. Tests with the Stanford Dependancy Parser have shown that the parser was unable to parse large complex sentences. Unlike Standord DP SpaCy can run its algorithm within the Python environment and return the SAO-relations in the preferred format. The second reason is its performance, studies by Jinho et al showed that SpaCy is performing better than competing dependency parsers [106]. Both the accuracy of the algorithm as the speed are higher than the Stanford Dependency Parser (**Table 8**).

Table 8 Comparative performance of dependancy parsers [106]

System	Language	Accuracy	Speed (WPS)
SpaCy	Cython	91.8	13,963
ClearNLP	Java	91.7	10,271
Stanford Dependancy Parser	Java	89.6	8,602
MATE	Java	92.5	550
Turbo	C++	92.4	349

The SAO structures that are generated are first stored within a list. A list is another tool within python enabling the storage of multiple elements in a comma spaced structure:

```
[nanoparticles, increased, hydrophobicity]
```

This structure is merged with the unique id of the record[4]. This is necessary in order to trace back the article the SAO-relation was extracted from. The algorithm of this step is shown in Algorithm 7.2.

Algorithm 7.2 Record-SAO construction

```
1.  Open JSON file as dictionary of records
2.  For all records define elements:
3.      Store record element: record_ID
4.      For all records:
5.          Extract record element: Title
6.          Extract record element: Abstract
7.          Merge Title and Abstract as string
8.          For all sentences in string:
9.              Dependancy parse sentence:
10.             create new_list
11.             If word in sentence is Subject add to new_list
12.             If other word in sentence is corresponding Action add to
                new_list
13.             If another word in sentence is corresponding Object add to
                new_list
14.             End if
15.         End if
16.     Merge record_ID with new_list as dictionary
17.     End if
18. Store all record_ID-new_list combination as dictionary of records and SVO
19. Store dictionary of records and SVO as JSON
```

As the SAO-relations are now constructed and stored in a new document the next step is to clean and search through these relations. Cleaning of the SAO-relations is necessary in order to map SAO-relations later on and increase the speed of knowledge retrieval. This step requires the removal of SAO-relations that are not related to technical characteristics or have no actual meaning. For example, the “all rights reserved” in every abstract can be removed. Also SAO-relations that include persons do not provide information about technological concepts and can also be removed. When the SAO-relations are cleaned the following step is to link the SAO-relations to the technical characteristics that have been generated within the company. There are multiple options possible; from the SAO-relation a network can be generated listing all the SAO-relations that are related to each other. This is a quantitative method to extract qualitative information from bundling SAO-relations and their technical relation. Another option is to look at the semantic meaning of the SAO-relation and try to formulate an input from the technical challenge that could link the structures together based on word meaning. If for example, the technical challenge is oxidation of a surface as a result of a reaction of the surface with water, the challenge is to find something that decreases the oxidation of the surface. This could result in the following SAO-relation

Subject (S)	Action (A)	Object (O)	
(Coating)	reduces	oxidation	Of surface

[4] For clarification: The record is the downloaded set of information of a scientific article comprised of title, abstract, journal, authors, citations etc.

In which the action and object describe the function that the subject is required to perform. By constructing Action-Object relations from the desired function, related subjects can be found that entail information how the function is executed. This way the problem-solving structure of the SAOs can be used. To link the functions to SAO-relations the algorithm is programmed to provide an input field that the data scientist can fill in with the action verbs and object nouns. The algorithm then loops through each SAO structure to see if any action-object (AO) within an SAO-relation is corresponding to the input. When this is the case the algorithm returns the corresponding SAO-relation on the screen. A downside of this approach is the dependency of the input. If only one input is provided the algorithm will search only for that input, while there may be multiple semantically similar relations possible. To cover this a synonym generator is built into the algorithm. This generator determines if any synonym exist for the input and if so it asks if the synonym must be added as a potential inputvariable. The generator uses the WordNet lexical database as synonym source. WordNet is accompanied with the NLTK package and can therefore be easily added to the algorithm. Other challenges are word conjugation and pluralism. Especially with the action-verbs a lot of different conjugations exist. For the word “reduce” there is “reduced”, “reduces” and “reducing”. To overcome this issue the inputvariable should be lemmatized. Which means that the word should be reduced to its common base for the word reduce. “reduc” is the common base for reduce. Lemmatized inputs like “reduc” allow the algorithm to search for words that contain “reduc”. The algorithm will therefore return the words reduce, reduces and reducing. With taking into account synonyms, conjugation and pluralism the next step is to acquire SAO-relations based on the input. To enable the acquisition of SAO-relations the looping function of Python is used. This looping functions runs through all the words and returns a word if similarity is obtained between the input and the individual words in the SAO-relations. The action-input loops through all the action-verbs within the SAO-relations and the object-input loops through all the object-nouns within the SAO-relations. If in both loops the input variables have similarity with the action and object a match is created and the relation is printed on the screen. The algorithm for this returning SAO-relation is shown in the table of Algorithm 7.3.

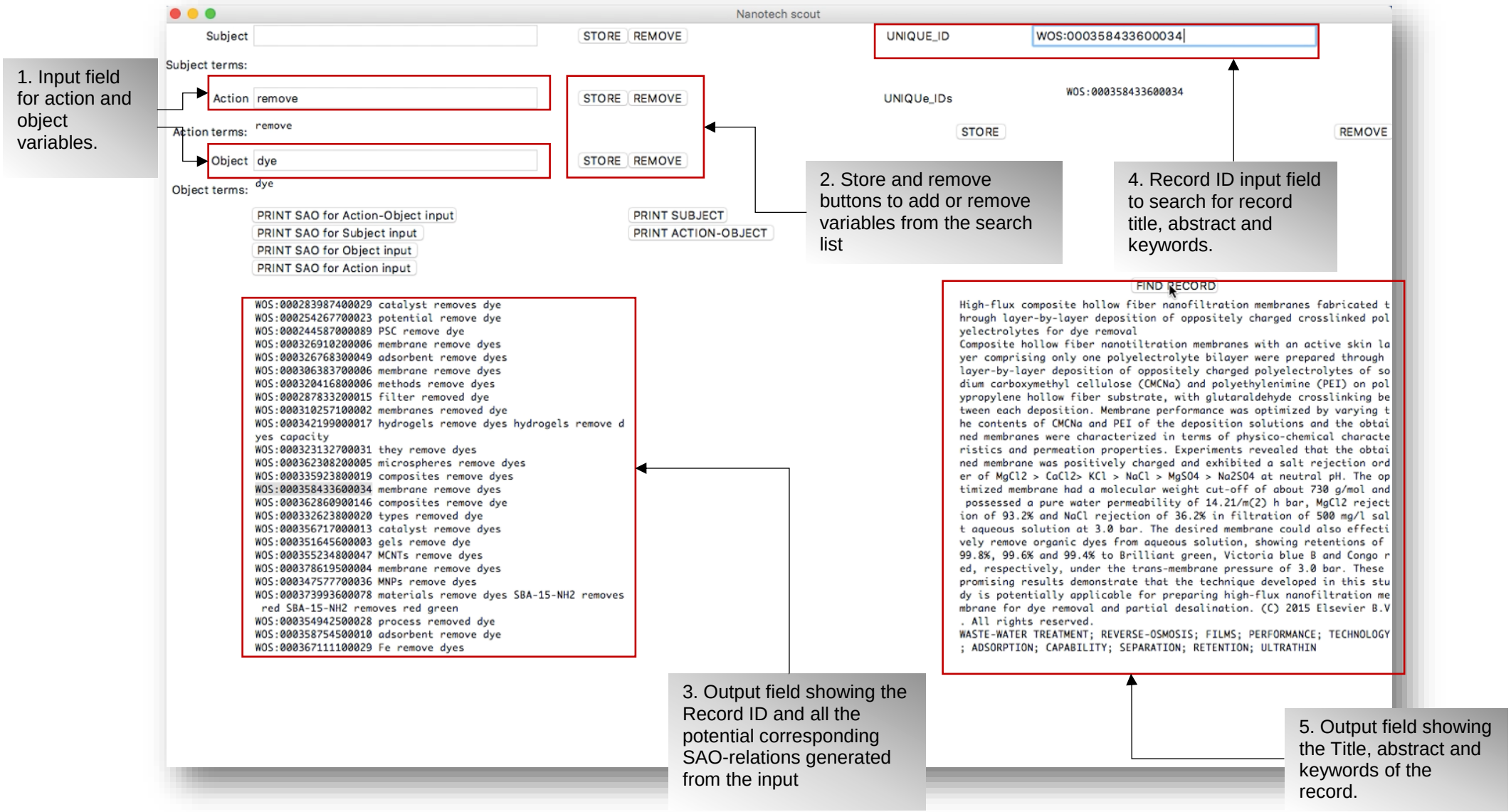
Algorithm 7.3 Search and return SVO relations

```
Open JSON file dictionary of records and SVO
For all SVO:
        Clean sets
        End if
Action is inputvariable_1
Create list_1
For inputvariable_1:
        If any synonym in WordNet for inputvariable_1
                Add synonyms and inputvariable_1 to list_1
        End if
Object is inputvariable_2
Create list_2
For inputvariable_2
        If any synonym in WordNet for inputvariable_2:
                Add synonyms and inputvariable_2 to list_2
        End if
For all cleaned SVO:
        If any in list_1 is equal to Action:
```

```
19.                 And if any in list_2 is equal to Object:
20.                 Print SVO
21.                 End if
22.           End if
23. For record_ID of SVO:
24.           Print Title
25.           Print Abstract
```

An important requirement of the methodology was the ease for innovation managers to access the tool and find, select and evaluate the outcomes. To foster this a user interface is constructed within python that connects the algorithm to a new window interface. Within this interface the user is able to execute the above code, find SAO-relations and interpret the SAO-relation further by allowing them to extract the title, abstract and keywords from which the SAO-relation is extracted. This interface is shown and further explained in **Figure 22**. With a user interface to browse technologies and knowledge constructed the next step is to enable the innovation manager to integrate the search algorithm within his or her technology scouting tasks. For this action and object variables (AO) must be generated that allow to search the technology and knowledge database. In the next section the step will be described how the innovation manager can structure an innovation problem and determine the objective that the required solution needs to have.

Figure 22 User interface of the model



7.2 Construction of the input variables

In the theoretical background described in chapters 2 and 3 a lot of insight is given in the process of innovation management, technology scouting and the nature of technologies and engineering design. The theories have shown that;

- Innovation is unconditionally tied to bulk manufacturing firms for survival;
- Bulk manufacturing firms make use of internal engineering and R&D for innovation management;
- There is a corporate strategist setting innovative goals from multiple drivers in the company;
- An innovation manager acts as an integrator in innovation management in the company by connecting the outside world with the corporate strategist and the engineering department. The innovation manager communicates information to both departments in the company at the pre-innovation process and during the innovation process itself.
- Innovation problems can be regarded as engineering problems and that the process of problem solving in engineering is an iterative process with continuous feedback and knowledge generation.
- Technologies are comprised of many functions and can be broken down into multiple components and that there is an overlap in the technology scouting process innovation management when structuring both processes.

7.2.1 Extracting functions from innovation problems

In this sections we will construct the input variables that can be used for browsing the database of SAO-relations. First there will be a contribution proposed to the theory described by Rohrbeck concerning the relation between technology scouting and innovation management. This theory shows that there is overlap between product specification of an innovation project as well as for a technology scouting project. The activity of product specification and development is widely described and numerous tools exist for this process [53], [71], [107]. These tools can be used to reverse engineer the pictured process towards external technology sourcing. This is shown in **Figure 23-B**. The purple arrow shows the conventional direction of technology management and innovation management. The grey arrow in **Figure 23-C** shows the potential reverse relation from the fuzzy front end of innovation towards technology sourcing.

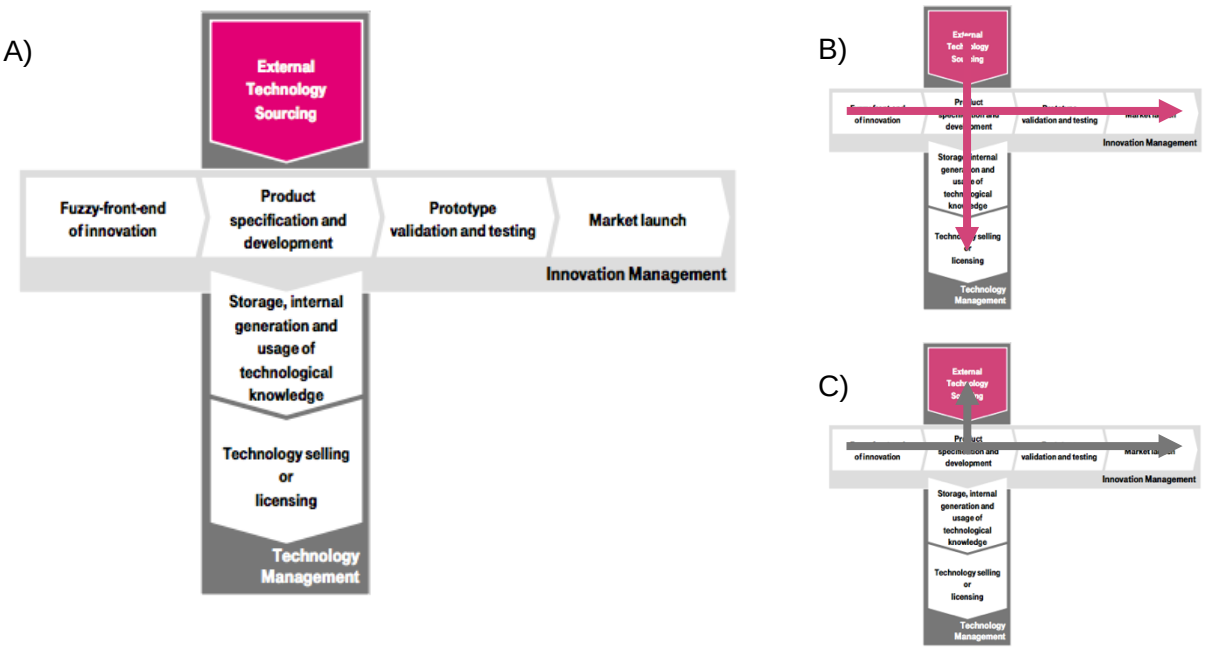


Figure 23 A) Figure showing the relation between innovation management and technology sourcing. B) The directional relation between innovation management and technology sourcing. C) The proposed relation from innovation management towards technology sourcing. Adapted from Rohrbeck *[72]*

This relation can be generated if, in some way, tools used for a formalized product/process specification can be applied to scout external technologies. Although many of these tools exist within engineering and systems engineering the basic idea is the same: Constructing a formal framework in which the objective of the "fuzzy front end of innovation" can be organized and designed. This process is described by Dym and Little that structures the engineering process with the following steps [53] a theory that is equal to the SIMILAR method described in section **3.4 Systems and functions in engineering design**. The steps in the structure are given below:

1. Problem statement
2. Problem definition
3. Construction of requirements
4. Conceptual design consisting of:
    a. Objectives
    b. Constraints
    c. Functional specifications.

After the last step (4c), **means** must be generated for the functions the "invention" requires to do. These means are technologies, components, tools or implementations for each function established. These function-means relations can be graphically organized using a function-means tree. In which the function is broken down in multiple sub-functions supporting the generation of means. In **Figure 24** a function-means tree is shown for the function "igniting leafy materials" in which these functions are connected to means. These functions itself can be broken down into multiple sub-functions. The functions are simple sentences consisting of a noun and a verb. Representing an Action-Object relation. The means is the subject that

executes the function which together results in Subject-Action-Object (SAO) triplets. For example:

- [A laser] [ignites] [leafy materials];
- [A spark] [ignites] [fuel];
- [A miniature heat pump] [converts] [electricity] to heat … etc.

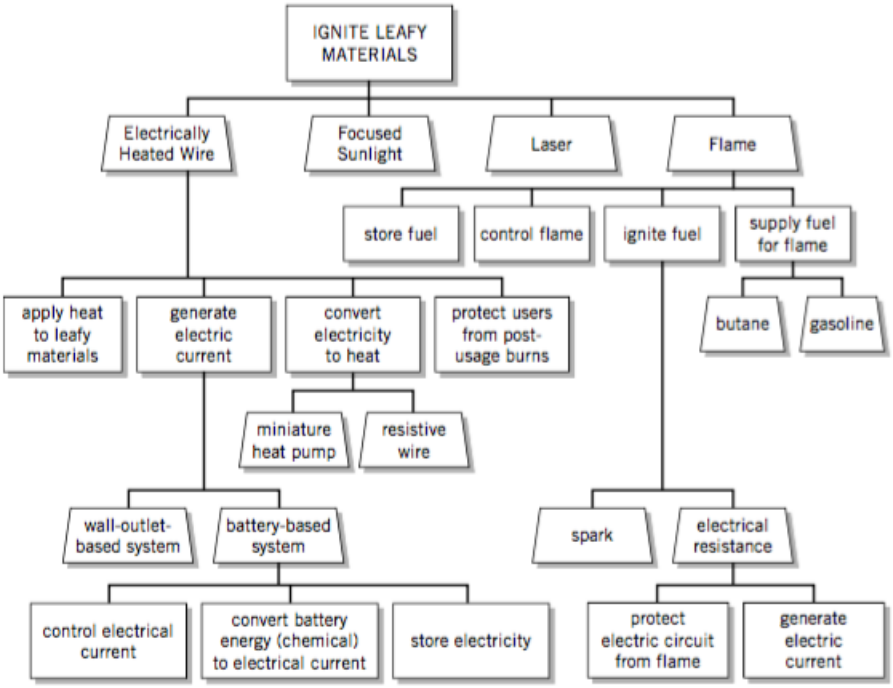


Figure 24 An example of a function-means tree. Adapted from Dym & Little *[53]*

These SAO-triplets show the minimalistic relation between the function (AO) and the means (S). And can be a source of potential solutions by searching for technologies based on their minimalistic function. This is helpful, by applying the engineering design methodology, for generating input variables for the search model. The search model is completely comprised of SAO-relations and allows to find subjects based on Action and Object. The task that lies ahead is applying the engineering design approach to generate minimalistic functions and use these minimalistic functions as input for the search model.

Note that this proposed text mining SAO approach is a very linear type of reasoning. This is a result of the linear problem-solution relation of the SAO structure itself. It therefore cannot be assumed that the innovation manager or the engineer is already helped by providing a linear tool for problem solving. As reasoned by Henriksen the problem-solving process is not linear [73]. Therefore, the IT tools should be embedded in a larger methodology that provide an approach to solve problems. This requires a methodology that structures the ill-defined innovation problem-solving process. By applying engineering design before using the search tool enables the innovation manager first to structure the problem, to define multiple functions and use the tool to generate means for those functions. These principal functions are then gathered within a morphological chart. A morphological chart displays the function and its possible means. An example of a morphological chart is shown in **Figure 25**.

FUNCTIONS	POSSIBLE MEANS						
Stabilize instrument	Hand	Stand	Clamp	Magnet	Edge of Laryngoscope	Wire	
Move instrument	Hand	Gears	Pneumatics	Ball bearings	Lever	Pulley	
Stabilize distal end of instrument	Magnet	Crosswires	Track System	Spring	Gyroscopes	Ball Bearings	Stand
Reduce muscle tension of surgeon during surgery	Instrument Stand	Hand Platform	Pillow	Elbow Platform	Forearm Rest	Shoulder Sling	
Stabilize itself	Gyroscope	Springs System	Stand	Magnet	Suspension System	Rest against stable surface	Attach to Laryngoscope

Figure 25 An example of a morphological chart. (Adapted from Dym & Little *[53]*)

The morphological chart is used to determine design options. In the case that the design is comprised of multiple functions a morphological chart can be used to generate design options by combining means for functions. In this fashion multiple designs can be generated which can be individually evaluated.

7.2.2 Extracting innovation problems from technical processes

Within the methodology it is assumed that the company is aware of technical problems or already has established an innovation project. But what if this is not the case? or what to do when the company is unaware on how to organize an innovation problem? In this section an explanation will be given for gathering information to see if there is an innovation problem or to structure the innovation problem itself. The main goal is to generate key questions that can be asked to identify and understand an innovation problem. The process starts with an objective, that might, for example, be constructed based on symptoms that have been observed in a product or process. When the objective is clear the problem must be explored further to cover the full scope of the situation and to map parameters and degrees of freedom. Michael Orloff has constructed an “algorithm for the diagnostics of a problem situation” [108]. Based on this framework questions are constructed to develop further knowledge on the innovation problem. This questionnaire is aligned with steps 1 and 2 of the algorithm provided in Olthoff and can be used to construct the goals of the system and the functional model of the to be studied system. Besides the technical questions there are also some creativity questions included that can entail the ideas that have already been studied within the technical reality. Adding these to the structure provided by Olthoff makes sure that all the knowledge that has been previously generated can be used throughout the project. During the questionnaire the system of study is decomposed. First the overarching goal is described looking at the system as a “black box”. The next step is to decompose the black box into multiple steps and look at the function of these steps. These steps can also be further decomposed in components. For example; if the objective is to increase the surface aesthetics of a concrete garden pole and the system is described as the production of a concrete pole then the steps for producing this pole is the production of mortar and cement, the mixing of mortar and cement, the casting of the concrete mixture in a pole cast, the release of the hardened concrete from the cast and the cleaning of the cast. The casting of the concrete mixture could then itself consist of multiple

components: The preparation of the cast, applying a release agent on the cast and the filling of the cast. The questionnaire is shown below:

Questionnaire

1. What is the input of the system?
2. What are the requirements of the input?
3. What is the output? What is produced?
4. Via which steps is the output produced?
5. What is the function of the steps?
6. Are the steps based on multiple components (i.e. static or dynamic)?
    a. What is the function of the components?
    b. Why are the components designed like this?
7. Are there any difficulties in the:
    a. Output
    b. Steps
    c. Components
8. What are the requirements of the:
    a. Output
    b. System
    c. Steps
    d. Components
9. What recent changes have been executed?
    a. What were the drivers for doing so?
10. Are there any future changes / requirements that must be incorporated in the:
    a. Output
    b. System/process
11. Brainstorming:
    a. Can we think of new steps in the process?
    b. Can we scan for functions?
    c. What nanotechnologies do already exist or have been studied before?

When the functional system is analyzed and documented the next step is to see where in the process problems or bottlenecks can be identified. The problems are steps in the process that have a negative influence on the performance of the system. They are useful to see components that can be of interest to optimize or replace. It can also be that certain steps in the process occur without knowing why they occur. Based on the outcomes of the questionnaire the technological innovation problems can be identified and described. Returning them as input for methodology described in section **7.2.1** Extracting functions from innovation problems.

7.3 Evaluation and interpretation of the results

The last and essential step in the methodology is decision making. To make decisions knowledge must be interpreted and results must be compared. Within systems engineering design several tools are available to compare results and to select the best option. To make decisions as objective as possible they need to be measurable and comparable. Especially if multiple options can be generated. In the previous sections the measurable and quantitative information is directly connected to the requirements. Low level objectives and constraints are

given a measure to make decisions on, in the decision phase of the innovation process. To organize the process in this methodology two concepts are used. The first is the Pairwise Comparison Chart (PCC). The PCC ranks the importance of an objective (R_t) towards the other (R_i). This is done to make sure that objectives or constraints that are less important, do not get the same measure as the requirements that are very important to the design. A picture of a pairwise comparison chart is shown in **Figure 26**.

Goals	Reduce Tremor	Sturdy	Safe	Inexpensive	Easily Used	Score
Reduce Tremor	••••	1	1	1	1	4
Sturdy	0	••••	0	1	0	1
Safe	0	1	••••	1	1	3
Inexpensive	0	0	0	••••	0	0
Easily Used	0	1	0	1	••••	2

Figure 26 An example of a pairwise comparison chart (adapted from Dym & Little)

Formula 1 for calculating the weight per requirement:

$$W_{req} = \sum (R_t > R_i)$$

A PCC is a useful tool to calculate the score of a potential design or technology based on their relative values (W_{req}) of the objectives. Therefore, also the technologies itself must be ranked based on their performance towards the objectives. This scoring can be done based on multiple concepts. An often used concept is giving the design or technology a score between 0 and 10. But as, in this case, it is not known how 0 and 10 should be defined it is an arbitrary concept in the explorative phase of the innovation process. Also, the concept does not show how the different means compare to each other. To cover both pitfalls another concept is used. This concept assumes that there is a fixed amount of points dividable over the means. For example, if there are 100 points available and 4 means (A, B, C & D) have to be compared the means with the best performance gets the most points, the second the second most points and so on.

Requirements	Score A	Score B	Score C	Score D	Total points
Requirement 1	40	30	20	10	100

Formula 2 for calculating the score of the means per requirement in which S_{MR} is the score of the requirement based on the individual relative value of the mean-requirement score $k_M R_i$.

$$S_{MR} = k_M R_i$$

The sum of all mean-requirement scores is the total dividable points x over the requirements:

$$\sum k_{1 \to n} = x$$

The points given per means per requirement are then multiplied with the weight of the requirement in the PCC. The sum of all the scores of the means per objective comprises the total score. The means that scores best on the total score is the best option. Based on these results further decisions can be made.

Formula 3 for calculating the total weighted score of the means for all requirements:

$$T_{means} = \sum_{M_1 \rightarrow M_n} W_{req} * S_{MR}$$

In which W_{req} is the vector for determining the individual mean-requirement score. The sum of all mean requirement scores make up the total score T_{means}.

$$T_{means} = \sum_{M_1 \rightarrow M_n} \left| \sum (R_t > R_i) \right| k_M R_i$$

7.4 Chapter conclusions and key findings.

In this chapter the methodology has been constructed for finding, selecting and evaluating means for technological problems. The methodology is comprised of three parts:

1. A systems engineering approach to structure the innovation problem to generate functions a potential solution needs to do.
2. It consists of an SAO-based search technique that has organized all nano* related literature from the Web of Science according to SAO sentence structure. This structure has the ability to hold a means-function relation and therefore can be searched for means based on function.
3. An evaluation approach to organize the results based on the requirements that rank the means based on performance.

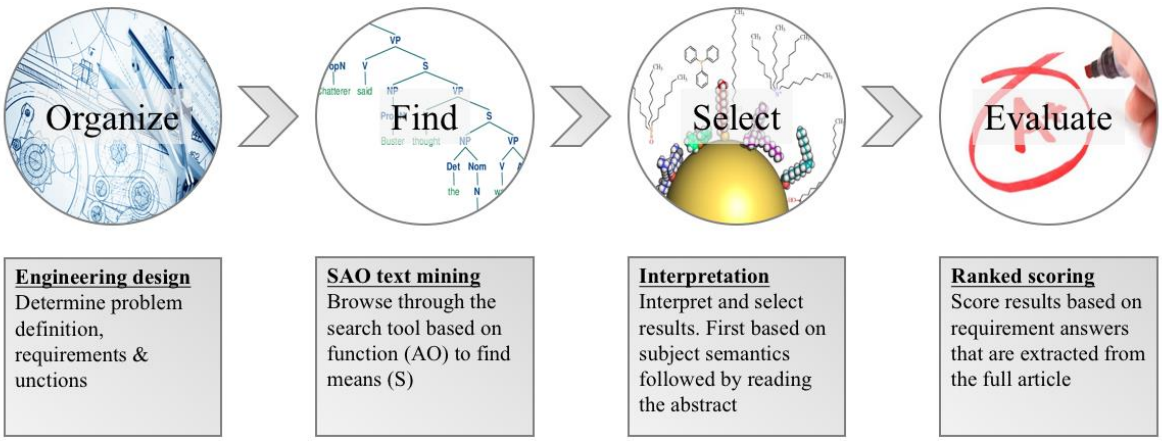


Figure 27 Nanotechnology scouting methodology

With these three steps nanotechnologies can be found and evaluated on multiple functions that can be deducted from innovation problems. An overview of the complete scouting methodology is shown in **Figure 27.** In the next chapter the methodology will be applied to case studies provided by DESSO.

8 Application of methodology

With constructed a methodology for finding, selecting and evaluating nanotechnologies the next step is to test the concept within the environment of the representative company. As explained in chapter 3 the company is a Dutch based textile product bulk manufacturing company. The company, named DESSO, produces carpet-rolls and carpet-tiles in large amounts. To test the methodology, the company has provided two of their current cases in technical development. In this chapter these cases will be individually assessed according to the methodology described in the previous chapter.

Within the company DESSO many targets have been constructed to increase the efficiency and competitiveness of the company. Many of those targets are problems or goals that need to be solved by means of technical innovation. In this matter technical innovation is the optimization or replacement of a component that improves the performance of the process. This component may be an innovative solution that can be found in the field of nanotechnology. Or, with other words, a material that has better performance due to its functionality that it gains from nanoscale engineering. To find out if nanotechnology can potentially improve a process or a product within DESSO two cases have been provided. These cases are technical innovation problems that are, or will be under investigation. The first case relates to the dyeing process of carpet yarn. Drivers for improvement are its large environmental footprint and its complex, and therefore uncertain chemical process. The second case provided by DESSO relates to the flammability control of the carpet. Customer needs and flammability regulations demand a continuous improvement of product fire retardancy while ensuring better performance. In the following three sections each case will be thoroughly explained. Throughout each case the methodology will be applied that has been proposed in chapter 7. This means that first the case will be described according to the problem definition, from this problem definition, requirements will be generated in the form of objectives and constraints. These requirements will shape the solutions space and functions. If possible functions will be decomposed to components of the system. Based on these outcomes the SAO search model will be used for generating means. These means will be displayed by a morphological chart and interpreted and evaluated according to the requirements.

8.1 Case 1 Dye production line DESSO

8.1.1 Problem definition

“The floor is yours” This is DESSO’s message to their users. And in providing every user the best flooring feeling in the world DESSO optimizes their flooring products in any possible way by thinking of design, look, feel and functions. The color of carpet plays a vital role in the flooring experience and therefore the dyeing is executed in-house. This happens by dyeing the fibers by means of a dyeing treatment in the semi-continuous carpet production process. DESSO has multiple types of carpets with differing weaving styles and fiber material. There are several weaving styles in carpet manufacturing and the type of weaving style influences what kind of fibers is used and how the fibers are dyed. The bulk of the sold carpet is dyed in a continuous dyeing facility. The facility is used and optimized for many years. There are however still many challenges in the dyeing process. The most important challenges are a waste free dyeing process with low environmental impact and increasing the control on the dyeing process. In the next sections we will clarify the requirements that solutions should have

for tackling the challenges and which functions the solutions need to do. A more in-depth description of the case is available in Fout! Verwijzingsbron niet gevonden..

8.1.2 Objectives

Based on challenges within the process the engineering department has set goals to increase the efficiency of the production line. On the highest level the engineering department simply wants to make dyeing more efficient and reliable with less environmental impact. On the production floor they want to realize this by reducing the amount of rework (faults in the process). Increase the overall performance and reliability of the dye fixation process to get more control of this process. Improve water management by reducing or replacing the water needed or by enable water purification for circular use.

Increase the performance of the process by:

- Reducing rework.

Improve the stability and speed of the fixation process:

- Reduce instability of fixation;
- Increase affinity of yarn with dye;
- Increase color equality of dyed surface;
- Reduce color change during fixation;
- Increase color fastness.

Increase water management and environmental footprint

- Reduce water consumption;
- Increase water reusability.

Based on these objectives an (high level) objective tree can be constructed for a dyeing process in which these objectives are presented. If a new technology can be found that could support some of the new objectives it still needs to comply with other objectives of the whole process design. This may limit the solution space. The objective tree is pictured in **Figure 28**.

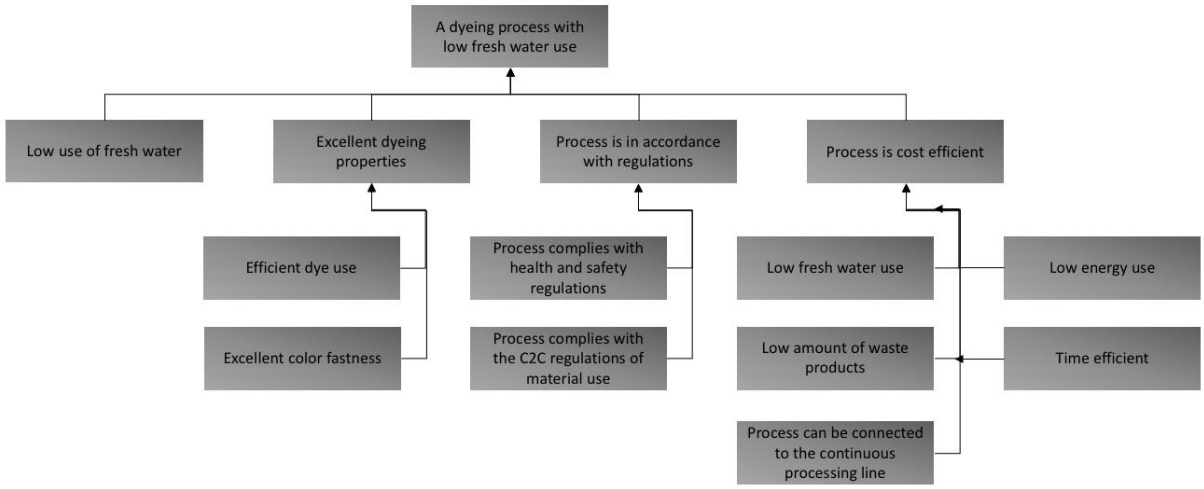


Figure 28 Objective tree of dyeing process

8.1.3 Constraints

In general, in the textile dyeing process, water is extensively used. This has resulted in a need to rethink the technologies used by DESSO to reduce its water footprint. DESSO expects that the cost of water will increase in the future and that further regulations will inhibit the disposal of wastewater in its current quality. To organize this problem one can look at the function of the process. The high level function is dyeing the fabric. To execute this function DESSO uses a water based dye fixation technique to chemically bind the dyes to the fabrics. The problem occurs as a result of the water used in the fixation process. This problem can be managed in multiple ways. First, DESSO could search for a new dyeing technology that extensively reduces the water used. Second, DESSO applies a purification technology that purifies the water to standards that is high enough in order to be reused in the dyeing process itself.

The constraints differ per means. In the case of water reuse the water needs to comply with certain standards that are provided by the dye manufacturer. These water constraints are shown in **Table 10**. Furthermore, all the technologies need to comply with the regulations regarding health and safety as well as the C2C goals. Materials that do not comply are not allowed to be used. Two types of requirement lists can be constructed. **Table 9** concerns the requirements for a complete renewal of the dyeing process. **Table 10** concerns another strategy to reduce fresh water use by means of water purification. The lists consist of measurable objectives and constraints

Table 9 requirement list of dyeing technology / ionic bond

Requirement	Type	Measure
Reduce water consumption	O	m^3 reduction per unity
Reduce energy use	O	kWh reduction per unity
Is a fast process	O	Production time
Decrease amount of dye necessary per m2 carpet	O	Carpet/dye ratio (currently 1:3)
Low amount of waste production	O	kg waste/kg carpet
Is a continuous process	C	Can be built in the current manufacturing line
Raise no health concerns for employees	C	No release of toxic materials/pollutants in air
Raise no health concerns for client	C	No release of toxic materials/pollutants during use
Process complies with C2C	C	Materials used are not banned in C2C regulations

Table 10 requirement list for water purification

Requirement	Type	Measure
Removes bacteria	O	Measure for bacteria
pH level	C	pH 6.5 – 8.0

Removes dyes from wastewater	C	Colorless	
Removal of minerals	C	Cu^{2+}	0.005 mg/l
		Fe^{2+} / Fe^{3+}	0.1 mg/l
		Mn^{2+}	0.05 mg/l
		Al^{3+}	0.2 mg/l
		Silicate	<10 mg/l SiO_2
		Cl^-	300 mg/l
		SO_4^{2-}	350 mg/l
		Total hardness	Max 5°dH(9°fH)
		Carbonate hardness	Max 2°dH(3.5°fH)
		Magnesium hardness	Max 2°dH(3.5°fH)
		COD	<50mg/l
Removes micro/nano particles	C	Residue on ignition 500mg/l & Total dissolved solids 1000mg/l	
Is cost efficient	C	cost <1,- / m^3	
Has high capacity	C	>100.000-300.000 m^3/year	
Materials/process used are C2C	C	Materials may not be banned by EPEA	
Materials/process are non-toxic	C	Materials or processes may do no harm to employees	

8.1.4 Functions

The role of functions in the engineering design is to describe what the required systems needs to do. It was already described that the new system should drastically lower the water use in the dyeing process. It was also described that there can be several means for realizing this objective. One is replacing the complete dyeing process with a water free dying process, another is the recycling the water for reuse. The next task is to establish the right functions that could be used to search within the nanotechnology SAO knowledge base to find knowledge concepts that describe this same function. Several functions can be generated based on the current system. Functions are expressed as a verb-noun (AO) pair and are displayed in **Table 11**.

Table 11 Current functions[5]

	Function
1.	**Remove (carpet surface) contaminants**
1.1	Remove avivage
1.2	Remove Spin oil

[5] To see the full table of functions and their current means see Fout! Verwijzingsbron niet gevonden.

2.		**Disperse dye (over carpet)**
	1.1	Mechanically distribute dye
	2.2	Enhance interface between dye and yarn
3.		**Dye fabric**
	3.1	Promote ionic bond of dye to fiber
	3.2	Create optimal environment of fixation
	3.3	Enable ionic bond dye-fiber
4.		**Remove Excess dye and contaminants**
	4.1	Remove chemicals
	4.2	Remove excess dye
I.		**Purify water**
	i.	Remove contaminants
	ii.	Remove dyes
	iii.	Remove minerals
	iv.	Control pH
	v.	Removes microparticles
	vi.	Removes nanoparticles

Based on these functions we can generate search terms that can be used to scout for means within the SAO based search model. The queries are constructed based on the functions generated and further improved using semantic similarity of words with the build-in WordNet function in the Nanotech scout. The first aim is to scout for technologies/means regarding a new or improved dyeing system, the second aim is to scout for water purification technologies. As explained earlier the dataset of nanotechnology abstracts is organized according to SUBJECT-ACTION-OBJECT (S-A-O) structuring in which the subject (S) describes what system enables the conversion from input to output as a “means”. The action-object (A-O) relation describes the process from input to output as the “function”. By searching based on the change from input to output we can obtain what kind of systems, technologies or components enable this action and could be added to the knowledge base as a potential means and thus solution for the innovation problem.

8.2 Sub-cases

In the following sections we will convert the requirements and functions into search queries that are input for generating means by using the search model. Because the case is comprised of multiple functions the case is broken down in three individual sub-cases; Dyeing technology (1), Ionic bond promotion (2) and water purification (3). For each of these sub-cases queries will be designed and the outcomes will be measured based on differing requirements. First we will discuss new dyeing technologies, followed by the ionic bond promotion and eventually the case of water purification.

8.2.1 Sub-case 1.1: Dyeing technology

The first sub-case concerns the broad search towards alternative dyeing technologies within the field of nanotechnology. The search query will be designed in such a way that a high level

function needs to be executed. In this fashion complete technologies can be search that could replace current dyeing process if it would score positively on the requirements

8.2.1.1 Search queries and morphological chart for dyeing functions

The following tables present the search queries for the search model. The action terms are described for the scouting of new dyeing technologies. The queries are identified based on the function in
8.1.4 Functions**.**

Query 1 Scouting dyeing technologies / enable ionic bond	
Action terms (A)	dye, dyes, dyeing, dyeability, color, colors, coloring
Object terms (O)	Fabric, textile, PA6, polyamide, nylon, clothing, yarn, polyester, wool, PA-6, nylon-6, polyamide-6, nylon-66, polyamide-66, PA66, PA-66, garment

Query 1 resulted in 6 SAO-relations of which three SAO-relations have been evaluated as relevant to be a possible means for the function. The extracted technology is therefore included in the morphological chart. 3 were not regarded as useful because they did not serve the function. 1 was about conductive fabrics, 1 was about the coloration of functional textiles and 1 was about adsorbing color in the washing machine. The complete morphological chart can be found in Fout! Verwijzingsbron niet gevonden.**.**

8.2.1.2 interpretation and evaluation of results for dyeing functions

With the means generated they can be tested based on the predefined requirements. To extract this information first, the titles and abstracts are analyzed. If not all the information can be extracted from the abstract the article is searched online and analyzed to extract the required information for answering the requirements. The means are individually assessed based on the requirements (objectives and constraints). The means are shown in the first column and the requirements are shown in the first row of Fout! Verwijzingsbron niet gevonden.. If the information cannot be extracted from the article the requirement is left blank for this means. In Fout! Verwijzingsbron niet gevonden. the means requirement relation for dyeing fabric are shown that can be found in Fout! Verwijzingsbron niet gevonden.**.**

For one of the means the abstract was insufficient to extract information. To extract the required information, the article was searched online. Search results did not display the article and therefore the requirements could not be tested. The second means was not technically described in both the abstract as the article. As a result, only qualitative information could be provided. This technology does directly print on the fiber enabling a direct reaction that could quickly dye the fabric of the carpet. Assumed is that low waste is generated because no water will be necessary during the process. As no information could be extracted regarding the type of dyes used, the toxicity and C2C-constraint could not be measured. The third means is the use of metal organic frameworks as replacement of the dye. These frameworks can be synthesized in many types of colors while having functional properties. The application uses no water but instead uses ethanol and acetone. However, this technology is in the exploration phase and as a result has a low technology readiness level (TRL). To support decision making

a pairwise comparison chart and scorecard was constructed. The requirements were ranked in the order:

Complies with C2C > Is continuous > Nontoxic > TRL > water reduction > Dye reduction > Process length > waste reduction > Energy reduction

Fout! Verwijzingsbron niet gevonden. Lists the scores of the three technologies which can be found in Fout! Verwijzingsbron niet gevonden.. Metal dyeing could not be assessed and therefore got zero points. Based on the evaluation gamma ray irradiation was the most potential technology. Both technologies list an equal amount of unmeasured objectives.

8.2.2 Sub-case 1.2: Ionic bond promotion

The second sub-case describes a more specific part in the dyeing process and can be part of the current continuous dyeing system. The main aim of this sub-case is to improve the current system rather than replacing it by looking at the specific function of the ionic binding of dye to the fiber.

8.2.2.1 Search queries and morphological chart for ionic bond promotion

Query 2 was constructed based on the functions generated in the problem definition.

Query 2 Chemical bond promotion	
Action terms (A)	increase*, improve*, support*, strengthen*, strength*, favour*, promote*, fix*
Object terms (O)	dye*, color*, colour*, paint*

Query 2 resulted in a total of 39 SAO-relations. From these SAO-relations 24 could already be filtered out based on their subject. 22 of those relations had objects with the word “ink” inside like l**ink**age and wr**ink**le. These had nothing to do with the means. The other two had doping as a subject which is part of solar cells and semiconductors. The 15 remaining relations were qualitatively analyzed based on their title and abstract. This scoped the potential means down two 8 possible technologies. The 5 technologies were removed because their topics were about glass, cancer, solar cells, dye removal and tissue engineering. 1 article had a similar topic as other results and therefore was positioned under the same means in the morphological chart. 1 article was specifically about color fastness and was added to a new function of increased color fastness. All the remaining means are described in the morphological chart in

For the increased dyeability eight potential means were generated. These means were evaluated based on eight requirements. The means and requirements are shown in Fout! Verwijzingsbron niet gevonden. that can be found in Fout! Verwijzingsbron niet gevonden.. four of the means are technologies that are added as extra layer on the fabric. 2 technologies are additives that need to be incorporated in the yarn by means of melt blending or before polymerization. 1 technology is a plasma surface treatment and 1 is as the application of ultrasonic waves during the coloration process. 7 of the 8 technologies are applied on different yarns than DESSO currently uses. Only the melt blending of nanoclays are with the same fiber type. This study has positive dyeing results with disperse dyes but not with acid and metal complex dyes. As DESSO uses a variety of dyes in their process this technology is not ideal.

The use of chitosan or a derivative of chitosan has a positive effect on the color fastness of acid dyes in both research papers. Especially the surface treatment with plasma on the polymer shows interesting results as dye uptake was increased two times and color fastness increased with 20%. As the polymer is a potential future displacement for their current fiber at DESSO it is a technology to lookout for. The use of silver nanoparticles in the fabric has potential especially because it increases the dyeability of the fabric while adding an antibacterial functionality to the yarn. However, there is debate on the toxicity of using silver nanoparticles for the environment [109]. To be sure about applying this the health an environmental aspects need to be more thoroughly assessed.

8.2.2.2 interpretation and evaluation of results for increased dyeability

To assess the outcomes the pairwise comparison chart and comparative scorecard were constructed. The results of these analyses are shown in **Fout! Verwijzingsbron niet gevonden.** Which can be found in Fout! Verwijzingsbron niet gevonden.. The requirements were ranked in the order:

Complies with C2C > Continuous > Increased color fastness > Non toxic > Reduction of dye > Low waste generation[6]

The comparative analyses show that ultrasonic dyeing gets the highest score while also having a lot of unmeasured objectives. This high score is mainly the result of the low toxic and C2C impact. The same is true for atmospheric pressure plasma. Row 3 to 7 show the highest ranked additives in the process. In which the chitosan is the most promising as it has four 4 unmeasured objectives.

8.2.3 Sub-case 1.3: Water purification

The last sub-case is part of the current dyeing system. The main aim is to improve the water purification system by scouting technologies that execute the specific functions to enable complete water purification. This eventually needs to result in circular system which is able to purify and reuse the water.

8.2.3.1 Search queries and morphological chart water purification

The water purification challenge could be decomposed in multiple individual functions for the specific removal of contaminants and particles in aqueous solution. 4 types of materials were identified for removal: dyes (1), minerals (2), bacteria (3) and other micro/nanoparticles (4). For each contaminant an individual query was designed. To enhance the full coverage of SAO-relation extraction from the SAO-relation nanotechnology database also a general water purification query was designed. The constructed queries are shown below. For each query, the results will be individually described.

Query 3 Dye removal	
Action terms (A)	remove, adsorb, absorb, decrease, delete, eliminate, lessen, extinguish, filter, filtrate, sift, sieve
Object terms (O)	dye, color, colour

[6] Calculations of the requirement ranking in the PCC and total score calculation can be found in Fout! Verwijzingsbron niet gevonden. **and** Fout! Verwijzingsbron niet gevonden.

For query 3 a total of 77 SAO-relations were returned. Of those 77, 28 relations were removed because their subject related to other processes that absorb color like fluorescence or the adsorption of dyes in human cells. The 49 remaining SAO-relations were qualitatively interpreted based on their titles and abstracts. 36 records remained for further analysis. The 36 relation could be grouped in 6 technological fields for dye removal: Nanofiltration (1), photocatalysis (2), adsorbents (3), hydrogen peroxide (4), electrochemical oxidation (5) and flocculation (6). The bulk of the results were related to the first three fields. The first principle, nanofiltration is a membrane technology that only allows nanometer sized particles to cross the membrane. This way most of the particles are removed and only water molecules and small particles like small minerals are removed. Multiple types of membranes are described in the articles. Photo catalysis is a technology specifically for degrading dye molecules by means of the formation of free radical induced by light that break down the dye molecules. Adsorbents are molecules specifically designed adsorb as much dyes as possible. The technologies explained in the articles show reusable adsorbents, adsorbents with high efficiency or selective adsorbents. Hydrogen peroxide and electrochemical oxidation use the same degradation principle as within photo catalysis by means of free radicals. The highly active radical molecules break up the dye molecule. Lastly there is one article specifically about using a flocculent for dye removal. All the means are displayed in **Fout! Verwijzingsbron niet gevonden.** which is displayed in Fout! Verwijzingsbron niet gevonden..

Query 4 Mineral removal	
Action terms (A)	remove, adsorb, absorb, decrease, delete, eliminate, lessen, extinguish, filter
Object terms (O)	Cu2+, Fe2+ / Fe3+, Mn2+, Al3+, Silicate, Cl, SO42-, mineral*, salt*, copper, iron, manganese, aluminum, alumina, chloride*, sulphate*

Besides the removal of dyes from the dyeing process minerals are also a contaminant of interest. As can be obtained from the requirements for water purification there are standards for the optimal mineral concentration in water. Due to the large amount of additives used for dyeing the mineral concentration of the water increases. To optimally control the dyeing process these minerals should be removed. The search query resulted in 66 SAO-relations that based on subject analysis was reduced to 15 SAO-relations. This selection could be done because the subjects related to the removal of metals or other inorganic materials instead of ions in aqueous solutions. The selection also showed that the search query may be too broadly defined for the current function. As it is unclear what the current mineral levels are, only general demineralization and salt removal techniques might be sufficient. From the 15 remaining SAO-relations the abstract and title were interpreted. This resulted in 8 relevant articles that described the process of mineral, salt-specific ion removal from aqueous solutions. The technologies can be grouped into two main concepts: Membranes and adsorbents.

Query 5 General water purification	
Action terms (A)	filter , purify, clean
Object terms (O)	water

Next to the specific function describing the removal of a certain group of contaminants there might be a loss in general solutions that describe the overarching goal: the purification of water. To cover these articles an extra query was designed. This query resulted in 10 SAO-relations. From those relations 4 concepts could be extracted: microfiltration, nanofiltration, reverse osmosis and electrosorption.

Query 6 Removing bacteria	
Action terms (A)	remove, adsorb, absorb, decrease, delete, eliminate, lessen, extinguish, filter, filtrate, sift, sieve, kill
Object terms (O)	bacteria, bacterium, fungus, organisms, microorganisms, microbe*

For the removal of bacteria 22 SAO-relations were found, 10 of those were analyzed on content based on their subject. These resulted into the concepts of electrokinetic adsorption, micro/nano/ultrafiltration, aluminum nanofibers and filters improved with antibacterial functionalities.

Query 7 Removing nano/microparticle	
Action terms (A)	remove, adsorb, absorb, decrease, delete, eliminate, lessen, extinguish, filter, filtrate, sift, sieve
Object terms (O)	Microparticle*, contaminent*, nanoparticle*, residue

For query 7 many SAO-relations were found, this was due to the general description of the function. Description as contaminant or particle are too general for getting a specific technology for removal. Therefore, no means were added to the morphological chart. Moreover, the morphological chart already displays many potential techniques for the removal of micro- or nanoparticles.

8.2.3.2 Interpretation and evaluation of results water purification

The technologies described in the morphological chart are grouped and evaluated based on the requirements defined in **8.1.3 Constraints** the evaluation can be found in Fout! Verwijzingsbron niet gevonden.. A total of 8 means could be adapted from the morphological chart. The technologies are evaluated for every requirement, this shows the limitations of the technology and enable the possibility to create combinations of water purification technologies. The values are extracted from the articles describing a certain technology. Most articles describe the removal of a specific type of dye, which is unfavorable as wastewater at DESSO contains all kinds of dyes. This is due to the dyeing of wool, nylon and polyester. Therefore, adsorbents that have only showed successful applications to certain types of dyes are not the ideal. Nanofiltration is covering almost every requirement, the biggest challenge is the certainty of removing all the dye. Nanofiltration cannot extract all minerals from the solution, which is favored because removing all salts results in oxide rich water. Oxide rich water can increase the oxidation of the pipes and machinery. It is unclear if the right mineral levels will be met with nanofiltration. Another downside is the clogging of the filters. Reverse osmosis covers almost every requirement, however, it would return oxide rich water which is not favorable. Adsorbents

do have a very high adsorptive capacity and remove almost all dye, especially in combination with photocatalysis. Challenges are however the adsorption time, regeneration of adsorbent and the selectivity. Electrochemical oxidation in combination with a filter is a promising technology, it oxidizes dye and filters water. Like electrosorption this is an early technology and not commercially available yet. The results of the PCC and comparative scorecard analysis are shown in **Fout! Verwijzingsbron niet gevonden.**, which can be found in Fout! Verwijzingsbron niet gevonden.. The requirement order is as follows:

> **Dye removal > complies with C2C > Non Toxic > High throughput > pH level > mineral removal > Bacteria removal**

The table confirms the potential of reverse osmosis (RO) and nanofiltration which have a much higher score than other potential technologies. Note that this scorecard does not include a measure for cost. The biggest challenge for applying this technology is cost. Currently the cost of water and disposal is €1/m^3, for example if DESSO uses about 300.000 m^3 water per year. The technology, in the case of 100% removal and reuse rate, may cost a maximum of €300.000 a year in fixed and variable cost. A study has shown that a nanofiltration system combined with a photcatalytic cleaning unit drops below $1 per m^3 if the nanofiltration unit is able to filter more than 20L/m^2h with a water demand that is bigger than 100m^3 day with a 10 year use [110]. The filtration systems described in the articles have a throughput between 10-20L/m^2h. Which indicates that, if DESSO would use the system for at least 10 years and the purification level is high enough for reuse, water purification might be competitive to the discharge of water.

8.3 Case 2 fire retardancy

8.3.1 Problem definition

DESSO is selling its carpet all over the world serving a flooring demand in various different industries. An important requirement in many industries is the ability of a product to withstand fire. This ability ensures that the product does not accelerate the growth of a fire and rather slows the spread of the fire down. In order to do so regulations have been designed to control the flammability of products and the formation of smoke when ignited. Products of DESSO need to be compliant to these regulations. There are several levels of flame retardancy of which aero, marine and hotel are of the highest level. Residential housing carpets are obliged to lower standards. In the industry both the standards for fire safety and customer demands are increasing. Therefore, DESSO must continuously improve the performance of the carpets to meet the standards. Nanotechnology could provide new insights in solving the fire retardancy problem. In the following sections we will set up requirements on what fire retardant technologies need to do and create and develop functions on what these technologies need to do. An extensive description of the case and its problem definition is described in Fout! Verwijzingsbron niet gevonden..

8.3.2 Requirements

The broad problem definition in flame retardancy creates quite a large solution space. DESSO is not looking to phase out their current fire retardant products it is trying to map the field of fire retardancy with an open minded perspective. How fire retardancy will be embedded in the carpet design is not of importance as long as it fits some general requirements. There is nevertheless an urge to explore the field of fire retardancy because currently the carpet does not meet the strict fire retardant regulations. Because of the open strategy for finding and solving the problem regarding fire retardancy only few constraints have to be generated. Based on the problem definition an objective tree is constructed that visualizes the main objectives and constraints. The objective tree is visualized in **Figure 29**.

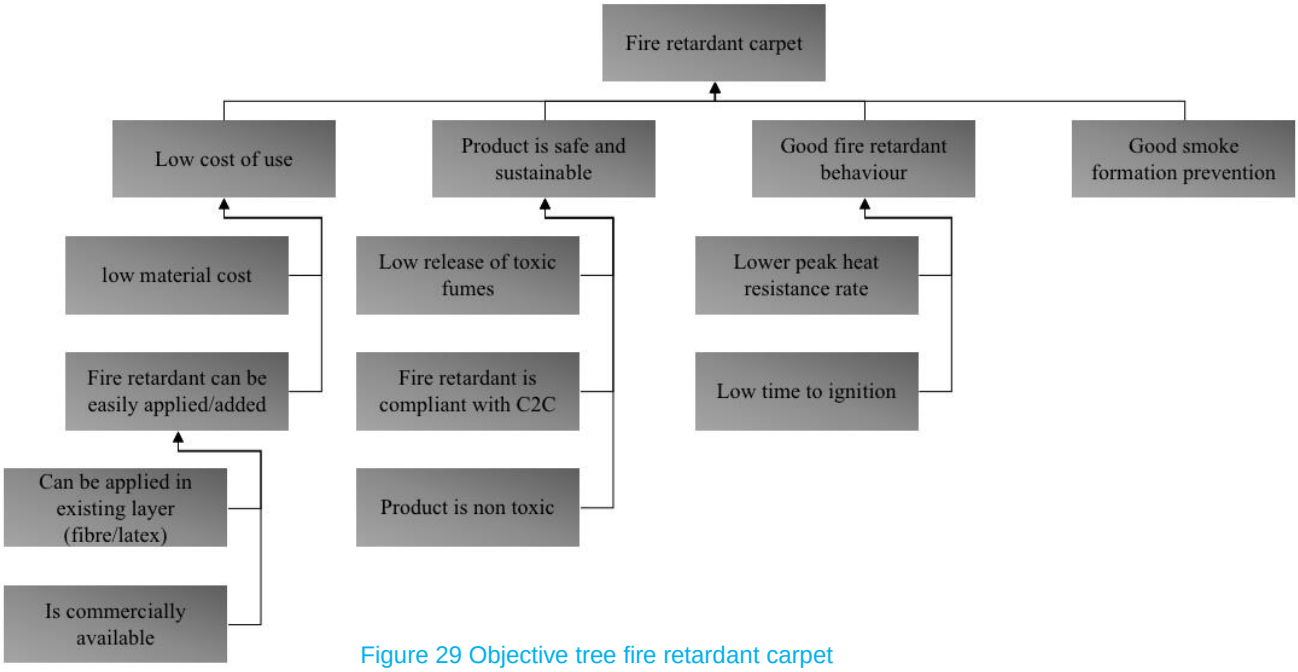


Figure 29 Objective tree fire retardant carpet

From the objective tree objectives and possible constraints are adapted and listed in **Table 12** These requirements are granted with a measure in order to successfully measure if a scouted technology can be potentially applied as flame retardant.

Table 12 Requirements and measures for fire retardant carpet

Requirement	Type	measure
Can be incorporated in latex or can be incorporated in fiber	O	Method of application, when incorporated in fiber no reduction in fiber quality.
Is non toxic	C	No release of toxic materials/pollutants during use and in production
Is allowed as material in C2C list	C	Materials used are not banned in C2C regulations
Lowers flammability of the entire carpet up to aero standards	C	UL-94 V0
Lowers the smoke formation of the entire carpet up to aero standards	C	-
Is cost efficient	C	Lower cost than current fire retardant or more efficient.
Is easy to apply	O	Can be incorporated by DESSO or DESSO suppliers
Is available and can be tested	O	(commercially) available

8.3.3 Functions and search queries and morphological chart

The function that the new technology should execute are shown in **Table 13**. Three main functions can be obtained. Flammability reduction, smoke reduction and self-extinguishing behavior of the product after combustion. For each of these functions a query is constructed. The search results will be individually described.

Table 13 Current Functions for fire retardants[7]

	Function
1.	Reduce flammability of carpet
2.	Reduces smoke formation during combustion
3.	Extinguish fire

Query 8 fire retardant technologies	
Action terms (A)	reduce*, decrease*, is
Object terms (O)	flammability, fire, fire-retardant,

[7] To see the full table of functions and their current means see Fout! Verwijzingsbron niet gevonden.

Query 9 Smoke formation reduction	
Action terms (A)	reduce*, decrease*, is
Object terms (O)	smoke, fumes

Query 10 Self-extinguishing technologies	
Action terms (A)	extinguish
Object terms (O)	fire, flame

For **Query 8** a total of 40 SAO-relation where generated. As the majority of the subjects did not show to be noise every title and abstract was briefly interpreted within the nanotechnology scout. This resulted in an in-depth analysis of 28 SAO-relations. 22 of those SAO-relations were after thoroughly reading still a potential means. Eventually 2 SAO-relations could be grouped into 1 technique resulting in 21 potential means. These 21 means were evaluated according to the requirements constructed in section 8.2.3. **Query 9** did not result in any SAO-relation. This may the result from a poor query construction, or because there are no sentences with this specific function-means relation. This is imaginable because the structure [SUBJECT-reduces-smoke formation] would render the SAO-relation [SUBJECT-reduces-formation] with the SpaCy algorithm. **Query 10** resulted in a total of 6 relations which were all examined based on title and abstract. The 6 results provided two extra means for potential fire retardancy. 5 articles described a layer by layer nanocoating technique and 1 article described a onepot coating technique. All the means are visualized in Fout! Verwijzingsbron niet gevonden. that can be found in Fout! Verwijzingsbron niet gevonden..

8.3.4 Interpretation and evaluation of results fire retardant carpet

Based on the requirements each technological means will be individually assessed and evaluated. The results are shown in Fout! Verwijzingsbron niet gevonden. which is displayed in Fout! Verwijzingsbron niet gevonden., the information necessary to test the requirements are extracted from the articles that describe the technology. Due to the large amount of results it is hard to obtain the best possible options from the table. One way to get more sense of the potential of a means the outcomes need to be scored and compared. This is done by using the PCC and the comparative scorecard method described in **7.3 Evaluation and interpretation of the results**. The requirements are ranked in the order:

> **Complies with C2C > Toxicity > Flammability reduction > Smoke reduction > Application complexity > Price > Availability**

The results of the comparative scorecard are shown in **Fout! Verwijzingsbron niet gevonden.** that can be found in Fout! Verwijzingsbron niet gevonden.. The scorecard shows that the combination of a nanostructured metal and a phosphate gives the highest score. The combined nanomaterials with a fire retardant also shows promising results. In the lower regions, the organic nanomaterial and mineral -flame retardant combinations also can be promising if more of the objectives are measured.

8.4 Chapter conclusions and key findings

To test the methodology that was designed in chapter 7 two case studies have been executed in a textile based bulk manufacturing company. For all two case studies the three steps of the

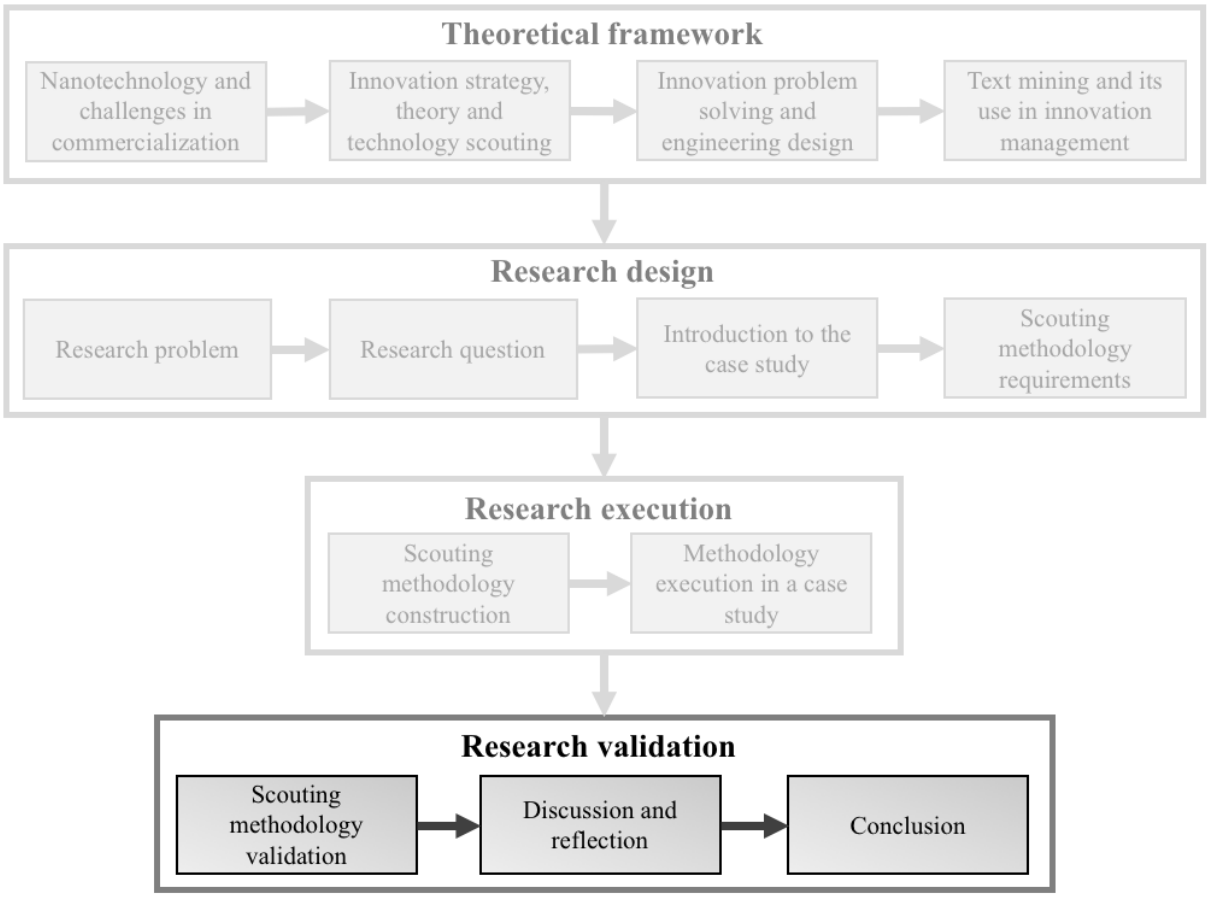
methodology have been applied. First the case study problem has been structured, by means of problem definition, requirements and functions. Based on the function search queries have been designed. The results of the search model that were presented as SAO-relations have been interpreted by answering the requirements using the abstract and scientific article as a data source. These data sources were not sufficient to answer all the requirements but were efficient enough to give a preliminary insight on the potential of the scouted technologies. In numbers the methodology rendered:

- 10 unique search queries based on the functions
- 266 returned results by the search model
- 139 relevant results based on subject
- 95 relevant results after interpretation of the abstract
- 44 unique means

In the next section we will validate the methodology and case study results based on quantitative and qualitative measures to gain more insight in the functioning, reliability and performance of the methodology and its components.

Part 4

Research validation



9 Verification and validation of the methodology

In the previous chapters the foundations for the methodology have paved the construction of the methodology itself. To find out if the methodology could render outcomes in terms of nanotechnologies for innovation problem solving the methodology has been applied to two cases within DESSO. These cases have been structured using systems engineering design methods. Within these methods requirements have been generated about how the solution should perform and functions on what the solution is required to do. The functions are used as input to generate nanotechnology means and the requirements are used to evaluate the means as possible solutions. By applying the methodology in cases about fire retardancy, water purification and dye fixation multiple individual nanotechnologies and nanotechnological concepts have been found. Based on the morph charts and the requirement analysis the technologies promise to be useful as solutions to the company. But how does the company rate these outcomes? Were they already aware of these technologies? Does nanotechnology make a difference? What to say about its multi-applicable character? Can the results the methodology generates be trusted? Are results missed? And does the methodology substantially improve the operation speed and quality of the innovation department? To answer these questions this chapter will verify and validate the methodology. This is organized as follows; first the search tool is internally verified to determine face validity. Then the the search model will be externally validated by comparing it with conventional scientific search methods. Eventually the full methodology will be discussed by means of the outcomes of semi-structured interviews with operation managers from the case. The outcomes of the validation techniques will be measured according to the requirements obtained in chapter 6 are shown in the table below:

Table 14 list of requirements

#	Requirement	Measure
1	Makes scientific research more accessible and usable	Amount of articles used per innovation objective / amount of articles used without the methodology
2	Produces new solutions for technical goals	Amount of unknown technologies scouted / query
3	Simple user interface	Ease of use compared to other scientific information retrieval systems.
4	Fast results	Effort needed from the problem definition until the evaluation of the means.
5	Easy handling of model outputs	Effort needed to interpret and apply results
6	Fast generation of model input	Effort needed to create input to run an effective search
7	Fast tool for reviewing state of the art research papers	Effort needed to find and understand research papers
8	Generation of valuable means for innovation problems	The sum of the useful means scouted
9	Easy to find relating knowledge	Option to deepen the understanding of a certain technology

10	The software part of the methodology is face valid	Yes/No
11	Increases information retrieval performance	Rate of precision and rate of recall

9.1 Internal verification of the search model

The search model is an essential part of the methodology. Therefore, it must be verified to show if the model performs the function as if not what the reason is for not performing. Quantitative information can be gathered about the functioning and indexing of the database and the algorithm. For example, it is important to know how many SAO-relations are constructed from all the records to interpret the accuracy of the SAO algorithm. Furthermore, it is also interesting how many SAO-relations remain after cleaning the abstracts to say something about the number of valuable SAO-relations. This information is provided in the table below

Table 15 quantitative information of the dataset and SAO indexed records

#	**Description**	**Data**
#1	Total number of unique records before parsing	1,236,840.00
After executing algorithm 7.2		
#2	Total sentences (title and abstract)	9,008,262.00
#3	Total number of SAO-relations before cleaning	3,035,010.00
#4	Total number of unique records with SAO-relations	1,050,462.00
#5	Average amount of SAO per unique record	2.89
After executing algorithm 7.3		
#6	Total number of SAO-relation after cleaning	2,450,975.00
#7	Total number of unique SAO-relations after cleaning	988,594.00
#8	Average amount of SAO-relations per unique record	2.48
#9	Total loss of records after cleaning (**#7 - # 4**)	61,878.00
#10	Total records without SAO-relation (**#1 - #4**)	186,378.00
#11	Total unindexed records in search model	248,246.00

From **Table 15** it can be observed that 79,9% ($\left(\frac{\#7}{\#1}\right)$) of all records (**#1**) result in SAO-relations that are regarded as useful after parsing and cleaning. 15.1% of this loss is because the parser was unable to generate an SAO-relation from the title and abstract ($\left(\frac{\#10}{\#1}\right)$). This can partly be explained by the accuracy of the parser, which is 91.8% [106]. Meaning that in 8.2% of the cases the parser is inaccurate on the parsing. As the algorithm extracts first the subject-root relation (in which the root represents the action-verb) from a sentence then extracts the root-object relation and after that matches the root to create an SAO-relation. If one of these extractions is inaccurate no SAO-relation is constructed. Other losses can be explained by the complexity of abstract sentences. Grammatical mistakes in the abstracts or because of the grammatical structure of a sentence result in the inability to extract SAO-relations. Another reason is the absence of an abstract. 5% is lost due to the cleaning of the dataset ($\left(\frac{\#9}{\#1}\right)$). It

can also be observed that cleaning the unique records lowers the amount of SAO-relations per record (**#8 and #5**). This can be explained because the cleaning function removed introductory sentences like “we showed that” and irrelevant information from the publisher like “all rights reserved”. The total amount of sentences in the dataset is over 9 million. Only 34% of these sentence renders an SAO-relation ($\left(\frac{\#3}{\#2}\right)$). This means that almost 2/3 of the all the information that is stored in the sentences is not converted into SAO-relations and therefore is not searchable and extractable by the search model. This can be explained by the grammatical fallacy of sentences that do not have the S-A-O structure. Titles for example are also counted as sentences but have a very different structure than normal sentences.

To understand why only 1/3 of the sentences renders an SAO-relation 10 random record samples are individually parsed. If a similar amount of sentences remains without SAO-relation the parses of these sentences can be analyzed on why this is the case. First the title and the abstract of the 10 record samples are parsed using the same algorithm (**algorithm 7.2**) used for indexing complete nano* knowledge base to create SAO-relations. This will be the reference set. Afterwards each parsed sentence is individually parsed and the SAO-relations are manually constructed by combining the subject, action and object. The goal of this study is not to verify the SpaCy dependency parser. The dependency parser and its possible limitations are accepted and left out of the scope of the verification. As a result, the parser is used to grammatically parse the sentences in both studies. The results of the study are shown in **Table 16**.

Table 16 Results reference set applying the same code as in the algorithm		
#12	Total amount of records	10
#13	Total amount of sentences	65
#14	Average amount of sentences per article	6.5
#15	Total amount of SAO-relations	27
#16	SAO-relations / Sentence ratio	42%
Results manually analyzed set		
#17	Total amount of sentences	63
#18	Amount of false sentences	2
#19	Total amount of SAO-relations	29
#20	SAO-relation / Sentence ratio	46%
#21	Extracted SAO similarity ratio	107%

From these results it can be observed that there are some differences between the reference set and the manually analyzed set. First of all, parsing the reference set resulted in the creation of two additional sentences ($\#13 - \#17$). Manually analyzing these sentences showed that one sentence is without any content and the second sentence was part of another sentence. These two are not counted as sentences in the manually analyzed set. The total amount of SAO-relations was higher in the manually analyzed set ($\#19 - \#15$). Two SAO results are from sentences that have multiple SAOs in one sentence.

The two SAO-relations from in one sentence
interferometry', 'is', 'technique', 'it', 'provides', 'information'
channel', 'being', 'm', 'that', 'form', 'array'

In the reference set the algorithm used does not count multiple SAO-relations in one sentence as multiple SAO's. This shows that the amount of SAO-relations in the complete SAO-relation database is higher than calculated. By manually comparing the 27 sentence SAO-relations it can be observed that the manually extracted relations are all equal to the computationally extracted relations from the reference set. This confirms that the algorithm used in the reference set does sufficiently extract the SAO-relations compared to manually extracting the SAO-relations. In the reference set 42% of all sentences are converted to SAO-relations. Which is 8.1 percentage points higher than within the complete SAO-relations database shown in **Table 15**. For the other 58% (66%-8.1%) of lost sentence information it can be said that the SpaCy dependency parser is unable to extract SAO's because these sentences do not have a Subject-Action-Object relation. A gap of 8.1% remains between the sample test and complete database. More sample record sets must be analyzed to determine if the 42% SAO-relation/sentence ratio is an outlier or the average. The fact that the number of sentences per record is higher in the complete database (7.3 sentences per record) than in the sample (6.5

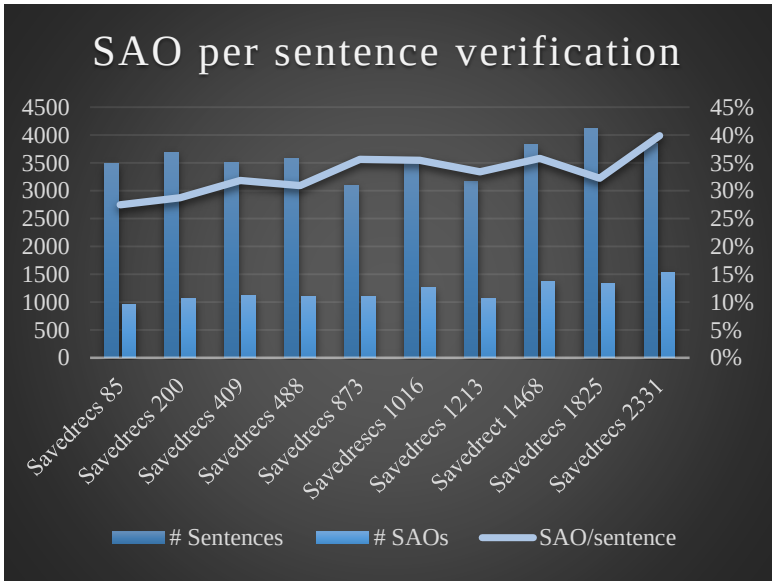


Figure 30 Average amount of SAOs per total sentences

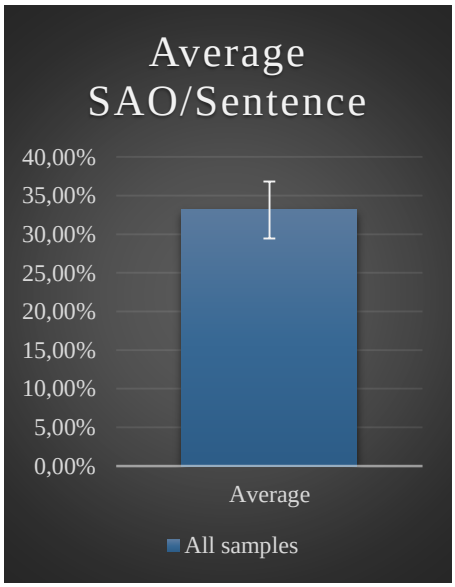


Figure 31 Total average of SAOs per sentences

sentences per record) motivates that more information is necessary to describe the difference in SAO-relations per sentence. Therefore, a set of ten random selected files (named as savedrecs*) with 500 records have been further analyzed. The results are shown in and **Figure 30** and **Figure 31**. **Figure 30** shows for 10 savedrecs*-files; the total amount of sentences per record files, the total amount of SAOs in the file and the relation between the sentences and the SAOs). **Figure 31** shows the average of the latter. The calculated average is 33,14% which is almost similar to the 34% that calculated from the complete set in **Table 15**. Based on the various analyses executed, the internal verification of the search model shows no faults in the algorithms used and therefore can be accepted as a useful algorithm and applied for searching.

9.2 External validation of the search model

After verifying the search model algorithm and performance the next step is to validate the search models use. This is necessary because verification does not mean that the search model delivers the claim that it increases the efficiency of finding, selecting and evaluating nanotechnologies. To do this, multiple requirements have been constructed in chapter 6 regarding what the methodology needs to be (**Table 14**). Not every requirement relates to the search model itself because these requirements were designed for the complete methodology. However, as the search model is a key part of the methodology several requirements exist that can be measured by validating the search model. The highest level requirements mainly show that the need of having a methodology has the aim to increase the quality of knowledge generated and lower the cost of information retrieval. The search model and its logic have the task to generate technology means from the scientific nanotechnology landscape. To validate if the search method improves the efficiency of knowledge generation for generating **means** to functions the search methodology will be compared to conventional methods for extracting science based knowledge. The most obvious systems are scientific databases. Therefore, two databases will be compared with the search model. One is Web of Science, this one is especially interesting because it uses the same dataset as the search model. Two is Google Scholar because it does not require any subscription and is freely available. Before the search model will be compared it is important to note that Web of Science and Google Scholar have not indexed their database according to SAO structuring. This means that searching those databases based on the same input as the input generated for the methodology will not render the same results. Instead the search engines would render different results if the search query is organized according to keyword based search. This creates a dilemma, on the one hand the methodology is organized to browse scientific titles and abstracts based on syntax that enables to identify a function-means relation. On the other hand, companies would in the absence of the methodology search scientific databases based on keywords. Therefore, 4 queries will be constructed per search engine. Two concerning an action-object (verb-noun) based search that are similar to the query terms used for the Nanotech Scout. and two based on keyword sentences.

Two search engines will be evaluated; Web of Science and Google Scholar. For the queries the Boolean search options will be applied. 4 variables are of interest from the search results. First the total amount of generated results, second the amount of articles that will be evaluated by interpreting title and abstract, third the amount of results that can be obtained as relevant to the problem and fourth the total number of means. This information will be extracted for further analysis. The relevant articles will be selected based on the case provided and the title or abstract will at least contain a technology that is able to perform the required function. This decision is subjective as it depends on the knowledge and understanding of the engineer or innovation manager. In this research this decision is made by the researcher under the assumption that the future decision maker, as problem owner, has good understanding on what technological performance is relevant to the case. Besides the variable there is also a constraint added as a parameter. This constraint is related to the maximum amount of results that will be evaluated because in a real situation, for example 400 search results, the engineer will not interpret all 400 results but will only read the first three or two pages with results. Therefore, the maximum amount of results that will be analyzed is 40. In **Table 17** the parameters for the validation analysis are summarized.

Table 17 Parameters of the analysis	
Evaluated search engines	Nanotech Scout, Web of Science and Google Scholar
Amount of queries per external search engine	4
Search query strategy	1. Action-Object 2. Action-Object in specific field 3. Keyword and sentence 4. Keyword and sentence
Variable 1	Number of search results
Variable 2	Number of evaluated results (reading)
Variable 3	Number of relevant results (based on problem)
Variable 4	Total number of means
Constraint 1	Max 40 articles are evaluated in Web of Science

Background of Web of Science

Web of science is designed to provide access to almost every imaginable research and is a platform designed for researchers, students, faculty, analysts and program managers. The design of Web of Science is very comprehensive. It allows to search and analysis search results based on various tools. This is imaginable as the platform is designed for many different types of users that want to analyze both the contents as meta-information of research. Web of Science is an online scientific search engine. It is possible to construct comprehensive Boolean algorithms to optimize the search outcomes. Web of Science is not a free access search engine. This is a downside as engineers or innovation managers may not have the access granted by their companies. It is therefore not the most accessible scientific search engine.

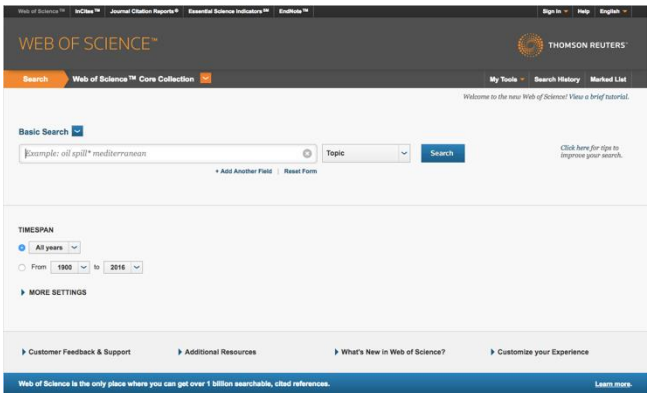


Figure 32 User interface Web of Science

Background Google Scholar

Unlike Web of Science Google Scholar is an opensource scientific search engine. It is freely available through the url scholar.google.com. The search abilities provided in Google Scholar are less advanced and powerful than Web of Science but there is the ability to construct a Boolean like search-query. The user interface is somewhat similar to the conventional google environment and therefore easy to learn.

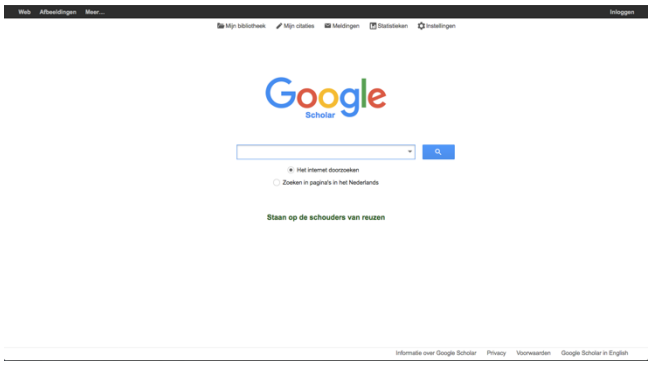


Figure 33 User interface Google Scholar

The analysis will be executed for two unique functional queries that are also executed by the Nanotech scout. There will be 4 comparative search queries per search engine per case resulting in a total of 16 queries and thus 16 analyses will be executed according to ***Table 17***. **Query 2 Chemical bond promotion** and **Query 8 fire retardant technologies** are the queries that will be mimicked in web of Science and Google Scholar.

Table 18 Sample queries and their result

Query	Search engine	Results
Chemical bond promotion		
A=(increase*, improve*, support*, strengthen*, strength*, favour*, fixate) O=(dye*, color*, colour*, paint*)	Nanotech Scout	39
TS=(nano*) AND (TS=(fix* dye*) OR TS=(strength* dye*) OR TS=(increase* dye*) OR TS=(improve* dye*) OR TS=(support* dye*) OR TS=(fix* colo$r*) OR TS=(strength* colo$r*) OR TS=(increase* colo$r*) OR TS=(improve* colo$r*) OR TS=(support* colo$r))	Web of Science	19220
TS=(nano*) AND (TS=(fix* dye*) OR TS=(strength* dye*) OR TS=(increase* dye*) OR TS=(improve* dye*) OR TS=(support* dye*) OR TS=(fix* colo$r*) OR TS=(strength* colo$r*) OR TS=(increase* colo$r*) OR TS=(improve* colo$r*) OR TS=(support* colo$r))	Web of Science	75
TS=(nano*) AND (TS=(improve dyeability textile) OR TS=(improve dyeability nylon) OR TS=(improve dyeability polyamide))	Web of Science	19
TS=(nano*) AND (TS=(improve dyeability textile) OR TS=(improve dyeability nylon) OR TS=(improve dyeability polyamide))	Web of Science	13
nano * nano dyeability dye support OR improve OR increase OR strength OR fixate OR fix	Google Scholar	1410
nano * nano fix fixate dye color colour polyamide OR nylon OR textile	Google Scholar	1180
nano dye fixation on nylon OR textile OR polyamide nano nano* improve increase dyeability of nylon OR textile OR polyamide	Google Scholar	5260
nano nano* improve increase dyeability of nylon OR textile OR polyamide	Google Scholar	1270
Fire retardant technologies		
A=(reduce*, decrease*, is) O=(flammability, fire, fire-retardant)	Nanotech Scout	40
TS=(nano*) AND (TS=(reduce* flammability) OR TS=(decrease* flammability) OR TS=(reduce* fire) OR TS=(decrease* fire) OR TS=(is fire retardent))	Web of Science	1542
TS=(nano*) AND (TS=(reduce* flammability of polymer) OR TS=(decrease* flammability of polymer) OR TS=(reduce* fire of polymer) OR TS=(decrease* fire of polymer) OR TS=(is fire retardant polymer) OR TS=(reduce* flammability of nylon) OR TS=(decrease* flammability of nylon) OR TS=(reduce* fire of	Web of Science	958

nylon) OR TS=(decrease* fire of nylon) OR TS=(is fire retardant nylon))			
TS=(nano*) AND (TS=(reduce* flammability of polymer) OR TS=(decrease* flammability of polymer) OR TS=(reduce* fire of polymer) OR TS=(decrease* fire of polymer) OR TS=(is fire retardant polymer) OR TS=(reduce* flammability of nylon) OR TS=(decrease* flammability of nylon) OR TS=(reduce* fire of nylon) OR TS=(decrease* fire of nylon) OR TS=(is fire retardant nylon))	Web of Science		119
TS=(nano*) AND (TS=(flame retardant nylon) OR TS=(flame retardancy nylon))	Web of Science		98
nano nano* decrease reduce flammability OR fire OR fire OR retardant	Google Scholar		46200
nano nano * reduce decrease flammability fire flame-retardant polymer OR nylon	Google Scholar		3790
nano nano* flammability fire retardant reduce decrease polymer OR nylon	Google Scholar		5660
nano flame nylon retardant OR retardancy	Google Scholar		5620

Table 18 shows all the executed queries per search engine and the total amount of results. All the results of sample 1 and sample 2 are shown in **Figure 34** and **Figure 35**. The first sample shows that the amount of results in WoS and GS are much higher than for the Nanotech scout. This also means that the cap of max 40 articles will be used for evaluation. The grey bar shows the evaluated results. These are the results that are actually interpreted. You can see there is

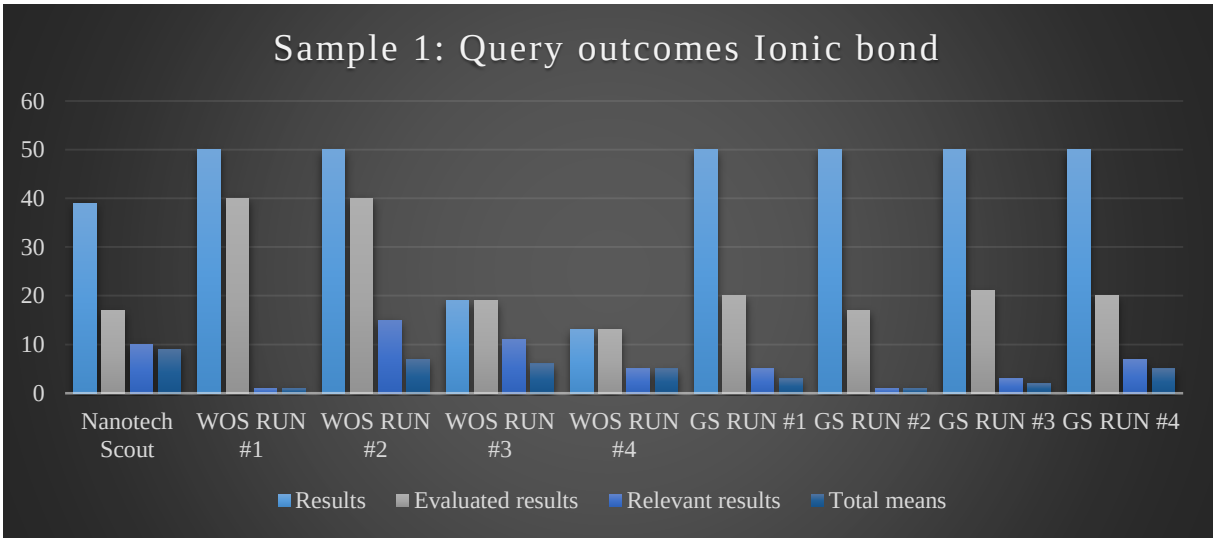


Figure 34 Sample 1 query results

a difference in the total results and the evaluated results for the nanotech scout, this is possible because the S-A-O organization of the results allow another pre-selection based on the subject. Both in sample 1 and in sample 2 results can be filtered based on subject. This drastically reduces the time of interpretation. The third bar is the amount of relevant results. This the total amount of results from the evaluated results that show the potential of being used for solving the case. The ratio between the amount of evaluated results and the amount of

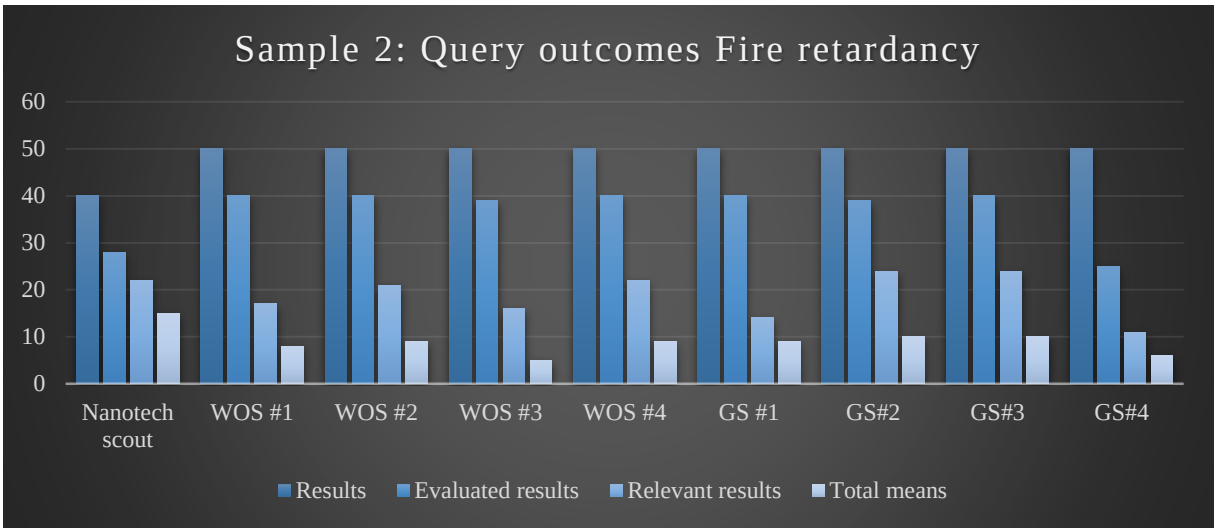


Figure 36 Sample 2 query results

relevant results shows how precise the search engine works for the function that is searched for and thus the time and quality of the information. In sample 1 the difference between the amount evaluated results and the amount of relevant results is quite high for the search engines. For the nanotech scout this difference is a lot smaller which is the result of the pre-selection based on the subject. In sample 2 the differences between evaluation and relevance is a lot smaller, this can be explained by the query being a more focused technology search that is better founded in scientific literature. Still a lot of results are generated in all the online search engines.

To get more understanding about the information withdrawal performance of the search engines a ratio is constructed also known as precision. This ratio is the comparison between the amount of evaluated results and the relevant results:

$$precision = \frac{|\{relevant\ results\} \cap \{total\ results\}|}{|total\ results|}$$

This rate gives an indication of the total performance of the search engines for the specific case. A high precision means that the search engine is highly precise while a low precision shows there is a lot of false positives in the results. The rate of precision is shown in **Figure 37** and **Figure 38** for both samples. Because multiple runs where executed per search engine the average is taken per search engine per case. The standard deviation is displayed with error bars in the figures. In both case the Nanotech scout has the best precision performance just below 60% and 80%. Based on the standard deviation the volatility of sample 1 is confirmed. Sample 2 renders more specific results. Based on these outcomes it can be confirmed that the Nanotech Scout is giving more precise results for the case.

The second statistic that needs to be measured is the overall quality of the retrieved results, also known as the recall. The methodology is designed to provide a company with-

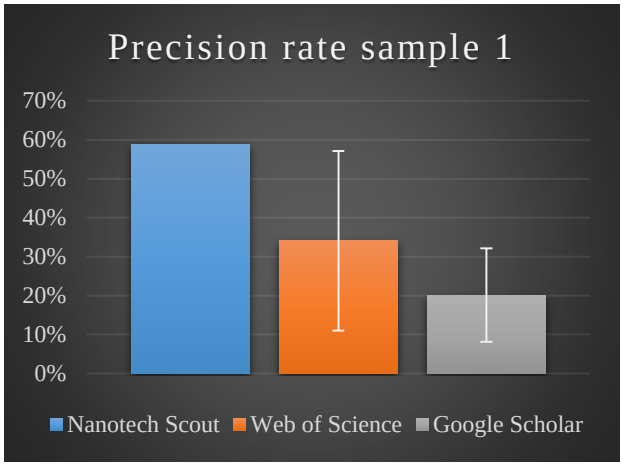


Figure 37 Precision rate for Ionic bond dye

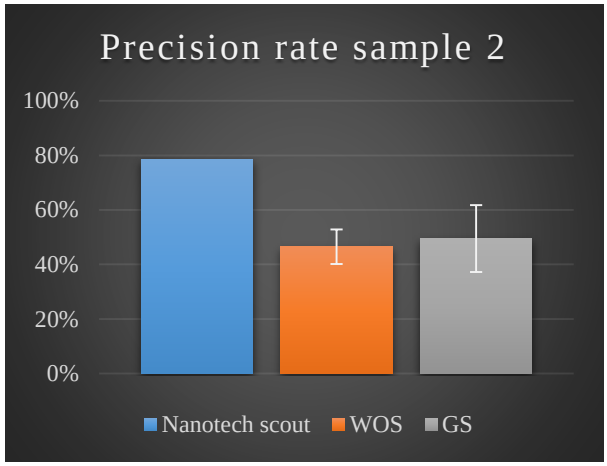


Figure 38 Precision rate for fire retardant technology

nanotechnology means for their innovation problem. The question is how many means a single run gives. A mean is regarded as a “unique” technology. So if two results describe the same technology they will be regarded as the same mean. The total amount of means and means per run can be found in Fout! Verwijzingsbron niet gevonden.. These tables first list the total amount of means that can be extracted from all the runs. It then lists the total amount of means per run. Both tables show that the nanotech scout lists the most amount of means per run. For sample 1 this amount is close to the total, 9 out of 14 possible means. For sample 2 it is obtained that only 15 of 36 means will be listed by the Nanotech Scout. Therefore 21 potential means are not listed in the technology scout. For this relation a similar equation can be used as for precision called the recall rate:

$$recall = \frac{|\{returned\ means\} \cap \{total\ means\}|}{\{total\ means\}}$$

The recall rates for are shown in **Figure 39** and **Figure 40** and confirm that the recall rate for the nanotech scout is relatively the highest. Showing good performance in sample 1 of around 70% but a remarkable lower performance in sample 2. The behavior can be explained by the SAO-structuring of the titles and abstracts of the records. As obtained in the verification 66% of the information is lost because sentences are not SAO parse-able. For example, abstracts that just list characteristics of a technology like “tensile strength”, “flame-retardant” or “abrasion resistance” will not be viewed as Subject-Action-Object relation. This is an important notice about the performance of the Nanotech Scout. Although it shows to have extracted precise and relevant information the limits of grammatical structuring are certainly there.

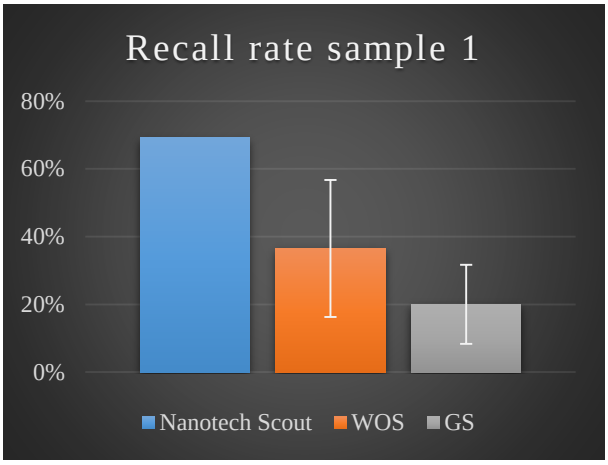


Figure 39 recall rate sample 1 Ionic bond

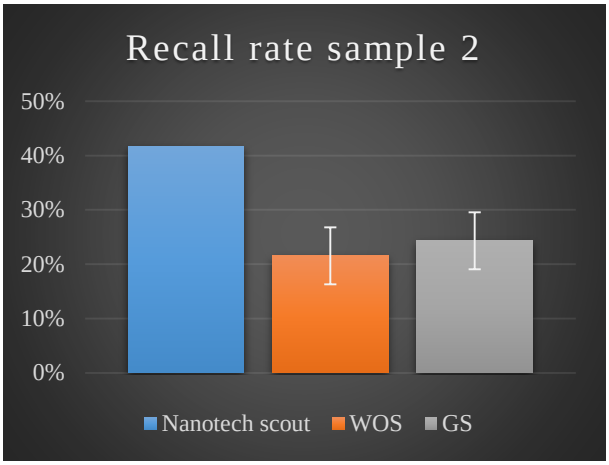


Figure 40 Recall rate sample 2 fire retardancy

The combined measurements show that the average precision and recall increase is respectively 91% and 114%. This is the combined average of both samples for the relative precision and recall increase of the Nanotech Scout in comparison to the combined performance of Web of Science and Google Scholar. Based on the results from the validation analysis on the performance of the search model several conclusions can be drawn. First, the possibility to filter the results based on subject converges the amount of time necessary to read and interpret titles and abstracts. Thereby reducing the time necessary to evaluate results. Second, because the user is able to remove results based on subjects the ratio to the evaluated and relevancy of the results increases. Less time needs to be spend and the quality of the results increases. Third, as the user is searching for potential technologies he or she has the aim to generate as much possibilities as possible. The analysis shows that the Nanotech Scout returns the most unique technologies per query supporting the quality of the results for the user. Fourth, the analysis shows that a lot more means are available especially in the case of fire retardancy. This shows the downside of SAO parsing that will only return results when there is a Subject-Action-Object relation described. Leaving out potential technologies that are described in a sentence in a different way. The next step in validation is the evaluation of the nanotechnologies itself. This will be described in the following section.

9.3 Qualitative analysis of the methodology

In the previous sections the search model has been verified internally and validated externally. It shows that the methodology is operable as designed and also shows that SAO parsing is an interesting potential technology to structure technical texts and browse through this data based on function. The last step is to validate how the methodology and its outcomes are perceived by the engineers and innovation manager and if they are obtained as useful to the company. This is done by executing semi-structured interviews with the problem owners of the cases. In these semi structured interviews multiple questions will be asked regarding the methodology

and the generated results. The interview structure and questions are shown in **Figure 41**. The results of the interviews will be described per main question.

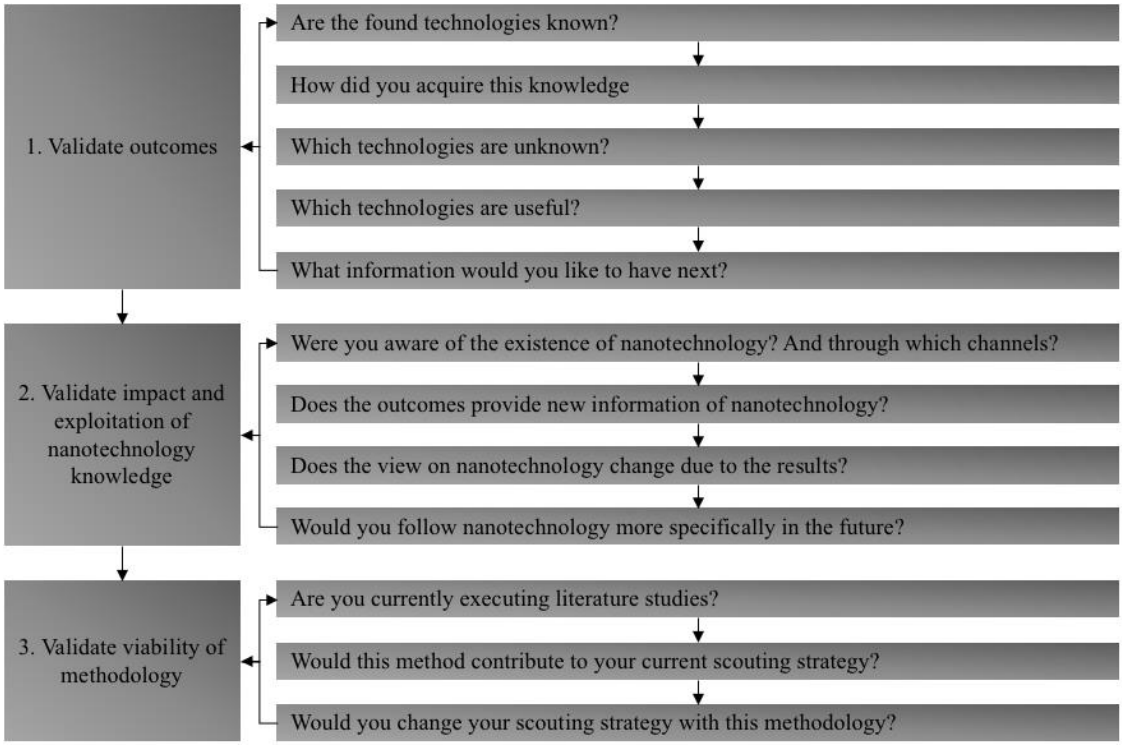


Figure 41 Structure of the interviews (own figure)

The interviews were conducted with the problem owners of the case studies. These were the same R&D managers that provided the information in the questionnaire that were conducted at the front end of the methodology execution. Upfront of the interviews the managers were already aware of the study I was conducting and the study had the aim to scout Nanotechnologies based on their innovation problems that we had discussed before. Both R&D managers had an open minded attitude towards the outcomes of the research. Although they were aware of some nanotechnologies they were not studied in depth before. Furthermore, the R&D managers have an urgency in solving the problems provided. The positive and interested attitude of the R&D managers could therefore result in a biased outcome on the reflection of the results. The politeness of the R&D managers also can influence the results and the answers given in the questionnaire. Moreover, only two people have been interviewed to reflect on the result. Which is a relatively small sample size. For that reason, a semi-structured interview will be executed that allows to extract in-depth information and reflection to the questions in a structured order. We measure the uniqueness of the results and the usefulness of the outcomes, the latter is the most arbitrary and therefore we also scored the results based on requirements in the methodology itself to determine the value of a means. For validating the methodology, we discuss the current approach and determine if the methodology fulfills needs that are not included current approaches.

9.3.1 Validate outcomes

The first question relates to the validation of the outcomes. First the results were discussed and within the case of dyestuff most of the technologies for water purification were already known. The plant manager was aware that he had the choice between adsorbents and nanofiltration. For him the main task was to find out which technology would be most suitable

for the water purification of the dye up to a standard that it can be reused. Two solutions were found valuable for both water purification as for ionic bond promotion of the dye. For water purification the main challenge was getting the reusability of water viable in contrast to the disposal of water. The scouting of technologies was not the main problem. From the results it became clear that one type of technology was the most suitable according to ranking of the means. The other type of technology was interesting because it had two functionalities; dye bond promotion and antibacterial activity.

For flame retardancy the project manager was very surprised by the results. He expected about 2 or 3 results not knowing that 22 results would be presented. Especially the organic flame retardants were interesting because good performance could already be shown in the literature. Also an interesting notion was the possibility to combine technologies to render the complimentary strength of both technologies. Furthermore, the articles described the way of application allowing to speed up the process of testing. For dyestuff the next steps were knowing the cost of a nanofiltration system. Mainly to find out if more steps should be undertaken. For both cases the question was were to order these materials to enable testing. With regard to flame retardants the next steps were first to test the viability of the technologies by gathering more knowledge, to find out if the technologies/materials could be ordered and if the price would be realistic.

Beforehand many materials that were found were not known, but the concepts did. For example, many types of adsorbents were scouted, the materials were completely different while they all use (about) the same technical concept. The knowledge and notion of these technologies came from various sources. The notion for using water filtration systems came from company representatives. The plant manager explained that he had a positive feeling about nanofiltration because he was contacted a lot by representatives before. Flame retardant technologies came through competitor analysis, fairs, conferences, universities and collaboration projects with suppliers.

We conclude that the methodology showed new possibilities for optimizing both processes. On the one hand it brought new knowledge concepts to enhance decision making and, on the other hand, it brought completely new technologies. The technologies that were already known came through several information channels like representatives, conferences and research projects. In the further process the managers would like to know more specific information on how the technologies work, if they could be applied in the process, how to order and the cost of the materials.

9.3.2 Validate impact and exploitation of nanotechnology knowledge

An important part of this research is comprised of the multi-applicability and market opportunities of nanotechnology itself. It has been explained that, although companies would greatly benefit from nanotechnology, there are some deficits in the transfer of this knowledge towards companies. For the case this was underwritten by the innovation manager of the company. She acknowledged that nanotechnology is indeed a potential technology and should be investigated for further application within the company. The plant manager of the dyeing plant and the project manager of flame retardancy have a different attitude towards nanotechnology. It is the task of the innovation manager to do both, to scout for technologies based on internal (innovation) problems and to follow the newest trends to scout technologies no one would ever think about. Nanotechnology is regarded that way, a technology to follow.

The project- and plant managers however are more pragmatic. They have problems to solve and for them it does not matter whether this knowledge is nanotechnology or industries. As long as it fits the requirements every technology is potentially interesting. This is a very valuable finding with regard to innovation management and how new technologies are obtained by companies to solve a problem. Nevertheless, the results showed new findings, findings that indeed could greatly support the problem. Both managers said that nanotechnology is a field where knowledge and solutions can be withdrawn from. They both were familiar with the field. The plant manager mainly sees nanotechnology as a useful technology for functionalizing materials like carpet finishes, dye-delivery and antibacterial properties. The project manager knew some possibilities of nanotechnology. Some nanotechnology finishes had been explored before. But due to the short life time of the functionality (it washes off easily) and the potential health hazards it was never applied. To the question if their view on nanotechnology has changed by this research both managers responded that this will remain the same. Nanotechnology is a field of technologies with potential solutions and possibilities. They would not actively scout for nanotechnologies. But would embrace nanotechnologies if they could be used for technical problem solving.

9.3.3 Validate viability of methodology

The third validation step from the semi-structured interview is the strategy for problem solving by means of the methodology. Currently, literature studies are executed and information is retrieved for problem solving. This information is gathered from several information sources: conferences, representatives, trade associations, journals, research institutes and universities. For solving problems, the knowledge is often retrieved externally even if the solution or solution area is not known. Especially institutes are activated when a certain symptom pops up in one of the processes. Then the iterative process of problem solving is activated. First the symptom is linked to a problem and then the process of problem solving starts. This confirms the theory of the chain linked model and the nature of problem solving of engineering design. In which the problem solving is a process of continuous knowledge, feedback loops and conceptualization. Furthermore, projects are executed within companies and universities. In this process search engines are used for searching technology. For the project manager this is part of his work for at least half a day a week. Both managers confirm that the (online) search activity is time consuming and not always renders valuable results. For example, Google returns a lot of false positives and its results are highly depending on the search terms. In this regard both managers underwrite the usability of the methodology and search technology. A methodology to browse and retrieve information would greatly enhance the problem solving process. For the plant manager the largest benefits are the more focused search possibilities and the possibility to solve and generate potential solutions by yourself. Currently he starts a problem solving process with a problem or a symptom like described **in 3.4 Systems and functions in engineering design.** The search methodology would help him to generate potential solutions for the problem by himself. Enabling him to go to representatives or trade associations with a potential solution in mind instead of asking them what technology could be a solution. This approach would help him to better understand the solution possibilities earlier in the process and reduce time in the problem solving process. This finding is partly supported by the project manager that would also use the Nanotech scout for more specific information retrieval. He regards the nanotech scout as an information extraction methodology and not as a problem solver. He argues that human interaction and reasoning is important for problem solving and creativity. A claim that is also described in section 4.4. There it is explained that the problem solving process is an iterative process information retrieval and conceptualization.

He would use for its search activities. Especially because he is searching knowledge half a day per week for problem solving.

For both managers it would definitely change the way technology scouting is organized, both see an increase in knowledge quality and retrieval and problem solving speed. Furthermore, it would enhance the symptom-problem-solution process as a greater part can be executed by themselves. Allowing them to incorporate external experts in a later stage with more confidence of solving the problem.

9.4 Methodology requirement analysis

In chapter 6 multiple requirements have been generated to steer and measure the methodology design and methodology performance. In this section, after internal verification and external validation of the methodology, a reflection will be given on the performance and the usefulness of the methodology. Because only the external validation provided quantitative results and the methodology has not been applied by the (innovation) managers the measurements will be based on qualitative analysis and if possible uses the measurements are supported by the outcomes of the external validation. Green means that the requirement was (partly) confirmed within the methodology, orange means that the requirement could not be measured and red means that the methodology did not show improvement.

#	**Requirement**	**Measurement**
1	Makes scientific research more accessible and usable	The search model allows to find technologies based on abstract. Although abstracts are already accessible the accessibility is not improved. The requirement however was improved for making scientific research more usable because it enabled to search and extract technological concepts from the texts. This is underwritten by both managers that struggled with selecting the right information from scientific research. This is mainly the result of the information overload with poor precision and recall of the current methods.
2	Produces new solutions for technical goals	Confirmed by the engineering managers. in all the cases new solutions and technical ideas were provided. For case 1 there were two outcomes especially interesting. In case 2 there were multiple new means founded. Besides the means approved by the managers there were other unique means found as well.
3	Simple user interface	Could not be measured because the methodology was not applied by the managers or innovation manager themselves. The user interface is further discussed in the discussion.
4	Fast results	Confirmed by the search model external validation and the managers. The search model analyses showed that both precision and recall are higher for the nanotech scout. Thereby reducing the amount of articles that need to be studied and increase in total options. The managers outlined that the use of the methodology would reduce their search time and speed up the problem solving process. The latter was theoretically discussed and not measured.
5	Easy handling of model outputs	This requirement could not be measured by the managers themselves. In a sense this could be confirmed by the use of

		engineering design structure in step 1 and step 3 of the methodology. By generating requirements one can execute a more directed search as the user knows what requirements should be answered. In this way the user gathers information more directed, searching for answers that fit the requirements based on the information provided by the search model. The interaction of the engineer with the interface is important for understanding the conceptualization of the given information by the engineer. If the engineer does not understand the given knowledge it would be useless even if it holds (part of) the solution.
6	Fast generation of model input	Objective six is hard to assess, in the first place one can assume the the engineer knows what he/she is searching for and therefore directly will use the search tool without setting up requirements and organizing the innovation problem. This setup costs time and will help the engineer to understand the process, resulting eventually in better outcomes. Searching directly would result in a linear problem-solution process, referring back to chapter 4 that the nature of engineering design is not a linear approach at all.
7	Fast tool for reviewing state of the art research papers	Objective seven relates to the recall of the search engine. As presented in **9.2 External validation of the search model** the recall of the search engine shows to be the highest when compared to Web of Science or Google Scholar. So in that sense the recall can be regarded as the highest. However, 66% of knowledge is lost meaning that the state of the art in science can only be assessed based on the results that have an SAO-relation. Furthermore, the methodology cannot organize results based on publication year. We can therefore not motivate that the methodology improves the reviewing of the state of the art.
8	Generation of valuable means for innovation problems	This objective was partly confirmed by objective two. However, some means were not found of value by the firm even though they scored high in the comparative analyses. For example because the means were already known by the company.
9	Easy to find relating knowledge	This objective could not be confirmed within this methodology, although new information is found the nanotech scout does not contain an option to find more info about a certain topic. However, it does feed the engineer with potential solution areas and by reading articles new ideas may be generated in the process. With the current outcomes this is not measured.
10	The software part of the methodology is face valid	Yes, the internal verification showed that the algorithm used worked as designed. This was tested by comparing the internal SAO-knowledge base data with data from two reference sets. In one of the sets the data was gathered executing the algorithm by hand. In the other reference set the data was gathered using the same algorithm but with a smaller dataset. 34% of the sentences converted into useful SAO-relations. No reference was found to confirm that 34% is a normal amount for abstracts.

11	Increases information retrieval performance	Based on the information retrieval metrics of precision and recall it is confirmed that both precision and recall were improved with respectively 91% and 114% compared to the performance of Web of Science and Google Scholar.

9.5 Chapter conclusions and key findings

In this chapter the aim was to verify, validate and evaluate the methodology. The verification showed that internally the search model worked as designed and that 34% of the sentences was successfully parsed and converted in valuable SAO-relations. To validate the model on its functionality and to show that structuring large amounts of technical information in SAO-relations would render nanotechnical solutions it was compared to conventional search systems. For comparing these systems, the concept of precision and recall are used. Both precision and recall showed to be better in all the search scenario's proving that the concept of SAO structuring. It must also be said that a lot of information was lost due to SAO-structuring. Leaving out information and potential other means. Interviews were conducted with the managers for the case. The outcomes confirmed that nanotechnologies provide new opportunities for problem solving and that the methodology would increase the speed and quality of knowledge generation and information. However, it also became clear that from a problem solving innovation perspective constraining the methodology to nanotechnology is too limiting. A problem just needs to be solved regardless whether its solution comes from a scientific field or not. All eleven requirements were individually evaluated based on the outcomes of the three validation steps. Six requirements are positively confirmed, three requirements could not be measured and 2 requirements were not improved by the methodology.

10 Discussion

In this research, a methodology has been constructed that allows innovation managers to explore nanotechnological opportunities based on innovation problems. In this chapter, a reflection is provided on the methodology, the results of the methodology and its validation. In addition, a reflection is provided on the generated knowledge concepts and how this could be researched in the future. Five key discussion points are addressed. First we will discuss the generalizability of the methodology. Second, the pitfalls of the SAO algorithm used and SAO in general. Third, the reflection on the multi-applicable character of nanotechnology and how this is obtained by the engineers and innovation manager in bulk manufacturing. Fourth, is the debate on the role of the engineer and the required prior knowledge to lower information stickiness and five the other possibilities SAO-structuring has for further research are addressed.

10.1 Generalizability of the methodology

In **5.1 Conditions for a representative company** we have outlined that this methodology has been designed for companies that are subject to 5 conditions:

- The company is technology driven;
- The company has constructed innovation goals;
- The company has designated roles within the innovation strategy;
- The company has not assessed the implication of nanotechnology;
- The company Is aware of technology scouting.

The case study company did meet the conditions and its innovation strategy was extensively described in **5.2 Introduction to the case study in bulk manufacturing**. Based on the conditions and the innovation strategy specific requirements were generated for designing the methodology. Therefore, the methodology is partly based on input from the case study company. In this section we want to argue how generalizable the methodology is. When we look at the methodology itself, we can see that the first step consists of engineering design methods for structuring an innovation problem. This method is very generalizable, Dym and Little state in their book (used as a source for describing the engineering design in this research) that a designer works "*in many different kinds of environments: small and large companies, start-up ventures, government, not-for-profit organizations, and engineering services firms*" (Dym & Little, 2014, p. 4). This description of a designer is too broad for designing using nanotechnology as a knowledge base but it does show how general the theory of engineering design is. In this research engineering design is used to identify minimalistic functions from an innovation problem and not for extracting nanotechnology knowledge. To extract nanotechnology knowledge, we use SAO-mining organized in a unique way in order to use the minimalistic function as an input to mine means that execute the function. Now this part is the most essential part of the generalizability of the methodology because not every function will render an executing subject in the nanotechnology knowledge base. Nanotechnologies are a nanoscale enabler for chemical reactions, materials, medicine, semiconductors etc. It is important to note that its functionality therefore also occurs on this scale. The methodology designed is therefore only applicable in situations where a small scale based chemical, physical or biological situation occurs. This was true for both cases in the case study. First to promote a chemical reaction in dyeing, second to enable a physical, biological or chemical reaction in water purification and third to improve a chemical reaction or

adjust the physical structure to indirectly influence a chemical reaction in flame retardancy. This methodology is therefore completely generalizable to be applied in any situation in which the minimalistic function exploits a chemical, physical or biological relation. Thus, the methodology is only generalizable to a company that has to manage a challenge that is subject to a chemical, physical or biological relation. The knowledge base therefore determines to a large extent what information can be found. To increase the generalizability of the methodology other knowledge bases can be added to the search model. A chemistry, material or medicinal knowledge dataset allows the use by different disciplines that also have a task of designing or solving. We can state that the methodology consists of two flexible components. The first component is the engineering design methodology and the second component is the database that is indexed in SAO-relations. The current methodology is generalizable to companies that fit the 5 conditions and is searching for technologies in which small scale physical, chemical or biological interactions determine the outcome. The flexibility allows to broaden the methodology applicability to other technological fields because engineering design is a generic method and the knowledge base can be enlarged with other information sources.

The previous paragraph discussed the generalizability of the methodology from a theoretical perspective. In reality we find more challenges in the generalizability. We can state on paper that we can easily adapt engineering design methods and datasets. In reality the execution of the engineering design methods are not that obvious. It is a complex process of reflection and understanding. The performance of the process is highly correlated with the quality of the requirements and functions established [111]. Bad construction of requirements and functions leads to low quality results and therefore to a negative experience of methodology usefulness. Furthermore, the system is designed in such a way that, beforehand, you can search without knowing a solution. At DESSO the cases resulted from an existing list with problems that need to be solved in the near future. A selection was partly based on the urge of the company to solve the problem but also partly because it was reasonable that nanotechnology could deliver a solution. This was the result of defining in which of the proposed cases the chemical, physical or biological interaction of nanotechnology could be useful. This requires an upfront notion of what nanotechnology is and how it works. This was known within DESSO but it cannot be assumed that every company that fits the conditions also has this knowledge. The same is true for methodology application in other technical fields using different datasets. The user requires to know whether the field he or she is searching in would logically lead to a solution. We can therefore refine the generalizability of the methodology with the condition that the user is able to reason that the knowledge base he or she is searching could logically lead to a solution.

The methodology was designed and executed in the operation and process improvement department of the firm. This meant that the cases provided were also emerging from operational needs within the firm. The location of the execution in the firm has influenced the methodology for becoming an innovation problem solving and technology scouting solution. The methodology would have been different when it was designed and applied at the department of new product development. In that department ideation and creativity are important for designing new and innovative products. In that situation the search tool would have been applied as an ideation tool, by finding technologies that could innovate product use and functionality. The engineering design methods would then be of value for determining the feasibility of the ideas. The methodology is currently not optimal for ideation as it does not display any creative and novel insights in nanotechnology functionality. Both departments are

in innovation but do not have the same innovation approach. We can therefore further generalize the approach to the following scheme:

Generalizability of the current methodology	**Rule No.**
The company needs to fit the five predefined conditions.	1
The company is searching for technologies in which small scale physical, chemical or biological interactions determine the outcome.	2
The user is able to reason that the knowledge base he is searching in could logically lead to a solution.	3
The user has an innovation approach for finding technologies to solve, replace or improve processes in the company.	4

Within this scheme the second rule can be replaced by adjusting the dataset from nanotechnology to chemistry, materials or mechanics under the condition that rule 3 is then still met. Reflecting the outcomes on the theory of Pavitt where this methodology can be applied are production intensive firms with an operation department that actively searches for external technical solutions for innovation.

10.2 Knowledge loss and SAO parsing

Within the methodology, a certain logic is used to parse text based on syntax. This logic allows extraction of subject-function relations from sentences. In the verification a loss has been calculated of 66% of the total of parse-able sentences, showing the downside of syntax based parsing. This is because the used sentences do not have an SAO-relation and therefore do not have a subject-function. Because this subject-function relation is used to find technologies/components in this research the other 66% of the knowledge could not be indexed as an SAO-relation. This is also acknowledged by Abbas et al [13], who describes that SAO-based approaches suffer from grammatical ambiguities and the lack of representing the semantic relationships among the grammatical structure. Combining SAO-based NLP technology with keyword-based technology might reduce the amount of knowledge that is lost, but also could lead to a decrease in precision, as false positives increase. A way to solve this is using a more machine learning and neural network approach. In this approach the dataset is indexed based on function (action-object) and after refinement from the engineer with the SAO-relations, new information is withdrawn on what is relevant. The relevant SAO-relations including titles and abstracts of the articles can be used as a body for browsing the dataset a second time for similarity. This search method is trained by human interaction indirectly acting as an expert annotator. A practice that is a bottleneck in the optimization of natural language processing as annotators are often expensive experts [112]. In this fashion, a gamification approach is applied to use expert annotator knowledge and improve the precision and recall of the search logic.

Another downside in SAO parsing is the construction of the subject. Because abstract sentences are long and consist of a lot of information, the subject is often a referral to another domain. Therefore, the parser indicates subjects as “that” and “this”. These are meaningless words and more in depth understanding of the title and abstract is necessary to find where the words are referring to. Overcoming this is simple, if the referring element is in the same sentence, which allows the parser to locate the referral. However, if the information is located

in a previous sentence this information cannot be extracted using the current algorithm. For overcoming this pitfall additional analysis must be performed on the linguistics of abstracts and how information can be extracted from sentences for problem solving beyond SAO. By understanding how subjects grammatically relate to other words and by understanding which words add extra value to the understanding of technologies and components by engineers and innovation managers, the information extraction will increase.

10.3 Multi-applicability of nanotechnology and commercialization

An important driver and objective of this research was the exploration and exploitation of the multi-applicable and general purpose character of nanotechnology. This is done by generating functions allowing to browse a database filled with enabling characteristics of nanotechnology. The results of the case study provided several popular nanotechnologies and materials for application. The technologies are shown in Fout! Verwijzingsbron niet gevonden. that can be found in Fout! Verwijzingsbron niet gevonden.. The results show that there are five nanomaterials used in multiple applications. Applications that have been almost randomly provided by the company. Four of those nanomaterials are found in two cases and one of those queries are found in three cases. These results show valuable insight in the multi-purpose character of nanotechnology. Something that has been described by many [5], [113], but is now also confirmed in the results of the case study. The question now is, and that has been stated by many others, is how these engineering opportunities can be accelerated to be applied by firms. The R&D managers have explained that they will not explicitly search for nanotechnologies in their problem solving activities. The only one left in the case study company that has this role of opportunity scouting is the innovation manager. So there are two challenges; how to provide the information and the multi-applicability of nanotechnology that;

1. The R&D managers browse nanotechnologies out of interest or for problem solving purposes and;
2. Present the information in such a matter that the innovation manager is able to link the knowledge concepts heuristically to the needs of the company.

The current methodology does allow browsing nanotechnology as such but the general opinion of the R&D managers and the innovation managers is, that nanotechnology is just an emerging field where technologies come from. One way to change the opinion of the R&D'ers is by communicating the field as a toolbox of new technologies. This would help startup companies that provide nanomaterials as they are changing their activities from a material supplier towards a solution provider [7]. If the supplier and the innovation department of a firm understand how nanotechnology is communicated by the supplier and obtained by the firm, the transfer of nanotechnology is likely to improve. Many theories exist on how nanotechnologies should be commercialized, Maine showed that there are several strategies to transfer science-based information[6]. However, there have been few studies on the acceptance and public opinion of nanotechnology, on how it should be market and on when it becomes interesting for companies to address the field as a general purpose toolbox. This research shows how nanotechnology is perceived as a field in a bulk manufacturing company. However, more research is necessary on how nanotechnology is perceived in multiple industries, firm size and firm strategy. Based on this information, the governance frameworks of nanotechnology towards commercialization and transfer of nanotechnology can learn from the outcomes. In section **2.3 Knowledge character** We have discussed the Dutch national innovation program for developing and transferring science based nanotechnology for societal and company growth. The program has primarily focused on developing new knowledge that partly is directly applied by company that is involved in the research project. It is assumed that

those companies were aware of the nanotechnology implications. With regard to the outcomes of this research we have found that understanding what nanotechnology is and where nanotechnology could be used for solving problems enables companies to use a methodology like this. Rafols argues the same way but puts the responsibility in the hands of the suppliers. The optimum will be somewhere in the middle, on the one hand market parties need to be able to adapt to a different approach of doing business. On the other hand, to increase the adoption and commercialization of nanotechnology more firms need to understand what nanotechnology is and how it can be applied. Governance programs should focus on making nanotechnology understandable to enable traction of nanotechnology knowledge in the business landscape.

Besides the commercialization strategy there is an elephant in the room for nanotechnology. In this research the role of risk and health have not been thoroughly described. This is mainly a result of the requirement-based focus of searching technologies, which automatically excludes any material that may cause harm. However, there is risk related to nanotechnology and this influences the public opinion and adoption rate. The amount of nanomaterials is large, with an almost endless conformation freedom. A general description of nanotechnology being “unsafe” undermines the potential of all nanotechnology. It has been debated that the trade-off of nanotechnology adoption is to exploit the nanotechnology capabilities without knowing the risks [114]. A knowledge base would be valuable that summarizes the pros and cons of nanotechnologies and nanomaterials and its characteristics. This allows nanotechnology suppliers and consumers to do and contribute to risk assessment. This supports the ideas of Rafols, on changing the risk governance of nanotechnology to innovation governance, while enhancing the transparency of nanotechnology risk [7].

10.4 Sticky information and general knowledge

An important point of discussion is the required knowledge the user of the methodology needs to have to generate the same or better results as shown in the case study. This relates to the input generation and the outcome evaluation of the methodology. This methodology uses the concept of engineering design for problem solving. A concept that is not used by every R&D manager and innovation manager. Engineering design is used to structure the innovation problem and is necessary to define the minimalistic functions that are turned into search queries within the methodology. This process of conceptualization requires thinking and without applying the engineering design methods the user will construct queries to early in the process. That approach would result in a linear problem solving process as the user starts constructing functions based on the problem and not the requirements and objectives have been identified. Users that are unfamiliar with this methodology and search logic will not render its full capabilities and therefore generate less valuable outcomes. The same is true for the outputs/results of the search model, as these outputs must be interpreted as well. The predefined requirements are used to measure the outcomes that gives the user the ability to search for specific information. For the case of flame retardancy, the requirement is for example the peak heat release rate or the type of polymer matrix. If the requirements are poorly defined the results cannot be measured appropriately they will be subject to a lot of uncertainties about the ability to embed the result as potential solution in the real system. Thus, the interpretability and performance of the results depend on the ability by the user to understand and structure the problem. In *“Sticky Information” and the Locus of Problem Solving: Implications for Innovation* by Hippel the process of problem solving and innovation management is described. Stating that when information, even if it contains the solution of a

problem, is transferred to the person that does not have the right knowledge to interpret it, the information will not be useful. Resulting in high information stickiness, meaning that there is a high cost to transfer the knowledge to a certain locus (the problem-solver) [115]. Within the methodology the found information has a high potential of being sticky when the problem is poorly understood and structured. We will discuss two possible ways of overcoming this within this research. First, increasing the methodology simplicity and lowering its stickiness can be realized by providing more automation of the tasks. For example by internally organize the innovation problem based on problem description and requirements. This information is stored, parsed according to, for example, SAO and then this parsed information is used as input to browse for concepts in the database. The results are then compared to the requirements, and selections are made in advance based on the given requirements. The information returns in the form of a technological concept with measured requirements. The second approach is by educating the locus and training how to optimally apply the methodology. This approach requires training the users in defining requirements and constructing requirements that optimizes the recall of the search software of the methodology. This enables to optimally understand and structure the problem.

10.5 Application areas and further research

SAO based text mining is a powerful tool to analyze and compare large amount of technologies based on their basic functions. Especially in nanotechnology where its functions can be exploited in multiple areas. In section **3.5 Computer aided techniques for innovation** we have motivated the powerful applicability of SAO-relations for technology and innovation. Previous research in text mining for innovation management has focused on SAO-relations to explore technical concepts, trends and innovation roadmaps from patent data [116], [117]. However, these are different SAO approaches because in these cases the SAO-relations are deducted from a smaller and more specific set of information. The goal of these papers are to explore fields of technology by comparing and linking the SAO-relations and determining which SAO-relations are most prevalent. The roadmapping trend approach visualizes what the most general technical concepts are from text and how they are embedded in a technology, using multiple patent sources. This is different from the proposed methodology in this research, in which SAO-relations are interpreted independently, and renders a good overview of the functions of nanotechnology. For the roadmapping trend approach patent data is used and patents are a useful source of functions because they are comprised of a lot technical concepts. Although titles and abstracts have a different purpose then patents, it is interesting to explore this data on technical concepts using SAO-based trend analysis. This would show the most executed functions in nanotechnology, heat maps of functions, relations between nanotechnologies that execute the same functions and so on. Note that this would be a different, more explorative, approach that has the ability to entail new concepts and linkages for technology roadmapping. Another interesting possibility in applying SAO is by using the subject as input instead of output. We designed a methodology for searching subjects by using action-object (AO) as input. However, the logic can also be executed to explore nanotechnologies like carbon nanotubes, graphene, fullerenes or certain types of nanoparticles. This would render action-object relations that show which functions have been demonstrated with the technology. This is interesting for exploring the multi-purpose character of nanotechnology by analyzing the difference in actions and to see for what applications the technologies have been tested. In **Figure 4** the relation between nanotechnology and other scientific fields have been explored and it is interesting to build further on this map to see what technology is operating in the field. This would display information about what kind of functions

nanotechnology is executing but also in what fields certain nanotechnology concepts are used. It should be possible to obtain this information with the current dataset and would show interesting information on how nanotechnology operates in the classical scientific fields.

So far, the potential of SAO is discussed for exploring nanotechnology but SAO-structuring can be applied and rendered for many other applications. An interesting research opportunity would be to categorize the strength of abstracts and titles based on their SAO performance. It is also interesting to explore SAO for optimizing search engine technology. Under the assumption that search engines work mostly keyword based, it would be interesting to see if the rate of precision and the rate of recall can be improved by embedding the SAO-principle in the search queries.

10.6 Chapter conclusions and key findings

In this chapter, the methodology knowledge concepts used in the research have been discussed.

First, we have looked into the generalizability of the results. We have created 4 rules that need to be met in order to ensure that the methodology is applicable in other contexts than the company that is used as a case study.

Second, the optimization of the data structuring to increase the recall for the search terms by using expert annotation and machine learning have been proposed.

Third, the results from the case study support the claims of nanotechnology being a multi-purpose technology as nanotechnology concepts have been found that can be applied in multiple application areas. Propositions have been given on how this multi-applicability can be adopted by R&D'ers and innovation managers. In general, the communication and understanding of nanotechnology needs to be enhanced.

The fourth point relates to the stickiness of information and discusses how nanotechnology knowledge can be transferred while lowering information stickiness. Two potential solutions have been proposed; increasing the automation of the tasks in the methodology or by teaching the users.

In the fifth point, we argue that SAO-structuring; can enhance the understanding of the nanotechnology field, can be used to analyze abstract structures and be researched to improve search engine technology.

Applying SAO to extract technical information is an interesting technique that can be applied to contribute to the innovation process. Previous research has shown that SAO is valuable to map technology fields and this research shows that the technique can be used to structure text and extract technologies and components for direct problem solving.

11 Conclusion

For many years, nanotechnology is on the threshold of mass breakthrough. The technological field that combines almost every imaginable traditional natural science field has been the subject of research projects, governance frameworks, public private partnerships and policies. Time has come for nanotechnology to be mass adopted by industry and applied to change society. The toolbox of nanotechnology has this potential. Unfortunately, the field of nanotechnology is rather complex, its emerging character, potential health risks and diverse scientific background limit mass adoption. The challenge is how firms can be guided through the complexity of nanotechnology as a whole.

In bulk manufacturing companies there is a continuous need to innovate to secure firm survival and enable growth. The general purpose character of nanotechnology can contribute to the performance of the company's operations if its knowledge can be found, interpreted and selected. Currently the retrieving of such science based knowledge is a costly and time intensive process. The innovation manager is a key factor in absorbing and communicating this knowledge. To guide the innovation manager through the web of nanotechnology, all aspects of the innovation process must be understood. Therefore, a design focused research question is constructed that asks what kind of methodology allows the innovation manager to select, find and evaluate nanotechnologies. The methodology needs to reduce cost of- and increase the quality of information retrieved.

11.1 Answering the research question

In this research a methodology is designed that **builds on innovation theory and practical innovation strategy** to **integrate engineering design methods** that enables the scouting of nanotechnologies. To browse the field in an efficient manner, a field that is constituted by scientific knowledge**, natural language processing techniques are applied**. These techniques are used to structure all nanotechnology related literature based on its functionality in SAO-relations. This methodology helps the innovation manager to structure the innovation problem and uses SAO-text mining techniques **to scout potential nanotechnologies** without the need of specific nanotechnology knowledge. The technologies can be evaluated allowing the decision maker to define if the technology can be applied.

The methodology has been evaluated by applying it to two cases within a production intensive company. The methodology resulted in several nanotechnology means that where new to the company and can contribute to the competitive advantage of the company. Analyses showed that the SAO-relation approach for structuring, indexing and browsing the nanotechnology field is more efficient than conventional scientific information retrieval approaches in terms of precision and recall. Moreover, R&D managers in the company motivated that the methodology reduces the time of finding information and improves the control in the innovation problem solving process. An approach that therefore should not only be restricted to nanotechnology. The methodology is generalizable to other bulk manufacturing companies and technology sources if the companies meet the conditions of the representative company, are aware of the technological concept it searches and face challenges in product or process that can be logically solved using the concept.

There are also downsides to the technique as two thirds of the information is lost in the SAO-parsing process, limiting the performance because of the grammatical structure of the sentence, and therefore excluding potential solutions. Multiple improvements are proposed by means of machine learning. Another threat is information stickiness due to the complexity of nanotechnology and difficulty of engineering design methods. These threats can be mitigated by automating the innovation problem solving process to a larger extent or by training the users. Future research should focus on improving the retrievability of knowledge using SAO-based text mining, reducing information stickiness and enhancing the understanding of nanotechnology by both suppliers and users.

A methodology has been successfully designed that supports the activities of innovation managers for finding, selecting and evaluating nanotechnology for direct problem solving. The methodology incorporates both the strategic and engineering perspective. Although many challenges are present for optimization of the concepts and algorithms used, it showed that nanotechnology is a valuable field of technologies that fulfill the need of continuous improvement in companies. It also showed that SAO based indexing is a promising technique to organize, index and analyze technological fields because of its function-means relation.

12 Personal reflection

In this section I will reflect on the graduation project at the personal level by looking into the motivation of this thesis, the design of the thesis, the learnings of the thesis and how I will continue with the results.

My motivation of doing this research emerges from a combination of drivers. First of all, I have a background BSc. in Science, Business and Innovation from VU university. The aim of this bachelor is to teach students how to transfer science based knowledge into valuable business to establish innovation. My interest has therefore always been in the understanding of natural science and turn the findings into business applications. For that reason, I also started a consulting firm with a classmate called Nanonow. We both did a BSc. project on the valorization of a nanotechnology from science to business. This is also the driver of my interest in nanotechnology. During my Master program I did some consulting work for Nanonow. In these projects I helped companies with interpreting nanotechnologies and finding new innovation concept within nanotechnology. Bridging the commercialization gap by finding, selecting and evaluating nanotechnology by hand. To increase my knowledge level on nanotechnology I followed courses in chemical and electrical engineering. I applied this knowledge directly within the projects of Nanonow where our main work was to find nanotechnologies by browsing websites, textbooks, scientific papers and patents for finding interesting technologies. This is also the moment where I started to think about automation of the tasks that I would do normally by hand. This brought me eventually around the table with Scott and the design of my thesis project was born.

At that stage I constructed my thesis project plan based on the need of companies to investigate the innovation potential of nanotechnologies, which I had seen in my consulting work, and the hypothesis that the tasks I used to scout technologies could be automated in some way. During the thesis preparation course I validated the hypothesis by finding the literature on text mining and bibliometric analysis in technology scouting and technology roadmapping activities. DESSO showed interest in the exchange of nanotechnology knowledge for designing a nanotechnology search system. Beforehand I knew that the biggest task would be the design and programming of the search tool. Mainly because I did not have any experience with Python and programming whatsoever. I knew however that I had to build a complex system and not a simple analysis tool. Luckily for me, programming was a lot of fun. It was only for that reason that I was able to get the expected level of programming skills. At that time, I was already halfway past my thesis project (end of July). But from that moment I was able to work quickly. The main risk in the project was not being able to get a model up and running and generate the results for scouting technologies. If that would not have been possible I would have to fall back on other techniques for finding nanotechnology results. This could be techniques that already had been demonstrated in the text mining literature for technology trend analysis of patents, instead I would then exchange the patent dataset for scientific information. Another possibility was gathering nanotechnology by hand and present an extensive literature review of the technologies of interest. Fortunately, I was able to make the model and get it workable. Although there are still many unknowns, performance issues and challenges in knowledge transfer the goal of designing a methodology for finding, selecting and evaluating nanotechnology knowledge was delivered. It is very interesting to look back in time and to see how I visualized the research myself in the beginning. The first ideas of this

research started in the course SPM5905. Below you'll find how the research question developed through time:

Version	***Date***	***Research question***
Draft project proposal SPM5905	January 5th	What kind of framework can be designed to discover relevant nanotechnology knowledge using the existing nanotechnology knowledge base for a technology driven enterprise based on their current technological process?
Project proposal SPM5905	January 31	"What kind of framework can be designed to discover relevant nanotechnology knowledge using the existing nanotechnology knowledge base for a technology driven enterprise based on their current technological process?"
1st project proposal thesis project	May 30th	What kind of methodology can be designed that would provide a company innovation executive clear steps how nanotechnology related scientific knowledge can be identified and evaluated to support the strategic innovation process?"
2nd project proposal thesis project	June 7th	What kind of methodology can be designed that would provide a company innovation executive clear steps how nanotechnology related scientific knowledge can be identified and evaluated to support the strategic innovation process?
Midterm draft thesis	July 28	What kind of methodology can be designed that would provide a company innovation executive clear steps how nanotechnology related scientific knowledge can be identified and evaluated to support the strategic innovation process?
2nd draft thesis	August 28	What kind of methodology can be designed that would provide an innovation manager clear steps how nanotechnology related scientific knowledge can be identified, selected and evaluated to support decision making in the inside-out innovation strategy?
Greenlight draft thesis	October 4	What kind of methodology can be designed that would provide an innovation manager clear steps how nanotechnology related scientific knowledge can be identified, selected and evaluated to support decision making in the innovation strategy?
Final thesis	October 31	What kind of methodology can be designed that provides an innovation manager clear steps on how nanotechnology related scientific knowledge can be identified, selected and evaluated to support decision making in innovation strategy?

The yellow marked texts represents a change in the research question. We can obtain two essential points where the thesis research question changed. The first was at the moment of delivering the project proposal and the second at the point of the draft thesis was delivered. Between the midterm draft thesis and 2nd draft thesis the model was finalized which explains the slight change in formulation.

An interesting question is if I would design the thesis project differently looking back through time. If I would already have the knowledge I would currently have the answer is yes, this would have saved a great deal of time. In that scenario I could get my objectives and deliverables more clear at the front-end of design and realize a more structured outcome. However, if I would not have the knowledge I have right now my answer is no. This is because a great deal of my time I have spent on understanding and conceptualizing the literature on text mining and the ability to program this into a functioning model. At the front end of this thesis I really

challenged myself to design this methodology. To design something that allows a company to explore the toolbox of nanotechnology, extract information out of the toolbox to eventually apply this in the innovation strategy.

In the future I will further explore the concept of using text mining and other NLP techniques in technical and innovation problem solving. This has everything to do with my ambition to make science based knowledge available for everyone. I see great potential in the further automation of the process and using the engineering design structure to increase the performance of information retrieval and present the information to the user in the simplest way. Ensuring that many people can be supported in their technology scouting and engineering activities.

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14 Appendices [CONFIDENTIAL]

Appendices are non-disclosed items of the thesis.