HELSINKI UNIVERSITY OF TECHNOLOGY
Department of Industrial Management and Engineering
Industrial Management Laboratory

Heli Orelma

Large Patent Portfolio Optimization

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering

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Supervisor: Professor Karlos Artto
Instructor: Licentiate Toni Jarimo

HELSINKI UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF INDUSTRIAL MANAGEMENT AND ENGINEERING

ABSTRACT OF MASTER'S THESIS

Author:	Heli Orelma
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Supervisor:	Professor Karlos Artto
Instructor:	Licentiate of Science Toni Jarimo

Abstract:

This master's thesis studies the systematic management and optimization of large patent portfolio. The objective is to explore the main characteristics of large patent portfolio management and to create systematical logic for the selection and management processes. The created logic will also be tested in a practical case.

The study is constructive and it is conducted as an action research. It combines both qualitative and quantitative data. The main emphasis of the research is the computational management of patents as a portfolio. The questions concerned are business decision making choices and the study doesn't cover questions like the exact valuation of a single patent or patent portfolio. The studied industry assumed to be the electronic and telecommunication industry.

First, the study explores the management of patents as a whole. Subsequently, different mathematical and computational methods are explored to understand, what kind of model and algorithm is needed. A model for managing patents computationally is presented as well as an algorithm for defining which patents should be studied for the decision of discarding them. The procedures also help to evaluate, which parts of the portfolio need additional investments. Finally, the study and assumptions beneath are discussed.

The study contributed to the existing knowledge by studying the factors affecting decisions about large patent portfolios and presented a model for the discarding process. It helps the managerial practices by listing the possible patents that could be further studied for discarding decisions. Additionally, it can help to justify the decisions of adding, keeping and discarding patents.

Number of pages: 96 + 2	Keywords: patent portfolio, patent management, portfolio optimization
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TEKNILLINEN KORKEAKOULU — DIPLOMITYÖN TIIVISTELMÄ
TUOTANTOTALOUDEN OSASTO

Tekijä:	Heli Orelma
Osasto:	Tuotantotalouden osasto
Pääaine:	Teollisuustalous
Sivuaineet:	Laskennallinen tiede ja tekniikka, Systeemitekniikka
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Tutkimuksen valvoja:	Professori Karlos Artto
Tutkimuksen ohjaaja:	TkL Toni Jarimo

Tiivistelmä:

Tässä tutkimuksessa tarkastellaan ison patenttiportfolion systemaattista hallintaa ja optimointia. Tarkoituksena on tutkia keskeiset ison patenttiportfolion hallintaan liittyvät tekijät ja luoda systemaattinen logiikka valintaan ja hallintaan. Luotu logiikkaa pyritään myös testaamaan käytännön tapauksessa.

Tutkimus on konstruktiivinen ja se tehdään toimintatutkimuksena. Tutkimuksessa yhdistyy sekä laadullinen että määrällinen tieto. Keskeinen painotus on laskennallisessa portfolionhallinnassa. Käsitellyt kysymykset liittyvät liiketaloudellisiin päätelmiin, eikä tutkimus kata esimerkiksi yksittäisen patentin tai portfolion arvottamista.

Ensimmäiseksi tutkitaan patenttien hallintaa kokonaisuudessaan, jonka jälkeen tutustutaan erilaisiin laskennallisiin metodeihin, jotta ymmärrettäisiin, millaista mallia tai algoritmia tarvitaan kyseisessä ongelmassa. Tämän seurauksena esitellään malli patenttien laskennallisesta hallinnasta ja algoritmi, joka päättää mitä patentteja kannattaa tarkemmin tutkia hylkäämispäätöstä varten. Käytetyt menetelmät myös auttavat arvioimaan, mitkä portfolion osat kaipaavat lisäinvestointeja. Lopuksi pohdiskellaan itse tutkimusta ja siihen käytettyjä oletuksia.

Tutkimus lisää olemassaolevaa tietoa tutkimalla keskeisiä vaikuttimia päätöksenteossa ja esittelemällä mallin ja algoritmin hylkäämisprosessille. Luotu työkalu helpottaa liikkeenjohdollisia käytäntöjä listaamalla mahdolliset hylättävät patentit, joita voidaan tarkemmin tutkia. Tämän lisäksi se auttaa perustelemaan päätöksiä koskien uusia investointeja, patenttien pitämistä sekä patenteista luopumista.

Sivumäärä: 96 + 2	Avainsanat: patenttien hallinta, portfolionhallinta, portfolion optimointi
Kirjasto: TU-22	Julkaisukieli: Englanti

Foreword

This Master's thesis was written in 2007 in VTT Business Technology as a part of project AINO which was about the valuing and management of immaterial properties. In a larger scale, AINO was conducted as a part of the project RPM-I, Robust portfolio modelling in innovation management.

I would like to thank Toni Jarimo for giving me this interesting subject and instructing me throughout the process. I would also like to express my gratitude to Karlos Artto, who was supervising my work and giving me valuable feedback. A word of thanks goes also to my team-mates Henri Hytönen and Kalle Korpiaho for their help and company. I would also like to thank Erkki Yli-Juuti and Marja Liisa Autti from the Nokia corporation for believing in me and giving us interesting insights to the subject.

I'm grateful for my parents Päivi and Arto for all their love and support. A special thanks goes also to my sister Laura, who always brings new meanings to my life. I'd like to express my appreciation to my grandmother Tuulikki, because she is such a wonderful grandmother, and thank my other grandparents – Pekka, Helli, and Jaakko – for the lovely memories. I'd also like to thank all my friends, especially Elina, Pilvi and Johanna, it has been an honour to have you around. I'd also like to express my gratitude to my fellow students and friends for the amazing time I've had during the years I spent in TKK.

Contents

1 Introduction

1.1 Background

In knowledge based competition patents are perceived as an instrument for protection. In the academic literature patents are pictured as a versatile tool for Research and Development (R&D) support and strategy implementation. As R&D support they represent a source of new information, an indicator for the innovativeness, an acknowledgement for the researcher or a reason to invest more into a new innovation. The strategic aspects of patenting are related with the creation of a more suitable environment in a specific field of technology.

Several researches (Schankerman, 1998; Cohen et al., 2000) have contemplated that many companies can not turn their patent portfolios into actual profit. The granting process is expensive and it is often difficult to separate the actual benefits achieved from a patent or patent portfolio. To make the situation even more difficult, the value of patents contains many uncertainties and it is strongly connected with future development. Companies are usually advised to manage their portfolios actively but in practice many companies leave their portfolios almost intact (for instance Soininen, 2003).

The number of patents in the world has been growing steadily since the 1980's. Only in year 2005, more than 410 000 patents were applied into the US Patent and Trademark Office (USPTO, 2006). Internationally operating companies have nowadays more than 10 000 patents each and the number is still growing. Also the expenses are growing to the limit where managers have to face the question of how to shape up the existing portfolio.

Large portfolios contain potential for explicit cost-savings, because they include substantial numbers of expensive objects. Therefore, why optimization can be used to free resources. Unfortunately, optimization methods alone are seldom a solution. It is also important to understand the world beneath.

The number of patents creates restrictions in the selection or removal process. The knowledge about a single patent gets lost in the portfolio and it becomes difficult to create an undistorted overview of the whole portfolio. The manual evaluation of patents and patent groups takes also a lot of time and effort. Computational tools can help in some of the difficulties faced, but before creating actual tools one needs to understand the underlying processes and constraints systematically. This is the gap in scientific literature where the current study tries to find answers.

1.2 Research Problem

The main research problem can be stated as follows:

How should a large patent portfolio be systematically managed?

It can be divided into the next sub questions:

1. *What are the main characteristics in the management of large patents portfolio?*
2. *What kind of systematics should be used in the process of adding and discarding patents?*
3. *How does the systematic approach work in practise?*

The objective of this research is to build a model for the systematic computational management process of large patent portfolios. In practise it means identifying the systematics in the selection and evaluation process of patents in a large patent portfolio. The approach is such that the different needs and constraints are translated into a model that a computer can understand. The model will be tested with a practical case where an actual portfolio is trimmed. The practical case includes the building of algorithms needed for the optimization process. Finally, the systematic approach will be evaluated and instructions will be given to improve current practises. The generalization of results to other portfolio decision problems will also be discussed.

1.3 Scope of Current Research

The main emphasis of this research is the computational management of patents as a portfolio. The questions concerned are business decision making choices and the study does not cover questions like the exact valuation of a single patent or patent portfolio. The patent portfolio at issue is expected to be quite coherent which means that the patents are expected to be concentrated into a specific industry. The use of patents depends on the industry and the viewpoint for this study is the electronic and telecommunication industry.

Patent holders can be roughly divided into four different categories: independent inventors, small new entrepreneurs, mid-sized companies and large companies, who all use patents for different purposes. This study focuses only into the management of large patent portfolios. Patent portfolio management process is also seen only as the management and evaluation of adding and removing patents. The aspects of actual applying, dispose or patent litigation control are covered only in the extent of their effect on the selection process.

The legal protection is not the same around the world. The annual fees as well as protection depth for patents differs in some degree from country to country, which sets the countries into different standings. This study does not discuss the specific differences between countries.

1.4 Research Methods

In constructive researches, problems are solved through the construction of models and procedures. An essential part of them is binding the problem and its solution with accumulated theoretical knowledge. (Kasanen et al., 1993). In this study the essential problem is to systemize the adding and discarding patents in a large patent portfolio. There is not much knowledge about existing practices so action research is used for constructing concepts and procedures.

This study combines both qualitative and quantitative data. Eisenhardt (1989) writes, that using both data types can be highly synergistic and that quantitative evidence can indicate relationships which may not be salient to the researcher. Besides, quantitative data can keep researchers being carried away by vivid, but false, impressions in qualitative data whereas qualitative data are useful for finding relationships revealed in the quantitative data or may suggest directly theory which can be suggested by quantitative support.

Action research engages the researcher in an explicit program to develop new solutions that alter existing practice and the test the feasibility and properties of the innovation (Kaplan, 1998). According to Avison et al. (1999), it combines theory and practice in an iterative process involving researchers and practitioners to act together on a particular cycle of activities, including problem diagnosis, action intervention, and reflective learning. The cycle has been illustrated in Figure 1.

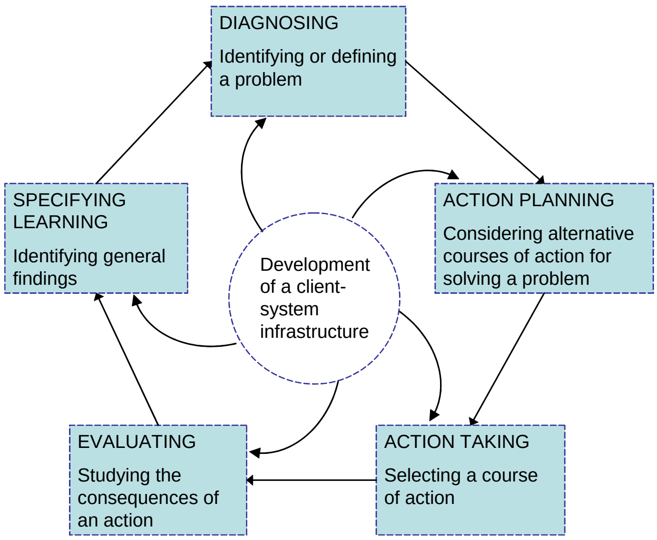

Figure 1: Action Research Cycle (Susman and Evered, 1978)

Action research receives its effectiveness partly from the immediately received feedback and it is considered the most effective technique for technique development or theory building. There exists also some critique towards action research, because it contains the same problems as many social science studies: it can't be objective, because the researcher is actively taking part in what is researched. (Westbrook, 1995).

In the development stage the concepts and practices are conducted step by step. Between the steps, the intermediate results and emerged questions are discussed with experts. These results and the opinions of the experts also affect the further development of the systematic management process. Information is gathered from qualitative sources, which include scientific literature and expert interviews as well as quantitative information from analysis of the data. The different steps and choices are explained to improve the reliability. The final achievements and their validity will also be contemplated and additionally discussed with experts.

1.5 Structure of this Report

The structure of this thesis is presented in Figure 2. The second chapter introduces patents and some business logic behind using them. The patent system and possible ways of valuation are also introduced. The third chapter sifts the actual portfolio which is helpful in defining more in specific what types of theories and algorithms are needed for building the actual optimization tool. The fourth chapter presents the mathematical and computational backgrounds used in the optimization and selection process. Several methods are discussed and evaluated in the view of current study. The fifth chapter introduces the model of the selection process and its constraints. The sixth chapter contains the implementation of the optimization and calculation of the results. The results are also analyzed more in detail. The seventh chapter includes the evaluation of both the model and the study. The eighth chapter contains a brief summary of the concluded work and presents conclusions, recommendations, and topics for further study.

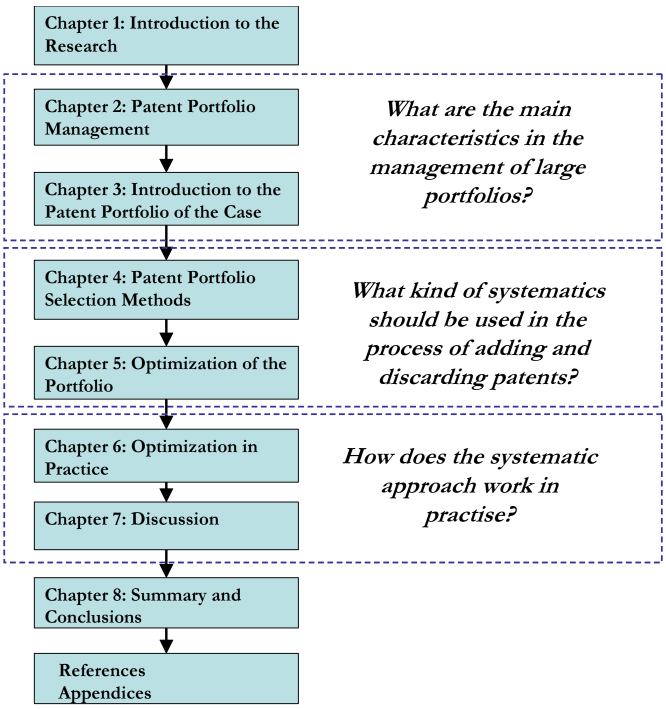

Figure 2: Structure of this Report

2 Patent Portfolio Management

The purpose of this chapter is to answer the question:
What are the main characteristics in management of patents?

Computers can be used for collection and systematic evaluation of information in cases where the data load is too much for human perception. They can be good tools for a manager, because they can be programmed to process large amounts of data into a needed set of information. Computers do not replace humans in decision making, because a machine never concludes anything that is not structured into its processes. Programs can still be a bid aid in supporting the decision making process. The decision maker still needs to understand both the limits of the computer and the world outside. Patent application and holding decisions are based on expectations and predictions of future, which is dominated by uncertainty. That uncertainty can't be removed with any decision making tool. It is rather important to understand what should be taken into account and what kind of help can be contributed with a systematic approach. The purpose of this chapter is to concentrate into the world outside the program and describe what kind of instrument patents are and what the decisions in the portfolio management processes are based on.

2.1 Introduction to Patents

2.1.1 What Are Patents?

Intellectual properties are intangible assets that enjoy special legal recognition and legal protection. Patents are part of the technology-related intellectual properties and they can be divided into several categories including utility, process and design patents. (Reilly and Sweichs, 1998). Patents are counted into intellectual property as well as trade secrets, copyrights and trademarks. Compared to for instance copyrights, however, patents carry a stronger legal protection.

US Patent office declares patents as the right to exclude others from making, using, offering for sale, or selling the invention in United States. The definition of patent varies a bit from country to country, but the main idea stays the same: the owner of a patent gets the right to control the use of patented invention in exchange for publishing its structure. The right of prohibition is usually granted for 20 years under several conditions: the innovation must be new, non-obvious and something concrete. Mere ideas or suggestions cannot be patented.

Three biggest reasons for patenting are prevention of copying, blocking and preventing suits (Cohen et al., 2000). Mazzoleni and Nelson (1998) compose the different reasons for patenting being innovation motivation, inducement of development and commercialization of inventions, disclosure of inventions and enabling of orderly development of broad prospects. Patents also help to create barriers for imitation of other competitors, but the use of patents depends heavily on the industry. To be anything worth they need existing competitors. There is no third party authority that would provide the overall supervision for infringements so companies also have the obligation to control the possible infringements themselves. The value of patents is determined exactly only in order of the court, but litigation is an extremely costly way to test patents. Therefore legal actions are usually avoided.

Patents are used for different purposes depending of the company size and industry in question. Small companies use patents in funding to get investors trust their company. For large companies patents stand for a tool for maintaining the strategic position in a competitive environment and they can have tens of thousands of patents each. For instance, IBM owns currently over 40000 patents. However, the number of patents does not necessarily reflect the income or absolute value of possessed asset. The value of the portfolio seldom grows at the same rate as the number of patents.

Appropriability describes the environmental conditions that define the ease of replication and the efficacy of intellectual property rights as a barrier to imitation. Patents are not the only way for protecting inventions. Cohen et al. (2000)

found out that no industry relies exclusively on patents and instead of patenting, secrecy and lead time are ranked comparably overall as the two most effective appropriability mechanisms for product innovations. For new processes, patents are even rated as the least effective mechanism of appropriation. Secrecy, lead time and learning advantages are considered as more effective. For products patents are considered as more effective than secrecy but lead time and learning activities are still considered as more effective. Patents are also seen more effective in preventing duplication than securing royalty income. (Levin et al., 1987).

2.1.2 Patent System

The patent system can be understood from historical perspective. It was initially created to improve the R&D incentives with information spread as well as protection of inventor's rights. First patents were granted already in the 15th century in Italy. Patent system itself is very old and the emphasis towards patents has changed heavily especially during the latest decades. Several studies (Kortum and Lerner, 1999; Hall and Ziedonis, 2001) state that the changes towards stronger protection in legislation in the early 80's and two major litigation cases with enormous damage awards increased patenting tremendously. That resulted into a lock-in situation in many industries, where existing patents can even hinder the technical development. Even though patent portfolios have grown across major industry players, a large number of products still trespass competitor's patents. The number of patent litigations has risen which again makes it more difficult to make the choice to abandon patents from the portfolio.

Technological advantage is often an interactive, cumulative process, which leads to the case where strong protection of individual achievements can slow down the general advance of the industry (Levin et al., 1987). Another problem with patents is that the patent system was not designed for the needs of knowledge-based business. The information spread is much bigger than even a couple of decades ago and many types of inventions like software patents create challenges. Semiconductor manufacturing has become very complex and one single semiconductor product often embodies hundreds or even thousands of potentially patentable products owned by suppliers, manufacturers in other industries, rivals, design firms, or independent inventors (Hall and Ziedonis, 2001). Competitors infringe each other's patents and in that situation they get some security from their own portfolio, because they can use the existing portfolio against possible complainants by raising countersuits. The complexity issue is not solely a problem of the semiconductor industry; it exists in electronics and telecommunication business as well. Because of the increased product complexity it has also become more difficult to prove possible infringements of an existing patent.

2.2 Portfolio Management

There exist several reasons for patents to be managed in a portfolio. There are practical reasons for managing portfolios, because patents support each others in possible infringement cases. In many uses – for example standardization – patents are used as numbers and not individually. According to Lin et al. (2006) there are two distinct ways to create synergy with a technology portfolio. One possibility is to keep well-diversified technologies to exploit business opportunities of many industries and the other possibility is to strategically focus on a small number of technology fields.

2.2.1 Managing Patents as Portfolios

The application process of a patent is costly, complicated and it takes a long time. The process is not described here, but for instance Shear and Kelley (2003) and the PCT Applicant's Guide (WIPO, 2007) describe the application process more in detail. Here the basic assumption is that patents are added to the portfolio at the time when they are applied. In the discarding process there are several different options to choose from. Patents can be either be published, sold or just dropped out by leaving the renewal fee unpaid so that the patent expires.

Most decisions concerned with patents are exclusive; a patent attached to a standard cannot be used for differentiation or the other way round. The decisions are made already in quite early stage and they cannot be changed later on. For the basis of decision making it is important to consider which purpose creates most value and how the decision affects the rest of the portfolio. Even individually weak patents can have value as part of a large patent portfolio, because the portfolio can be licensed as a block or it can serve to deter lawsuits (Parchomovsky and Wagner, 2005).

Intangible assets are difficult to add up (Webber, 2000). Patents are also difficult, because the value of the sum of two patents is not necessarily the same as the value of two patents added up together. Patents cannot be consistently compared with each other so that the comparison would be extensive. Length, which is the time period when the exclusive right is valid, is the same for every patent, but scope and breath are different to all patents. Breadth is referred to as the number of competitors able to enter the market. With a broad patent only few entrants are allowed while narrow patents allow many (Wright, 1999). Scope includes the applications of the patented invention that are within protection and it is a factor that is difficult to objectively compare among patents.

Patents always need existing competitors to be valuable. The actual value of patent portfolio comes usually as a result from negotiations between patent holding and patent using companies. In these negotiations the volume of the patents about a certain technology is significant; one or two patents are usually not enough to get the negotiations started. The negotiations can be for instance about the licensing or cross licensing terms in which a set of patents can be set for use under a specified amount of money. The value of a large portfolio comes in negotiations from two sources. Most important part comes from finding several patents, which the negotiation company infringes. The rest of the portfolio creates the critical volume, which poses another threat because the rest can contain additional infringements.

2.2.2 Benefits from a Patent Portfolio

The patent portfolio brings a company more freedom to operate, licensing and cross-licensing opportunities, as well as influence in the business environment. In addition, a portfolio can create cost reductions and, especially in the US, it can have a specific marketing value. Freedom to operate refers to the state in which the company participating in product business is quite free of constraints in making decisions of business and R&D. Licensing and cross-licensing revenue comes from different standardization or co-operation among industry players. In the process of standardization the patents are examined rather as a group than individually. So the portfolio size of a specified technology matters when the division of the income is negotiated among the companies participating in a standard.

There are several reasons and benefits for owning a patent portfolio. In some fields of technology one needs to own several patents to get even the negotiations started with the biggest patent owners. Hence an empty patent portfolio can impede the entrance to a specific market. In for instance electronics and communications sectors there are so many patents that almost every company infringes also its competitor's patents. This leads to the situation where the portfolio can also be valuable when looking for rights infringements of competitors. It can also protect the company from infringement suits from competitors by representing a threat of a countersuit. When filing a countersuit the own patent portfolio looked through for patents that current competitor injures and set them against the accused infringements. After both companies have sued each other for patent infringements they can start to negotiate about cross-licensing possibilities, because it is cheaper than going to trial. (See e.g. Yamada, 2006).

Owning several patents increases the certainty that at least some patents are found valid in trial. The validity of a patent is not tested until litigation comes upon. If a patent is found invalid in court, its property right will be evaporated. This is a tremendous loss, which comes to its price. Litigation processes are very expensive, for instance the median cost of litigating a major patent case in the US is around US $4 million (Jaffe and Lerner, 2004). That's why litigation processes are quite rare. Only 1,5 % of the patents are ever litigated and only around 0,1 % of patents go to actual trial (Lemley and Shapiro, 2005). On the average, around 50 % of patents stay valid in patent trials (Sherry and Teece, 2004), which means that the risks of losing with only a single patent are too high.

With the validity chances of 50 % per patent, more patents help to generate a bigger protection in case of trial. From there one could derive the probabilities that at least some patents stay valid in the case of a trial. Derived from the common laws of probability, the changes for at least one patent staying valid is $P(n) = 1 - 0.5^n$, where 0.5 is the probability for one patent staying valid and n is the number of patents. Figure 3 illustrates this effect, which could be defined as the S-curve synergy effect of the patents. This also implicates that after a certain number of patents, the marginal benefits of new patents decreases and last patents do not bring much improvement to the validity of the patent portfolio.

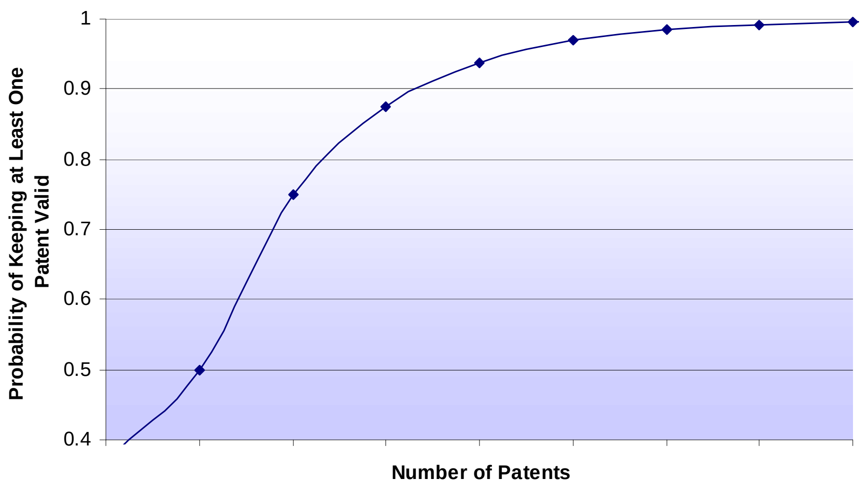

Figure 3: The synergies create an S-curve

2.2.3 Patent Tactics

In the US the patent customs have become more complicated during the last decades. Mainly patents are used for prevention of copying and blocking (Cohen et al., 2000), but patents can also be used for strategy implementation. The objectives of patents vary between the US and Europe. Soininen (2005) characterizes the European patent utilization different to the US; in Europe patents are still seen as legal tools rather than strategic assets. In Europe patents are also granted to inventions of technical character whereas the concept of patenting is much wider in the US containing also any new and useful processes (Koski, 2002).

Patent strategies are typically divided into three categories: defensive, offensive, and transactional strategies (Soininen, 2004). With an offensive strategy company is in the position, where it can fight off competitors by an active utilization of patents. Figure 4 presents the different ways of offensive business tactics.

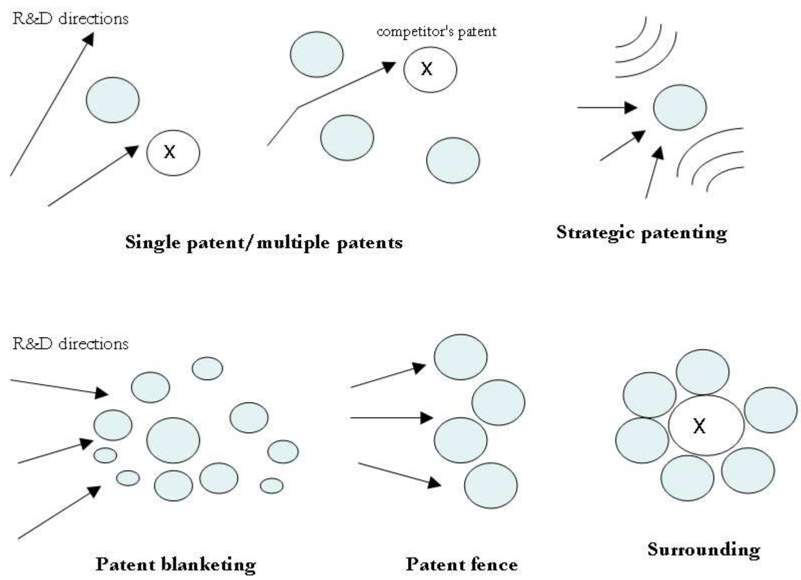

Figure 4: Different Patenting Tactics (Soininen, 2004)

There are several different tactics that are used within patenting: regular patenting, strategic patenting, patent blanketing, patent fencing and surrounding one patent with others. In single and multiple patent cases the innovation is protected with one or more patents. The patents don't create a block and it is possible to invent around the patents, even though it is more costly. This view can be criticised, because there are studies advising the opposite. Patent protection generally increases these imitation costs. To picture out the cost difference, according to Gallini (1992), inventing around a patent costs about 25 - 40 % more than the original invention in the chemical industry. A study of 48 product innovations concluded that imitation was on average around 65 % of the costs of original and the innovation time was on average 75 % of the original when competitor has not patented its innovation. About 60 % of patented inventions were imitated within 4 years. (Mansfield et al., 1981). Patents also do not have much of an impact on the delay of entry. For around half of the patented innovations firms stated that patents had delayed the entry of imitators by less than a few months (Mansfield et al., 1981).

In strategic patenting a single patent contains large blocking power and it becomes very costly to invent around the patent. The patent is also core in a specific field of technology. In patent blanketing there is uncertainty about patent scope and/or there are many potential R&D directions which are replied by creating a minefield of patents. With a patent fence patents are used for blocking certain directions of R&D. With surrounding the patent blocks are created for preventing the commercial use of a central patent of a competitor. It usually covers different applications of a basic invention and the tactic is much used among Japanese companies.

With defensive strategies the goal of patenting is to ensure the freedom to operate and to avoid patent infringement claims. Patents are not considered as one of the key resources of the organization. Transactional strategies include the patents as status elements, signs of innovativeness. Patents are then to ensure possible investors or co-operating partners and the height of the patent stack is examined rather than substance of the patents. (Soininen, 2004).

The companies can also be divided according to their IPR ownership. Flythström (2006) presents a framework (Figure 5) for dividing the companies into sharks, minnows, targets and glass houses depending on their IPR strength and product business strength. It is a classification of different players in telecommunication markets and it describes the emphasis on patents in the product business.

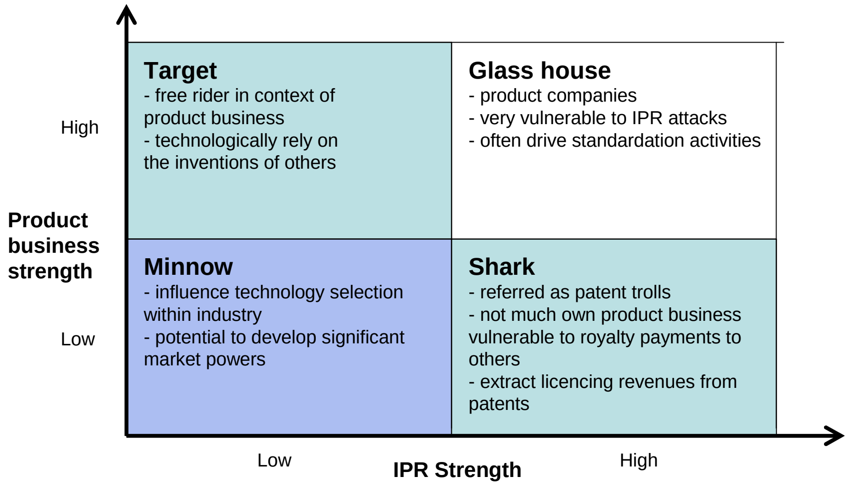

Figure 5: Framework for Dividing Companies According to their Positioning (Flythström, 2006)

Patent trolls are companies that gain their revenue based on the explosion of patents. They do not have any product business on their own. These companies buy their patents from bankrupt's estates and then use them for litigation and licensing purposes.

There are also other kinds of actions in patenting. Patent mining is referred to as actions in which the company tries to exploit the patents in a way where it asserts them aggressively against possible infringing firms. Submarine patents are called ones for which the granting process is purposely delayed until existing competitors are already using the specific technology at the grant date. After granting the competitors are either sued or asked to pay fees for using the patent in their products. Another reason for prolonging the application period is to keep the invention secret as long as necessary for the industry to mature on the basis of the technology (Soininen, 2005).

2.2.4 Constraints of Patenting

Constraints of patenting are expenses and the amount of inventions. Additionally, there could be shortage in know-how in smaller companies. In practice there is seldom lack of inventions, because companies have usually more patentable ideas than money for patenting. In the study of Mansfield et al. (1981) the companies patented around 70 % of their innovations.

The biggest constraints for patenting are the costs of patent application and holding. The most expensive part of patenting is the application process, which can take several years. The PCT application process of a patent costs around US $ 13 500, which includes the international preliminary examination (Schmoch, 1999). The patent has to be granted for each country separately, which also increases the costs of the process when the company operates on global scale. Additionally, there can be litigation costs in case where a competitor complains about the applied scope infringing its own inventions. During the application process there is no guarantee that the patent will fulfill the planned needs. Industry life cycles might be so short that the patent is already outdated at the granting date.

After the grant patent owner needs to pay a periodical fee to keep the patent valid. The fee is relatively small compared to the costs of application process. Nevertheless, around half of the patents are abandoned before the age of ten, probably because they have not reached their predetermined goals. The private value is also reflected radically into the renewal rates. Lanjouw (1998) describes that the private value of a computer patent discarded at the age of four is worth almost three times as much and the value of a another patent discarded at the age of 20 is worth over 26 times as much as a patent dropped at the age of three.

Many studies (see e.g. Scherer, 1965; Schankerman and Pakes, 1986; Pakes, 1986; Scherer and Harhoff, 2000) have proposed that the distributed value of patents seems to be lognormal skew. Figure 6 is an example of a mapping a logarithmic skew distribution.

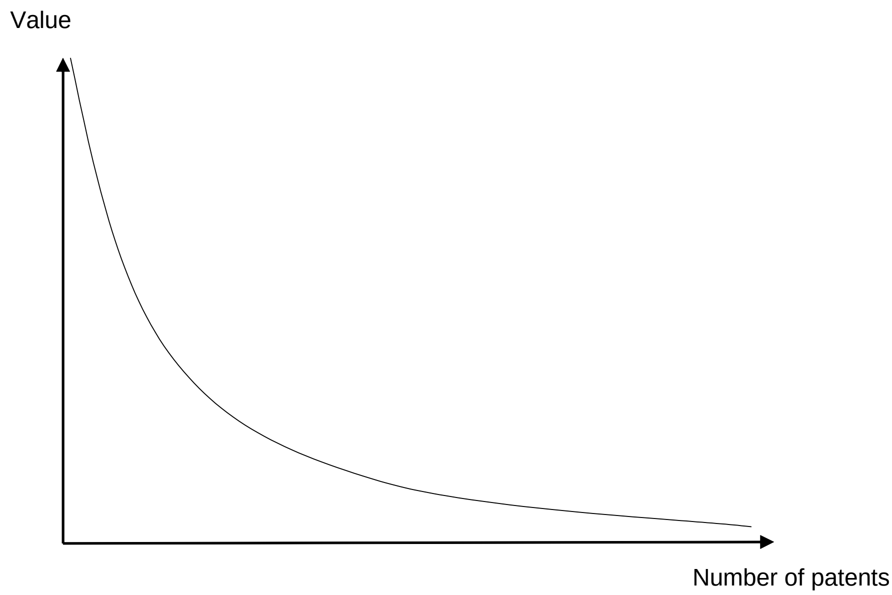

Figure 6: Log-normal Distribution of Value

The distribution of value reflects that in a large group of patents only few patents are of great value while the tail of distribution consists of almost worthless patents. The value of patents depends also of the industry. In some industries patents are almost of no use, but for instance in the electronic, telecommunication, or pharmaceutical industries patents are commonly utilized. Schankerman (1998) suggests that there are sharp differences between technology groups and that the main patent using industries could be roughly divided into two. Pharmaceutical and chemical patents have value distributions that could be characterized by relatively low mean and dispersion with slow rates of depreciation. Mechanicals and electronics on the other hand have distributions that could be characterized with a higher mean value, greater dispersion, and faster depreciation.

2.2.5 Standards and Licensing

An industry standard consists of a specified set of technologies adopted by an industry group in order to create compatibility among products (Feldman et al., 2000). Standards help to create interoperability between different technologies and they also help the distribution of the revenue between the patent owning companies.

Standards provide a common framework for a specific technology. Additionally, the standardizing companies do not have to cross-license all their patents separately to the firms using the standard. In standardization companies also agree of licensing fees and revenues for using the standard. For individual patents accepted into a standard it provides a certain value and constant income from licensing fees. It also means a certain safety for the patents value during the aging process. On the other hand the possibility of high income of a special patent is lost when the patent is appended into a standard. The standardization principles include often the FRAND terms - fair, reasonable, and non discriminatory - which means that the standard should be available for all companies for a feasible price. This kind of income does not necessarily last the whole life span of the patent. A standard can become obsolete and then all the patents of that standard loose their value.

Standards can be classified depending on the process of their creation. These two classes are de jure and de facto standards. De facto standards are determined by markets and de jure standards are created with an official decision making. For instance the GSM standard is essentially a de jure standard (Bekkers et al., 2002).

In industrial sectors such as electrical, information and communication technologies, patents are usually licensed to other companies rather than exclusively exploited by the inventor (Yamada, 2006). In cross-licensing the company makes one-on-one contracts with the licensing companies. The amount of licensing fees or revenue is defined by the proportion of the essential patents in a standard and the business exposure of the licensing company. Additionally, there exists aggregate reasonable terms (ART) that define the royalty rate of the standard. In practise it means that the user of a standard has to pay a certain percentage (defined as the ART level) of its revenue to the owners of a patent. It has been suggested that under FRAND, the income should be divided according to the principles of proportionality of the essential patents to the patent owning companies (Frain, 2006). In Figure 7 the payment rates are defined between companies A and C as follows:

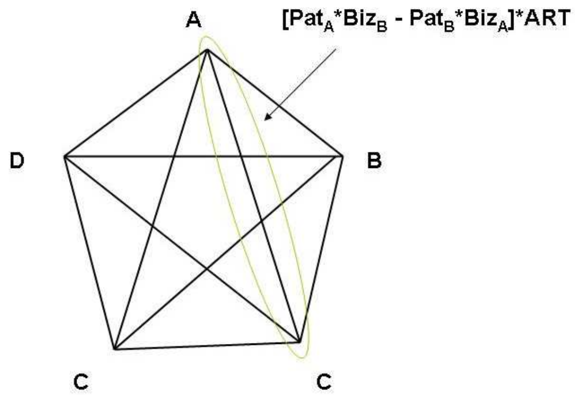

Figure 7: Cross-licensing Patents

The highlighted area in Figure 7 describes the payments flow between the companies A and C. Pat refers to the proportion of patents of a company and Biz refers to the size of business. If $Pat_A \cdot Biz_C$ is bigger than $Pat_C \cdot Biz_A$ company C has to pay the difference to company A. When it is the other way round company A has to pay to company C. In case where $Pat_A \cdot Biz_C - Pat_C \cdot Biz_A$ is equal to zero, the two companies and both players do not have to pay anything to each others and the level of aggregate reasonable terms does not matter. The ART level comes in question in the bargaining with the other companies that want to use standard in their businesses. Investments in the standard can then be affected by the need to keep the certain balance between the companies.

In telecommunications sector licensing is an important source of revenue for patents. When a patent is included into a standard, licensing is the only way to make business with it. It is also possible to license out patents, which don not belong to a standard. Licensing revenue is also quite easy to link to a particular patent. Incentives to license patents are the hope of reaping economic benefits in the short term and strategic value of exerting an influence on market trends and maintaining competitiveness in the long term (Yamada, 2006).

In knowledge management, the value can be extracted from several sources: 1) it can be disembodied transfer inside the firm (internal technology transfer and utilization), 2) disembodied external transfer or 3) bundled sale of technology, which means that the knowledge is embodied in an item or device. The main objectives for licensing are efficient commercialization, technology exchange, market enhancement and royalty generation. (Teece, 2000). Licensing decisions depend much on the competitive advantage created by the patents, the expected returns from the innovation of access, control of critical complementary assets and the amount of risks involved in commercialization of the patented invention. Pitkethly (2001) presents an interesting framework that combines the different actions with the appropriability and strategy aspects and it can be viewed in Figure 8.

Teece (2000) defines appropriability being a function both of the ease of replication and the efficacy of intellectual property rights as a barrier to imitation. Important factors influencing licensing decisions include the technical and competitive advantage of the innovation, the appropriability determined by the legal framework and possibilities to control the critical complementary assets, relative risk in commercialisation in-house compared to outsiders, costs and revenues with licensing as well as learning opportunities available to licensees. The greater the competitive advantage conferred, the greater the incentive is to preserve and exploit the assets in-house. As strategic appropriability increases, there is an increasing incentive to internalise the commercialization. Also the risk management in-house compared to outside impacts on the decisions whether to license or not. (Pitkethly, 2001).

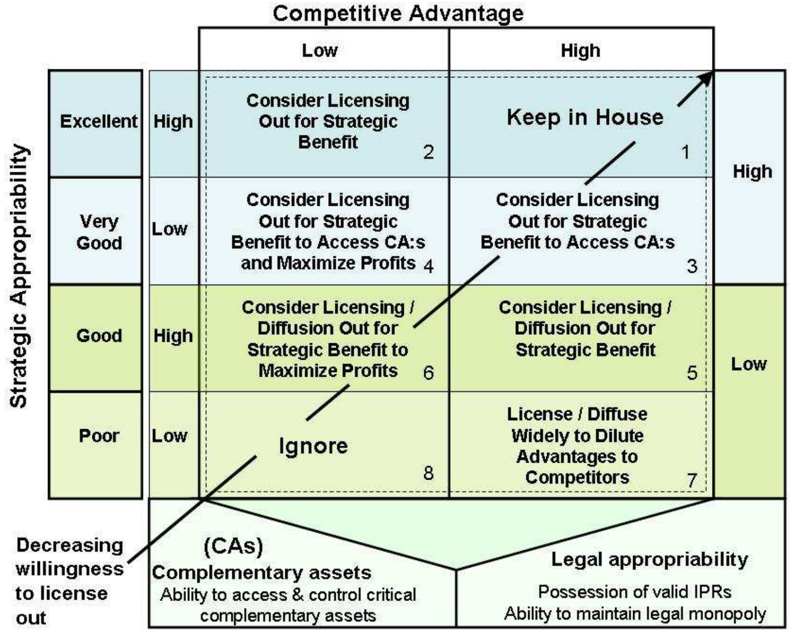

Figure 8: Framework about licensing incentives (Pitkethly, 2001)

Licensing strategies can also be divided in two groups depending on time when the patent is licensed. In ex-post licensing the superior technology is licensed after a potential licensee develops a substitute technology whereas in ex-ante licensing the technology is licensed before a potential rival develops an imitation technology (Shapiro, 1985). In cross-licensing there are also typically two different types of licensing contracts. The right to license can be obtained through a fixed fee or royalty that is paid depending on the amount of produced goods. The fixed fee can usually be for the next five year period or the rest of the life cycle of the patent. The income of the fixed fee licensing does not change along the goods sold. Both types of contracts carry uncertainty with themselves and depending of the case the uncertainty is divided between the companies. With a fixed fee, the licensee gains in case where it can sell more items than expected but it also carries the risks when sales do not turn out as expected. With a royalty rate directed to each sold items the revenue licensor is affected highly by the actual realization of the estimates.

The licensing decisions of other companies influence many decisions in patent portfolio management. It is quite natural that the expected growth of the market and the amount of still unlicensed players has an influence on the portfolio building incentives. It can also work the other way round. When all players have licensed the specific set of patents, there exists no reason to keep the patents valid, because all possible revenue has already been gained. In the creation of future scenario with licensing revenue, one should pay attention to the growth of the market and the amount of still unlicensed players.

How do the standardizing incentives matter in the patenting actions, then? In the creation of standard the number of patents in the standardized technology does matter. Every company counts the number of their essential patents contributing into the standard, and it has an impact on the division rates in which the royalties are divided between the companies. The ART level and proportion of the essential patents define the incomes of each patenting firm. When the standard is created it will be frozen in some point, which means that the final decision is made about patents attached to the standard. This leads to the situation that no more new patents are attached to the standard unless there a new version of the standard is created later on. Then of course, patents outside the standard are of little value.

2.2.6 Patent Valuation

In scientific literature patent portfolios are advised to be managed actively but information about the reasoning behind the actual management operations is rare. There are common advises about linking patents to company's strategy or goals, but these operations usually lack concrete actions. There are also few suggestions on which attributes are important in comparing patents against each other. Additionally, the scientific literature lacks proposals on what grounds patents should be discarded from a portfolio. These are all important questions when analyzing the patent portfolio for discarding or adding purposes. This section studies the common patent valuation methods, because understanding what creates actual value could also lead to attributes and other understanding that could be valuable in the implementation of selection methods.

Even though patents are one of the most concrete types of intangible assets, they are difficult to valuate. There are many uncertainties within the patented invention, which relate to the future predictions and the patent as a legal document. There exists also a division between future linked uncertainties: Some patents are based or relate to existing technologies, and they contain fewer uncertainties than those that belong to a completely new technology.

The value of the patent can be divided into two different kinds: private and corporate value. Every patent has its own private value. Private value represents the incremental returns generated by holding a patent on the invention (Schankerman, 1998). Corporate value on the other hand comes from the patent portfolio as a whole and its value derives from negotiations, which can be for instance about licensing or standardization.

The value of a patent can increase, decrease or even loose their value overnight. Patents are not especially valuable before they are granted because the granting process includes uncertainties itself. The value of the patent doesn't increase in the patenting process, but it can decrease, for instance when the scope of the patent is narrowed down by the patent officer. When the patent is finally granted the value depends on the granted scope and breadth of the patent. What comes to the possibilities of a patent loosing its value overnight it can happen for instance when competing technologies overtake the market or court decides that the patent is not valid.

As intangible assets also patents have a certain life expectation which can be looked with different aspects. These include:

1. Economic life: when a fair rate of return can be provided
2. Functional life: time in which the intangible can continue to perform
3. Legal or statutory life
4. Contractual life
5. Judicial life, resulting from a court rule
6. Physical life
7. Analytical life

These factors all affect the expected life span of the patent. (Reilly and Sweichs, 1998).

There are many different techniques that have been developed for valuation of intangible assets. These include for instance EVA, Tobin Q and different scoring frameworks. Exact estimates about the value on an intangible asset are rare. Andriessen (2004) lists different valuation methods for intangible assets. Some of the methods could also be used in the valuation of patents and they are presented in Table 1. The table also includes some methods of valuation found in other sources of scientific literature.

Table 1: Different valuation methods (Andriessen, 2004)

Method of valuation	Short description	Evaluation of method
Citation weighted patents	The value of portfolio is linked with the amount of citations	Citations are a disputed characteristic of patent and the link between citation and value is quite artificial. Additionally, the number of citations has increased dramatically because of fear of possible litigation.
EVA	Economic Value Added	Not been initially created for valuation of intangible resources and there is still much discussion about its suitability.
Options approach	Patents are evaluated with the same methods than stocks and options, for instance the Black and Scholes method	Patents are more difficult to valuate like stocks because they lack market transactions.
Skandia navigator	A scoring method in which scores are put into financial results, customer, human and process focuses as well as renewal and development focus	The framework doesn't take causal connections very well into notice.
Tobin's Q	The ratio between the market value of an asset and its replacement cost	The market price is difficult to estimate for patents because they are not traded as stocks.
Valuation approach	Intellectual properties are valuated based on three approaches: market, cost and income, which can be used individually or communally. The cost approach is based on economic principles of substitution and price equilibrium, market approach is based on the economic principles of competition and equilibrium and the income approach is based on the economic principle of anticipation.	Cost is not always a good indicator of value. For market approach data is needed on similar transactions. Income approach requires many assumptions about on income projection, funneling and allocation as well as useful life estimation and income capitalization.

Even though these methods could be used for the valuation they do not include actual characteristics that could be used in the selection process of patents. Nevertheless, there exist so few methods for the actual valuation of patents so that also these methods could be useful.

Andriessen (2004) also defines an interesting set of characteristic tests to recognize core competences which could be used in the evaluation of patentable ideas. It could be used for interesting inventions before the deciding whether to patent or not. The attributes include added value, competitiveness, potential, sustainability, and robustness. The modified framework contains following questions:

- Added value: Does the patent provide added value to customers?
- Competitiveness: Is the patent competitive with competitors' patents?
- Potential: How much potential does the patent have creation of new products?
- Sustainability: How difficult is it to imitate or invent around the patent?
- Robustness: How big is the risk that the patent loses too soon?

These are all factors that could be used for the evaluation basis also later on. In addition to these characteristics one should pay attention to the existing competition and possibilities of controlling and recognizing infringements.

2.2.7 Uncertainties Linked with Patent Value

Patents carry along many uncertainties. Legal uncertainties contain the uncertainties about the scope of the patent and the legal validity in case of litigation. One reason for legal uncertainties results from the granting process itself because the patent system is loaded with patent applications. Most of the patents become almost worthless, so it is not economical to spend ages into the exploration of the patented invention and patent filing in the applying company. There is not much time for one particular patent during its granting in the patent office either.

Technological uncertainties of patent come from the underlying technology of the patent. It is not clear whether the filed technology is one that will be actually used. It can be already old when it is granted or there might come superior or more advanced technologies. There might also be two competing technologies in which there is no certainty which one will dominate when the actual patents are granted.

Market uncertainties relate with the economic aspects of the patent. Some inventions are too expensive to use from the start on and due to that they remain unnoticed. Others lack the efficient commercialization or marketing. The market power and product life cycle lengths are also difficult estimate when the invention still is in the design phase.

Additional uncertainties come from the timely perspective. During the application process many occurrences can happen in the outside world that affects the interest towards applied patent. It is always difficult to predict the future and for example the choices other competitors will end up. Also short industry life cycles can become problematic.

2.3 Chapter Conclusions

In this chapter patents were introduced as tools for protection of innovations. Patents contain the power of exclusion and that is why they need existing competitors to be worthy. The constraints of large patent portfolios are costs, which are high. The application process is very costly and in addition fees must be paid regularly to keep the patent valid. The patent system is old and it has difficulties to cope with challenges of today. The number of owned patents has risen and the number of litigations has grown. Many industries have become so complex that almost everyone infringes each other's patents, which on the other hand increases the incentives to keep large patent portfolios for protections, even though it is costly.

In the optimization process it is relevant to keep the portfolio versatile so that it meets the different needs. The main objectives to keep a large patent portfolio are freedom to operate, licensing and cross-licensing opportunities, as well as influence in the business environment. The portfolio needs to cover patents for standardization and differentiation purposes. The actual value of the patents comes from negotiations between the different players. A patent portfolio needs a specific volume of patents for getting the negotiations started. When looking at the patent portfolio attributes, the most interesting characteristics are age and some estimate of the value of the patent. An estimation linking the uncertainties with patents would also be an interesting attribute, because it could provide information on the stability of the value.

This study concentrates mainly to the standard-related patents. Therefore, the principles of standardization and licensing were presented. These include the main value creation, licensing practices as well as a framework on licensing incentives.

The literature study of valuation methods for patents did not bring new characteristics for the optimization process. Patent valuation is difficult and there are very few methods that could be suited for the actual valuation. Many estimates can be given, though. It is easier to evaluate the ones which apply to existing technologies while the ones concerning a new technique are the most difficult ones. The estimations include also many uncertainties including legal, technological and market uncertainties that affect highly to the value and revenue of the patent. These uncertainties could be taken into notice with a scoring system, but the exact estimates are difficult to create.

3 Introduction to the Case Portfolio

The purpose of this chapter is to introduce briefly the particular portfolio and its constraints. The portfolio size of the current case is large, so it is profitable to consider a systematic approach to the adding and discarding issues. If it were a small portfolio, it would not need so much effort. This chapter concentrates on the actual patent portfolio that needs to be optimized, because it is important in the design stage to understand what kinds of constraints exist. First, the background information on the case is briefly described and then this chapter concentrates on the contents of the portfolio and the principles of how patents are compared against each other.

3.1 Background of the Case

Nokia is one of the world's leading manufacturers of mobile phones. The telecommunication sector has been growing rapidly during the last two decades. Koski (2002) writes that intangible assets have an essential role in the industry, because the success is increasingly based on non-physical assets and intensified competition has changed the business environment dramatically. Also the number of patents in OECD countries has increased 430 % even in years 1993 to 1998. This has lead to a situation where many global players including Nokia have large patent portfolios which could be optimized so that they do not create large costs.

The size of the sample under study is around 11 000 patents. The objectives for holding them are to respond to the diversified need with reasonable cost. The portfolio includes patents for differentiation, standardization as well as for influence in business environment. Differentiation patents are needed patents to separate Nokia's products from its competitors. Standardization patents are part of different technical standards and they create revenue from licensing fees. Influence in business environment can be explained on basis that Nokia is such a big player in its field so it can influence the coming development of the telecommunications industry. The patents that are used for influence in business environment don't create much revenue but they affect the coming trends to be more prospective for Nokia.

Patents are compared against each other on the same grounds. The objectives of the portfolio are to respond to the different needs of future with minimized expenses. The main constraints of the portfolio are the expenses and they have grown too big. That's why it is justified to do some selection in the existing portfolio. The size of the portfolio creates also computational constraints, which must be taken in notice in the algorithm design.

3.2 Patent Portfolio at Hand

3.2.1 Existing Data

In the computational management process it is relevant to pay attention to the existing set of information, because they create the initial basis for the algorithms to be built. It is also difficult to add new attributes to the comparison, because creating them would require too much time and effort. That does not mean that it is not possible to create recommendations about the existing attributes. New characteristics can be added in the course of time, but for current study it means that the focus is in the data that already exists. The patent data consists of the set of information for every patent, described in Table 2:

Table 2: Existing data elements

Project	Number of the patent family
Nokia Class	Name of the patent family
Status	Current status which indicates in which of the application stages current patent is
Rating	Estimated value of the patent
Country	The country or group of countries for which the patent has been applied for
Priority date	The first application date of the patent family
Application date	The application date that defines the age of the patent
Grant date	The grant date
Nokia Class	Technology class
CPA	Defines what the purpose of the patent is, possibilities: standard, implementation or influence in business environment
Priority year	The year of application
Grant year	The year of granting
Annual costs	The estimated costs of the patent

3.2.2 Value Estimates for Patents

Three most important fields of the data (Table 2) are the rating, age of the patent and annual costs. Additionally, the studied data can be divided based on the country, purpose and the status of the patent. Rating is an estimate for potential value which is based on expert opinions. It is based on an evaluation process where different sources of potential value are considered and concluded into a number from one to five. The value estimate beneath the rating is expected to grow exponentially so that the value grows as the Figure 9 describes. The cost field can be used with the profitability measurements. Age field describes the time counted from the grant date and it indicates how much uncertainty there exists in the value assumption of the patents. New patent contains much more uncertainty than old patents which are more stable.

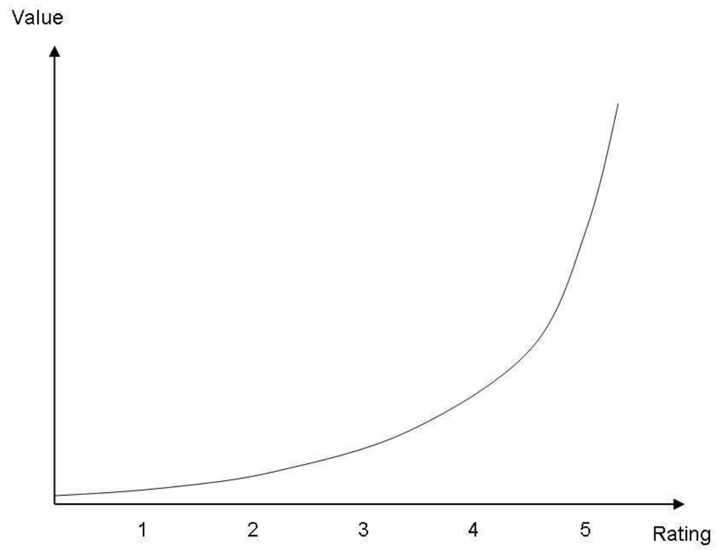

Figure 9: Distribution of value

The rating includes uncertainties linked with value. Every rating is based on a value tree analysis of the patent's value. There is not endlessly time for the examination so it is not totally certain that the rating of a patent is totally correct. Additionally, young patents have more variation in their estimates, because they are new and the technology might not yet be used. Hence, they have a bigger potential to evolve to more valuable patents. So there is a certain probability that a patent can have either higher or lower rating. This probability distribution is illustrated in Figure 10 for the rating four.

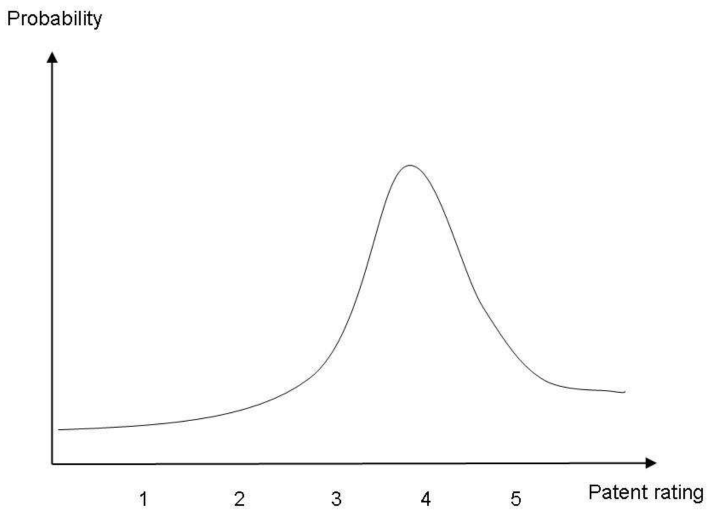

Figure 10: The uncertainty included in rating 4

Because the age of the patent affects highly to the uncertainty of the patents estimated value and rating, the density distribution is built up so that the age groups are divided into four categories: 0 - 2, 2 - 6, 6 - 12, and 12 - 20 years. These all have different rating probability distributions. To illustrate how the age affects the estimations, young patents have a broader probability distribution while the old patents are the most certain to stay with the specified rating. The first two years of a patents life span is spent in the application process and there are many uncertainties of for instance the scope of the patent. At the age of six the purpose of the patent has to be defined and at the age of twelve the last fee comes due in the US and one needs to consider the use and potential of the soon expiring patent. The last payment is also bigger than the previous ones, because it contains the years to the expiry of the patent. To simplify the concept of rating this study uses them as probabilities that describe the patents potential to become essential in the next ten years. These probabilities are defined in Table 3 and they are based on the discussions in the meetings. The numbers are not exact. They follow the main assumptions that higher ratings are more valuable than low ones and young patents contain more uncertainty, but there are no existing statistics or trends on which they would be based on. They are referenced as the value of the patent and they are created just for testing the existing assumptions and optimization in current study. They will also be discussed more deeply in Section 6.

Table 3: Estimates for probability to become essential

Rating/age	0-2	2-6	6-12	12-20
1	11	6	3	1
2	22	12	6	4
3	31	21	15	13
4	59	72	78	82
5	80	90	95	97

No patent gets the score 100 because of the uncertainty embodied in the value. These values have been designed for current exercise and using them in other connections is not advisable. The implemented probabilities are pictured in Figure 11, which shows how the age and value and value correlate with each other.

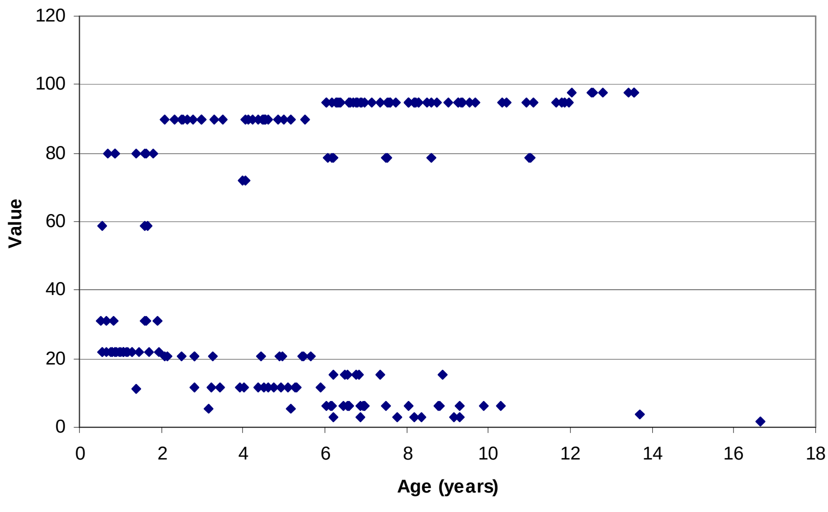

Figure 11: Distribution of age and value

Figure 11 shows how private value correlates with the age of the patents. It can be seen that the development of value is divided roughly into two: patents which contain a high rating become even more valuable when they age, because uncertainty of patent's value decreases. On the other hand, the patents with a low rating loose value when their age increases. There are also only few such patents with over the age of ten, probably, because most of them have been discarded because of their low rating. From the picture can be seen also that in case where patents are discarded just based on their low expected value, young patents are not the first ones to be discarded. That is good, because it is important to preserve young patents, because they keep up the value of the portfolio in the future. Patents can of course be dropped with a young age, but that is due to some feedback or decreased value in the application process.

The expected probabilities for patents developing themselves into essential patents are assumed to take place during a ten year period. This means that they are the probabilities that patents become essential in the next ten years. These probabilities are then allocated for the next ten periods so that the probability grows linearly to its peek. After ten years the probability stays the same for the rest of the years of a patents life span. This division is demonstrated in Figure 12. It is also the probability of which the revenue of the scenarios for each patent is counted from.

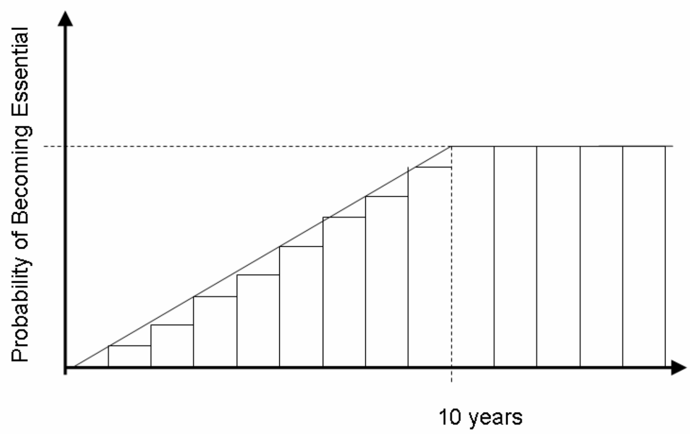

Figure 12: Probability development estimations

3.2.3 Brief Analysis of the Portfolio

The data consists of patents from various countries, but the actual optimization is done for patents applied and granted in the US. The emphasis in the analysis is in the granted patents, because the discarding of applied patents is assumed to be done separately and depending on the application process. The set of patents is divided into five different technology groups and the amounts vary quite much depending of the group. Figure 13 describes the distribution of value for a specific set of patents selected for the optimization process.

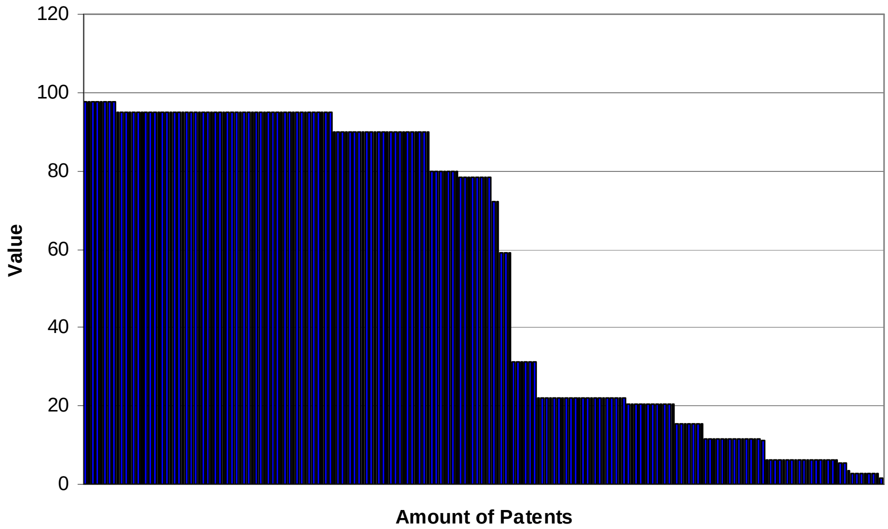

Figure 13: Distribution of estimated value

This set is only a part of the whole portfolio selected for current optimization case. The value described is a representation by the probabilities of becoming essential introduced in Table 3. Figure 13 does not look so badly like lognormal skew. There can be many reasons for that observation. Firstly, if the patent portfolio is managed actively the number of patents with little value can be smaller than the industry average. This also describes just the score indicating value of patents which is not linked with the profitability or other benefits created by the patents. Standard patents also differ a bit from regular patents. Because of the standard, the highest peaks of value of certain patents are cut off. On the other hand more patents create some revenue value than would probably without the patents.

Another thing to be considered is the division of patents into technology classes. Some classes contain only a few patents while others contain much more. Because of the synergy effects, all technology classes should include at least a certain number of patents. This characteristics sets the technology groups into different positions where it some groups do not have any patents to be discarded while others have more possibilities.

The distributions shows that there are not so many patents should be discarded from the portfolio just because of the score, but this score is not yet linked with any profitability functions of the patents, so the distribution can be misleading. One still needs an existing link between the patent's value score and the actual profitability. This link is created from the business development estimates, which are divided to the patents on the basis of the value score.

The examined portfolio consists of one particular technology group which is divided into smaller subgroups. The number of contents varies quite much from subgroup to subgroup being a number between three and sixty. There could be limitations that a certain number should be included into one subgroup, but in this case there is no need for such constraints. The option for having such constraints is still important for it could be used in the level of decision making of technology groups.

The studied set of data consists of all granted US standardization patents. When looking at the development of different ratings (See Figure 14), the previous picture shows that there are no special trends that could be identified from the existing data. This makes the validation of the assumed percentages for different ratings more difficult, because there are not enough patents that would support anything.

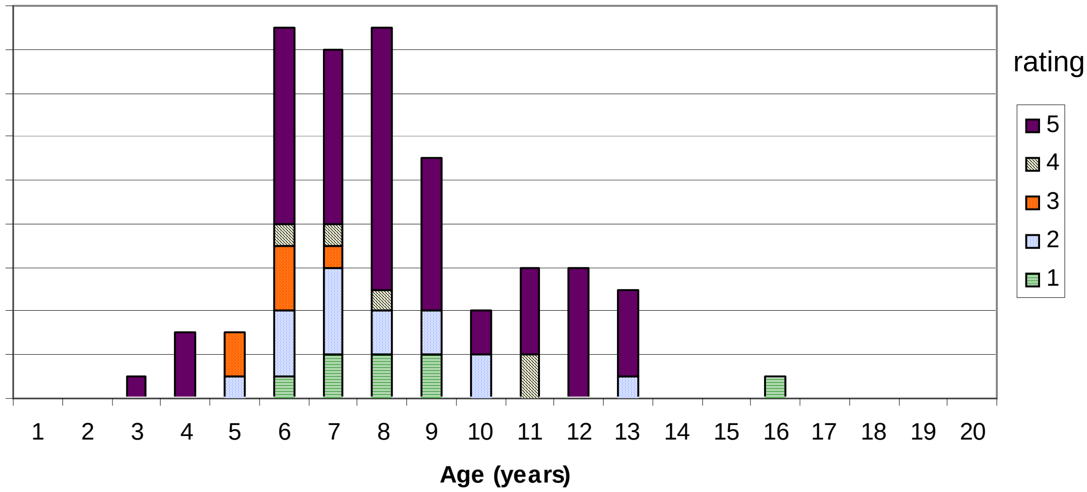

Figure 14: Age distribution

3.3 Decisions about the Portfolio

3.3.1 Overall Decisions about Adding or Discarding Patents

There are several sources of value that can be gained from a patent portfolio. These include freedom to operate, licensing and cross-licensing opportunities, as well as influence in business environment. In this study the optimization is about the optimizing of licensing and cross-licensing revenue and making choices about discarding patents or investing into the portfolio. With licensing the essential patents create revenue from payments of licensing companies. Additionally, value can be gained through cost savings in royalty fees. With licensing revenue and cost reductions the patents actually defend their existence. The other sources of value are more complex to distribute among the patents. This study concentrates mainly on the patents used in standards and Figure 15 the determinants of value or value potential in that case.

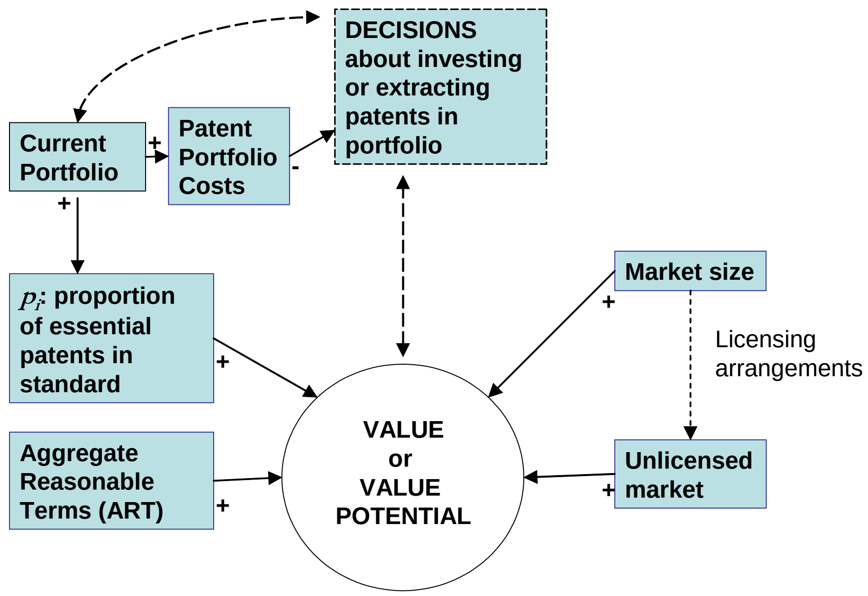

Figure 15: Influencers of decisions about patent portfolio

Here the licensing arrangements define how much potential there still is to gain value through licensing contracts from the market. The dashed lines implicate decisions that can affect positive or negative depending on the case. In other cases the sign indicates how the growing of the previous factor affects the following factor. ART represents the proportion that needs to be paid for using the standard. The created income rate and current existing portfolio define the management decisions made to maximize the benefits gained from the portfolio. The value or value potential defines the rates of further investment or other actions to the portfolio. The value or value potential is influenced by the size of unlicensed market. That can be estimated from the scenarios of market size and the estimations of how the market is divided between the different players. From the different companies can be stated whether they have already paid for the specific license or not and they can be divided into ones that already have paid the license and the unlicensed market. The unlicensed market is interesting, because it has an impact on the value that still can be gained from the portfolio. The companies that have already paid for using the license do not have to pay anything anymore for using the standard.

The value or value potential defines how much interest there is to invest into a certain standard. What comes to the income of one specific company there are two major influencers. The proportion of the owned essential patents from the standard defines the portion that the company gets from the revenue created by the standard. The ART level again defines the overall proportion that is needed to be paid for the standard. It can be a certain percentage of the price of the final product. When these to proportions are multiplied by the assumptions of the still unlicensed market the company can estimate its own revenue and make decision about discarding or investing into patents of that particular standard.

3.3.2 Dividing the Business Estimates to Individual Patents

The value of the patents can also be examined from another perspective. The value of the portfolio derives from business estimates. To divide these estimates down to the patent level, the patents are grouped according to their technology into a set of technology groups first. These technology groups are linked with different businesses which have value estimations of the future. One technology can be used in many different businesses and one business can contain various technologies. These links could be described with a matrix that includes businesses as rows and technologies as columns. These interconnections are described in Table 4. These connections are not particularly the ones used in this study; they just illustrate the links between technology groups and businesses.

Table 4: Dividing value to technology groups

	Technology group 1	Technology group2	Technology group 3	Technology group 4
Business 1	0.3		0.7	
Business 2		0.6		0.4
Business 3		1		
Business 4			0.2	0.8
Business 5	0.5	0.2	0.3	

The value estimates are added up column wise to get estimates that respond to the actual advantages of the different technology groups. In this example the estimates for technology group one are derived from the estimates of business group one and five. These scenarios for technology groups are then used to define the number of patents to be kept or added into a specific technology group.

The value of patents is not distributed evenly by patent numbers in the technology groups. There exists a synergy effect that was described with an S-curve in the previous chapter. Moreover, patents have different value estimates described by the rating and the proportion derived from the rating and the age. The matter is dealt in a way that the estimates of the technology groups are allocated to the patents by the proportion of the potentiality of a patent. That means that the proportion of the whole estimate is the patent proportion of becoming an essential patent divided by the sum of the proportions. The synergy effect is quite easy to handle that way, because when there are only few patents in one technology group the proportion of one patent is much bigger than in the groups with lots of patents. That means that lower rated patents in small technology groups justify their existence because there are so few patents in the group in total. Another approach take the synergy effect into notice would be to use different kinds of safety limits as constraints for each technology group.

3.4 Chapter Conclusions

This chapter introduced the patent portfolio in question, because it helps to understand the relevant issues in analysing and optimization process. The awareness of the contents helps also to eliminate some choices for the optimization. The portfolio included the need for cost efficiency which leads here to the question of which patents should be discarded from portfolio. For managerial purposes it would be also interesting to know to which technology groups patents should be added to for taking the use of synergy effect.

When looking the patents from the portfolio perspective, one should recognize that age of the patent is relevant, because young patents contain uncertainty about the coming value and old patents are going face the expiry in the near future. In the existing there was also an indicator of the estimated value of the patent represented as the rating of the patent. It was based on an expert opinion. Rating included some uncertainty itself and the logic behind that uncertainty was looked through. Additionally, the probability of the patent to become essential was introduced and analysed briefly.

The chapter also included an analysis of the structure of the portfolio. Because the probability of a patent becoming essential was very important part of current study, the distribution of it was taken into a closer look. Additionally, the distribution of patent ages was examined to understand the main profile of the portfolio.

The value created by the portfolio could also be examined from wider perspective. The chapter introduced the main influencers to the expected value or value potential of the portfolio. The clarification of principles of how estimated value was divided up to individual patent groups was also explained, because it is the link how larger scale estimations can be transferred into the level of patent groups, which are here mainly under study.

4 Portfolio Selection Methods

The following two chapters answer to the question:
How should patents be added to or discarded from a portfolio?

Every patent is unique in some sense, but for the evaluation of a large portfolio a certain set of comparison principles need to be made. The attributes for the selection process for the portfolio were already discussed in the previous chapter. This chapter concentrates into the logic used inside the program. It covers the mathematical background and some methods for the selection process. Computational challenges of the approaches are also evaluated for finding suitable ways to solve the optimization. Computational algorithms are usually compared against each other based on two measures: the needed time and space consumption. First, the links between mathematics and current problem as well as computational challenges will be briefly discussed. Finally, a couple of methods are introduced which can helpful in the design of the optimization process.

4.1 Basics of Algorithms

Algorithm is defined according to Cormen et al. (1997) as any well-defined computational procedure that takes some value, or set of values, as input and procedures some value, or set of values, as output. It is thus a sequence of computational steps that transform the input into the output. An algorithm is said to be correct if it halts with the correct output for every input instance. Incorrect algorithms might not halt at all or they might produce a less desired answer. The running time of an algorithm on a particular input is the number of primitive operations or "steps" executed where the step is a constant amount of time required to execute each line of pseudocode.

Algorithms can be compared against each other with different measures. The most important of these include the ability to find the most optimal point and time and space consumption. It is also important to understand whether there is a possibility that an algorithm never completes its runs. Like there are differences with algorithms there are also differences in problems. Some are easier to be solved while others may not have an unambiguous answer or solving the answer is not possible in reasonable set of time. For instance the combinatorial problems can turn out difficult to solve when there does not exist a specific algorithm for the problem.

The goodness of an algorithm depends also from its use. Some places are more sensitive for little variations in the answer or they might not contain so much computation power. The initial set can also be so large that even small modifications can take much time to compute. In this case the number of patents is still quite small compared to the computation power that normal computers make it possible these days. Therefore the computational power should not hinder unless the problem is computationally hard, like for instance the needed time or space is growing in exponential rates with regards of the size of the initial set.

To understand the issue of complexity, the usual measure of computation time is defined here. The asymptotic upper bounds are usually described by the O-notation: For a given function $g(n)$, $O(g(n))$ is denoted by the following set of functions:

$O(g(n)) = \{f(n)$: There exist positive constants c and n_0 such that
$0 \leq f(n) \leq cg(n)$ for all $n \geq n_0\}$

O-notation means that the studied function stays within a constant factor in $O(g(n))$. (Cormen et al., 1997). It gives an order of magnitude of how much time algorithms take, which is compared to different magnitude classes that are commonly acknowledged.

4.2 Bayesian Networks for Patent Rating Dynamics

Bayesian networks were developed in an attempt to devise a computational model of human reasoning Pearl (1986). Bayesian probabilities are conditional probabilities in which the probability depends on the current state of the object. Bayesian networks consist of a set of these probabilities and they contain information on how the evolving of the object depends on current state. In this study the probability network would provide information on how patent ratings develop with regards of its age and rating.

Bayesian statistical conclusions about a parameter are made in term of probability statements (Hörmann et al., 2004). In developing the criteria for decisions under risk, it is assumed that the probability distributions are known or can be secured. In this respect, these probabilities are referred as prior probabilities, $P\{\theta_i\}$. Sometimes it is also possible to perform an experiment on the system under study and, depending on the outcomes of the experiment, modify the prior probabilities reflect the availability of new information about the system, and these are known as the posterior probabilities, $P\{\theta_i|z_j\}$. (Taha, 1992). The posterior probabilities are calculated from the prior probabilities $P\{\theta_i\}$ and conditional probabilities $P\{z_j|\theta_i\}$ using the Bayes' Theorem which states that $P\{\theta_i|z_j\} = \frac{P\{\theta_i,z_j\}}{P\{z_j\}}$. The probabilities for the outcomes can be calculated then with the formula $P\{z_j\} = \sum_{i=1}^{m} P\{z_j|\theta_i\}$.

One drawback of the Bayesian approach is the fact that posterior distributions are in general non-standard distributions (Hörmann et al., 2004). Even though Bayesian networks would be the mathematically correct way to approach the question of how patent ratings evolve, defining the posterior distribution is also difficult in current study. One of the main problems is that the number of states is so large, that it is computationally hard to produce and use. The existing set of data is also quite scarce and lacks history information so that the probabilities would also be difficult to justify with the existing data. Hence, a more simplified approach is needed and it is described in Section 5.

4.3 Combinatorial Models

Combinatorics is a mathematical branch that studies collections of objects in finite sets that satisfy a specified set of constraints. Combinatorial problems include for instance sorting, searching, and selection problems as well as different combinations and permutations. Patent management can be seen as a combinatorial problem, because in the management process several patents are chosen to be either discarded from or added to a portfolio. Patent selection problems can be seen as making combinations from a given set so that the given goals are met as well as possible with respect to given constraints.

The difficulty in making combinations is that as the domain increases the needed time and space can grow up even in exponential rates if the solution is searched only with brute force. This is also relevant in the selection process of the current portfolio, because it becomes computationally hard to just try out all the different combinations in a sample of over 10 000 patents. Additionally, in this empirical case the number of selected patents is also prone to changes, which increases the number of trials even more.

The theory of combinatorics usually deals with quite small numbers of objects which are solved with their own separately designed algorithms. For patent portfolio selection a closely defined problem couldn't be found that would include the same type of constraints. Trying about billions and billions different alternatives with out brute force for each question setting would also be too much. Because of that, the solving of the selection problem needs such an approach that all different combinations need not to be checked. One prospect for that would be to create separate groups so that the number of combinations to be checked stays in a small scale. Another possibility would be to provide such an inner logic, which restricts the number of needed combinations or makes the creation of the feasible combinations more simplified.

4.4 Multiple Criteria Decision Making

4.4.1 Introduction to Multiple Criteria Decision Making

Multiple criteria decision making is usually optimization of a decision maker's problem in which multiple objectives exist. Usually the decision maker has only one target to be optimized, like for instance the profitability. Sometimes the influence of many different factors into one target can not be directly estimated, and then the problem is formulated as a multiple criteria decision problem. The nature of the problem can also be such that there are no unambiguous attributes that need to be optimized. Then the question turns to multiple criteria decision making problem. To these problems there is seldom only a single answer to be found, but rather a set of feasible answers.

A multiple criteria decision model consists of goals and criteria. Goals describe the decision maker's needs and the purpose of the optimization process is to reach the goals as close as possible. Constraints are called temporarily fixed requirements that cannot be violated in a given problem formulation. They divide all possible solutions into two categories: feasible and infeasible. (Zeleny, 1982). In this research the goals of the optimization are the minimization of costs and the maximizing of the value of portfolio.

The multicriteria evaluation function can be defined as $f\colon A \rightarrow R^q$ where $q \geq 2$ for a proper multicriteria evaluation function. If q = 1 is considered a special case of MCDM problem, because it is an ordinary scalar optimization problem which simplifies the analysis. Each function $f_k\colon A \rightarrow R$ with $f_k(a) = z_k$, $k \in \{1, \ldots, q\}$, $a \in A$ is called a criterion or attribute. (Hanne, 2001, p 1). Constraints come from the different safety levels for each technology group and the need of having both young and old patents. Also a minimal number of patents could be defined for each technology group. Formally, they could be written as:

$$\begin{cases} max f_1, & \text{where } f_1 \text{ describes the value of portfolio} \\ min f_2, & \text{where } f_2 \text{ describes the costs of portfolio} \end{cases}$$

so that $bx - c \geq 0$, where the minimal number of patents would exceed a specified limit.

Linear multiple criteria decision making models can be written as an optimization model into matrix form and solved with numerical linear algebra. Numerical linear algebra is dealing with large systems for linear equations. The constraints are expected to be linear to help the solving process. Still the computations for large matrices can be quite tough and need lots of time even with the efficient machines. With large systems the complexity is an issue. For a continuous problem the maximum amount of variables is around 10^6, whereas for already 100 variables can become troublesome for discrete problems. The round-off errors have to also be thought of, because in matrix iterations the errors tend to accumulate, which can lead to the situation where the result from the iteration can lie far from the correct one.

In the optimization of the portfolio the initial set is around 11 000, which is quite much for the computations. If the computation time creates an obstacle the original set could be divided into separate groups which again could be optimized one at a time. Still there exists an even a trickier problem which are the constraints of the portfolio. The patents created synergies in a way that it is beneficial to have at least five patents of a specific field. The synergies create an S-curve (See Chapter 2, Figure 3) based on the winning probabilities in litigation. For a small set of optimized objects, synergies could be reflected with value thresholds which grow when a specified amount of patents is exceeded but for this problem too many value thresholds would be needed.

The problem with the S-curve is the lacking additivivity, which is assumed to be one of the basic assumptions of constraints of linear programming. It is possible to construct the S-curve using linear matrix constraints with value thresholds. They simplify the system quite much, but they make it feasible for linear problem solving. As side-effects the use of thresholds is still troublesome, because they make the calculations much heavier. Together with the size of the portfolio they create a problem, which is almost impossible to bypass, because the algorithms would take too much time. Therefore a different approaches are needed.

4.4.2 Robust Portfolio Modeling

Robust portfolio modelling (RPM) has been developed to help in situations where selection decisions need to be made based on multiple attributes and multiple objectives. RPM extends the principles of preference programming and it is developed in the Systems Analysis Laboratory of the Helsinki University of Technology.

The algorithm presented by Liesiö et al. (2007a) bases its computations on a core index of non-dominated portfolios, and divides them into three categories: ones to be kept, ones to be discarded and ones that need further study. It takes incomplete information about criterion weights and project-specific performance levels. The extension of the paper (Liesiö et al., 2007b) includes also incomplete information about costs and varying budget levels into the optimization process. For current problem of portfolio selection the algorithm is even a bit too sophisticated: it includes the option that one patent can be part in several groups. That characteristic is not really needed in the current optimization, but because of it, the computational time grows exponentially with the number of optimized objects. With over 1000 patents the completion of the program takes too long. Another difficulty for the optimization are the nonlinear constraints that represent synergies between patents. Thus other, more simplified methods could be more suitable for the needed optimization.

4.5 Stochastic Approaches

Stochastic algorithms have been developed for global optimization problems in the 20th century. The advantage with these is that they are quite efficient what comes to computational time. With a result close to optimal they present an interesting possibility for the optimization heuristics. One important issue with global optimization problems is landing into local optima. The next two algorithms fight this problem with probabilistic changes of state. These are not the only probabilistic algorithms that exist, but they present an interesting view compared to the traditional subgradient and other optimization methods.

4.5.1 Simulated Annealing

The annealing algorithms are meant for global optimization problems. The annealing algorithms are based on a controlled reducing of magnitudes of random perturbations in Monte Carlo fashion. The purpose of annealing is the enhanced likelihood of avoiding local minima en route to a global minimum. Randomness of the algorithm helps to prevent the premature convergence by adding more jumps to the algorithm. Annealing algorithms are divided into the group of simulated annealing algorithms and ones that are based on principles of stochastic approximation. Stochastic approximations have different gain conditions for global convergence than the traditional simulated annealing algorithm. (Spall, 2003).

The simulated annealing refers to the use of Metropolis simulation technique in conjunction with an annealing schedule of declining temperatures. The annealing contains the Metropolis algorithm in its inner loop. (Johnson et al., 1989). The algorithm escapes it local minima with the randomized procedure, which allows occasional uphill moves (Goffe et al., 1994).

The algorithm looks as follows (source: Johnson et al. 1989):

Initialization : Get an initial solution S and an initial temperature T > 0

Loop : While not yet frozen

Pick a random neighbour S' of S

Count the difference $\triangle$ = cost(S') - cost(S)

If $\triangle < 0$, set S = S' (downhill move)

If $\triangle > 0$, set S = S' with probability $e^{-\triangle/T}$ (uphill move)

Set T = rT (reduce temperature)

Return S

Simulated annealing algorithms are good in situations where traditional optimization algorithms fail to converge in a reasonable set of time (see e.g. Corana et al., 1987; Goffe et al., 1994; Johnson et al., 1989). They also require less stringent assumptions regarding the optimized function (Goffe et al., 1994), which makes it an interesting choice for current study.

4.5.2 Genetic and Evolutionary Algorithms

Genetic algorithms (GA) are the most popular methods of evolutionary algorithms. They are mainly used for searching and optimization purposes, because they are good for otherwise hardly solvable problems. They do not require the continuity of the target function. The solution is also not the absolutely best one but rather an answer that is good enough. GAs are used for instance in some heuristic solutions for the classical traveling salesman problem. According to Spall (2003) genetic algorithms are roughly based on the principles of natural evolution and survival of the fittest. The difference to other algorithms and GA is that GAs work with a population of possible solutions to the problem. GAs work when multiple candidate solutions are iterated towards the minimization of the problem.

The stages of the algorithm are the following:

- Initialization of the population: The initial population size and values are selected and the elements are encoded suitable for the algorithm to operate.
- Parent selection: A predefined number of parents are selected in a way that only the fittest survive.
- Crossover: The crossover will be carried out for the selected parents for a randomly chosen splice points with a probability P_c.
- Replacement and mutation: The set of discarded parents are replaced with the offspring generated with crossover. In addition the individual bits are mutated with a probability P_m. With evolutionary algorithms the mutation is a small change of the mutated parent.
- Fitness and end test: The fitness values of the original problem are computed for the new population. These values are compared to the stopping criterion and additionally, the number of iterations will be tested. If no stopping criteria are met, the algorithm is continued by selecting new parents.

After the initialization the next stages are repeated until an answer good enough is found or number of iterations is exceeded.

Evolutionary algorithms can also be used as solvers for multiple criteria decision making. They resemble genetic algorithms quite much but there are also some differences between the two. According to Hanne (2001), the main strategies of mutation, selection and crossover are quite the same but genetic algorithms are based on bitstrings while evolution algorithms apply vectors of real numbers or floating point numbers. Because of that, the selection process also differs a bit for evolutionary algorithms.

Genetic and evolutionary algorithms are quite efficient for finding a good solution, but there exists also some criticism. One of the main problems of applying genetic algorithms lies in finding a suitable representation of the problem (Hanne, 2001). In this case this issue can create actual difficulties because patents are not necessarily easy to translate as bitstrings. Maybe they could be used in a way where the existence of a certain patent is marked as one in a string, but still the applying of the basic methods is quite troublesome. Therefore simulated annealing and other methods for MDCM look like more promising options.

4.6 Chapter Conclusions

This chapter introduced basic mathematics behind the selection logic. These included the concepts of combinatorics, multiple criteria decision making as well as several methods usually used in the optimization process. The chapter also introduced the concepts how algorithms can be compared against each other. One of the main measures, computation time, was introduced and explained.

Current patent selection problem can be seen as a combinatorial problem. Hence, the main characteristics and problematics of combinatorial problems were introduced. Combinatorial problems can be difficult because the time and space needed for the solution can grow in even exponential rates when the domain increases.

The optimization problem can also be written as a multicriteria decision problem. What makes the problem hard to solve with traditional optimization methods is that some of the constraints are not linear. That leads to the situation where the main problem needs to either be simplified or some heuristics will be created. One option for the method could be the probabilistic approaches such as genetic algorithms or simulated annealing methods. These can not provide the absolutely optimal answer in a reasonable period of time but they can provide answers that are good enough in the sense of the question posing.

5 Optimization of the Portfolio

This chapter introduces the actual optimization procedure and reasoning behind it. It presents the main concepts and the logic behind the organization and optimization process. The technology groups are assumed to consist of patents that are related closely enough. The technology groups are also assumed to be separate and there are no linkages between the patents in different groups. The division of the patents into separate technology groups makes the optimization much easier. That helps also to avoid combinatorial issues and decreases the need for stochastic approaches. The synergy effects are also taken care of, because the value is divided between patents proportionally, so patents in small technology groups get larger proportions.

5.1 Model for Portfolio Optimization

5.1.1 Main idea

The main idea is to divide the data based on countries and technology groups. Additionally, the patents are also divided between standardization and differentiation patents based on the usage of patents. Primarily, the patents from the US are evaluated. After their optimization one can think about extending the optimization also to patents from other countries. The process is described briefly in Figure 16.

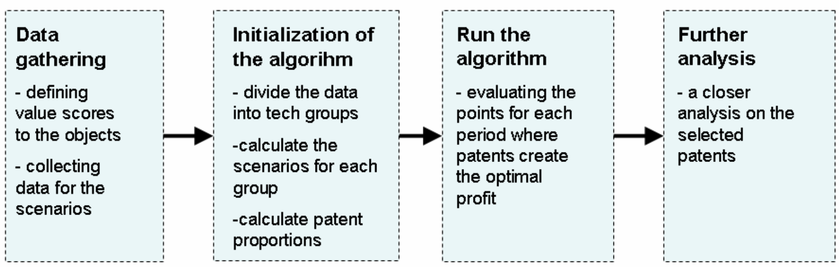

Figure 16: Model for portfolio optimization

The steps of the process go as follows:

- In the data gathering stage information is gathered about the patents and the scenarios, on based of which the algorithm can be used. Some sorts of estimates of patents values are needed. Additionally, data for creation of the business prospects are needed. They can be for each technology group, for instance.
- In initialization of the algorithm the data will be divided into the separate patent groups. The groupings can be based on interconnections or some sort of classification. The division can be based for instance on technological grounds or linkages to a specific innovation or purpose of use. The business scenarios are created for each group separately and additionally, the proportions of how the value is divided between the different patents are calculated.
- In the running stage the profitability of the patent is evaluated for the periods of the scenario. When calculating the proportion of value in a certain patent in a scenario, the value is divided between the patents in proportion of their goodness. The evaluation of the periods starts from the last period and continues to the first. Every period is checked through and the patents, which value does not exceed their costs are put into the list of discarded patents. The checking of each scenario continues until a patent comes upon that is not needed to be discarded. The patents after that do not need to be tested anymore, because they are better than the previously tested patents.
- The last stage is about further analysis on the selected patents. The algorithm can not explore the patents in detail so the selected patents are needed to be checked separately. This still helps the discarding process, because the algorithm leaves the maturity of patents out of the further analysis.

The goal of the optimization is to maximize the net present value of the portfolio. Mathematically, the main optimization can be formulated as follows:

$$\max z(p_i) = \sum_{i=0}^{n} \left(\sum_{j=1}^{p_i} [v_{\text{ij}}/(\sum_{i=0}^{n} v_{\text{ij}}) \cdot \frac{essPat}{essPat_{\text{tot}}} \cdot bizScen_j - c_{\text{vij}}]/(1+r)^j \right),$$
$$0 \leq p_i \leq periods,$$

where the used attributes are described in Table 5.

Attribute	Represents
v	the value that indicates the possibilities for the patent to become an essential patent for a standard
$essPat$	the number of essential patents owned by the company and essentialPatentstot represents the number of the patents in the whole standard. The factor is the proportion of patents owned by the company of all patents in a standard
$bizScen_j$	the estimated business potential for current period
c	the costs of the patent in a certain period
r	the discount factor
i	the number of the patent
j	the index of the period before discarding the patent
p_i	the number of periods patent i is kept
periods	the number of periods in total

Table 5: Attributes of the formula

The main issue is to recognize which patents are taken into the portfolio and how long each patent is kept valid. The keeping of each patent can be done separately, which makes the actual optimization a lot easier.

5.1.2 Global Optimum

The global optimum is in this case the discarding strategy where the net present value of the portfolio is the highest. The surface to be optimized behaves quite smoothly, which makes the optimization process easy. The global optimum can be defined as follows:

$\exists$ discarding strategy $(a_1, a_2, \cdots, a_n), a_i$ are discarding periods for patent $i, a_i \in \aleph, a_i \leq periods$, so that $f(a_1, a_2, \cdots, a_n) \geq (b_1, b_2, \cdots, b_n), \forall$ discarding strategies $(b_1, b_2, \cdots, b_n), b_i \in \aleph, b_i \leq periods$

It means that there exists a point that is superior or at least equal to all the other points in the surface, which means that the number of periods for each patents is at least zero and at most the number of periods.

5.1.3 Constraints

Essential constraints for the optimization process remain budget constraints which define the amount of patents to be kept or discarded. There are also lowest limits to the number of patents that should be included in each technology group. This could be defined as:
$count_{i=0}^{n}(p_{\text{ij}}) \geq t(j), p_{\text{ij}} > j,$
where $count$ counts the number of kept patents in period j and $t(j)$ is the lowest amount of patents allowed for period j. Then the synergy effect would be taken into notice quite easily when the technology group estimates are divided according to the value proportions to the patents and there is no need to keep the non-linear constraint in the optimization process.

Another constraint is also that when a patent is discarded from a certain period, it cannot exist in the periods later on. That's why in these cases the created value and its costs are compared to in all the following periods, and based on that the decision of putting the patent into the list of discarded patents is made.

5.1.4 Organization and Comparison between Patents

Every patent has a specific value, which is counted based on their age and rating. Additionally, every patent has a periodical fee. To compare the utility against costs, the next payment and period are taken into consideration. The value is presumed to stay the same each year. With that assumption the net present value is discounted over the next period of time that is provided with the next fee. Additionally, the next costs are also discounted into current time and the discounted value is divided by the discounted costs. Mathematically, the comparison index can be formulated as follows:

$index(i) = \sum_{j=1}^{p_i} [\frac{\frac{v_{\text{ij}}}{\sum_{i=0}^{n} v_{\text{ij}}} \cdot \frac{essPat}{essPat_{\text{tot}}} \cdot bizScen_j}{(1+r)^t} / \frac{c_{\text{vij}}}{(1+r)^{\text{t2}}}]$, where

r is the discount rate (presumed to be in this case 15%)
t and t_2 are the time, they are different because the period of one payment can cover several years whereas the value is discounted for each year separately.
c are the costs (periodical fee)
v is the value estimate for the patent becoming essential in ten years n is the number of patents in total in the technology group $\frac{essPat}{essPat_{\text{tot}}}$ is the proportion of current company owning from all the essential patents in the standard.

The discount rate depends on risk factors of the investment. 15 % is quite a common rate. For instance the required rate of return is around 10 - 25 % (Leppiniemi and Puttonen, 2002). Based on the index, the patents can be organized in the basis of profitability.

5.2 Algorithm for Portfolio Optimization

5.2.1 Core of the Algorithm in Pseudocode

Every technology group is organized based on the utility of patent against value. Technology groups also have some value estimates of the development of the future. With this information the groups are optimized one technology at a time. For each scenario the amount of discarded patents at particular times are counted. This is done by starting from the timely end of each scenario and optimizing the amount of patents in each time span starting from the last period. When a patent is discarded in a certain period, it does not exit anymore in the periods later on. In this algorithm patents are kept always when the value is bigger than the costs. It can also easily be translated into a form where a certain income is required from the investments.

The algorithm goes as follows in pseudocode:

```
initialize table keptPatents : each scenario contains all patents
initialize patentProportions
  do from lastPatent to firstPatent
    period = patent.lastPeriod
    initialize patentTotalValue
    do while (period ≥ 0)
      periodStart = countPeriodStart
      periodLength = countPeriodLength
      periodCosts = getPeriodCosts
      initialize periodValue
      for(periodLength)
        periodValue += proportion · estimate / (1 + discount)^period
      endFor
      patentTotalvalue += periodValue - periodCosts
      if(patentTotalvalue < 0)
        discardingPeriod[patent] = periodStart
      endIf
    endWhile
  endDo
```

The algorithm resembles the greedy algorithm (see e.g. Cormen et al., 1997) with small modifications. The difference is that current algorithm checks the set the number of periods and that there is also the constraint that demands that if one patent is discarded in one period, it cannot exist anymore in the following periods. The greedy algorithm consumes $O(n \log n + nf(n))$ time, where $f(n)$ describes time needed in the checking. The greedy algorithm has also been proved to provide the optimal subset (see e.g. Cormen et al., 1997).

5.2.2 Analysis of Algorithm

In this section the algorithm will be studied briefly with the methods of algorithm analysis. First, the ability to find the global optimum will be explained briefly, then the needed time and space will be analyzed.

The algorithm does find its global optimum. It processes every patent one at a time and looks for its optimum. The biggest constraint is that once a patent is discarded, it cannot exist in following periods. The evaluation of the discarding period is quite easy with the calculations of net present value of the profits created by the patent. Because each patent is a separate object with no internal linkages, the global optimum consists of a strategy where all the patents are treated optimally. The division into separate groups and the ordering of each group simplify the whole optimization so no heuristic approaches are needed.

Because there are limited number of periods and patents, the algorithm ends in finite time. What comes to the complexity of the algorithm, the consumed time and space can be calculated as follows for one scenario with p periods and t patents. There exist three loops in the algorithm. The first loop goes through all the patents and the next two loops go through the periods of the scenario. These two loops depend on each other, because the first loop tells on how many periods the whole time span is divided into and the latter loop counts of how many years exist in one period. The needed time for a single operation is presumed to be one to get understanding about the complexity of the algorithm.

$$
\begin{aligned}
& n + n + \textstyle\sum_1^n \{2 + \sum_1^c [4 + \sum_1^{p/c}(1) + 2]\} \\
&= 2n + \textstyle\sum_1^n \{2 + \sum_1^c [6 + p/c]\} \\
&= 2n + n(2 + 6c + p) \\
&= 4n + 6cn + np
\end{aligned}
$$

$\sim O(p \cdot t)$, where

n is the number of patents
p is the number of years in the estimate
c is the number of different payment periods. It is smaller than p and the number of different age periods is in current study four, because the payments need to be paid on years 0, 4, 8 and 12 from the grant date of the patent.

5.2.3 Defining the Minimum Requirements for Keeping a Patent

It is quite difficult to create an overview of the minimun requirements for patents just based on the list of discarded patents. This issue could be approached so that the algorithm would present the value (probability for patent becoming essential, presented in Table 3 on page 35) which is the boundary for which a patent will be kept in the portfolio for financial reasons. The attained threshold tracked backwards in the Table 3 and get the minimal conditions for new patents, which could help deciding whether or not to invest into new patents.

In practice the search for the minimum requirements can be easily programmed as a binary search which looks for the minimum value of the keeping of a patent with different initial probabilities. The binary search can be for instance found in Cormen et al. (1997). In this case the domain would be the probabilities from 1 to 100 which could be searched through for instance with binary search. It would start from the middle of domain and then bisect the range depending on the results the algorithm gives until it reaches the minimum requirements for a patent to be kept. The computational constraints would not be a problem, because binary search is a remarkably efficient algorithm for searching in a sorted array and it consumes computation time in the magnitude of $O(log_2 n)$ (Levitin, 2003). Combined with the evaluation algorithm the complexity of the search would then be $O(log_2 n \cdot p \cdot t)$, which is still feasible.

5.3 Chapter Conclusions

Optimization of complicated combinatorics can become computationally hard if the main problematics have not been properly planned. In this study the initial complexity has been decreased by dividing the data into several main classes, which do not have connections between them. This leads to the situation where every class can be optimized individually, which decreases the whole complexity substantially.

This chapter introduced the basic assumptions and algorithms behind the optimization process. The main model and its factors was presented in Figure 16 (page 55). It included four stages, which were the data gathering, algorithm initialization, algorithm run and the further analysis of the list of discarded patents. The main problem was also defined mathematically and the main constraints and reaching the global optimum were discussed.

The substance of the optimization algorithm was presented in pseudocode. In the optimization algorithm discarding of the patents was done periodically so that the utilities of the patents were maximized. Section 5.2.2 also calculated the complexity of the algorithm. Additinally, some thoughts were given for understanding the sensitivity of the outcome from the estimated probabilities (See Section 3.2.2). It introduced the principles of how the threshold for keeping a patent was defined. That measure could also be used to detect the parts of the portfolio that needed new patents most.

6 Patent Portfolio Optimization in Practice

The following two chapters discuss the question:
How does the systematic approach work in practise?

The purpose of this chapter is to study how the practical optimization process works. Some mathematical assumptions needed for the actual optimization are introduced. The previously introduced portfolio will be firstly studied more in detail. After that the algorithm will be implemented and finally the results will be reported and evaluated.

6.1 Need for Management

There exists a need to evaluate different patent portfolios systematically, taking also the technological strategy aspect, incomplete information and dynamical system into consideration. The selection process should pay attention to the computational aspects such as the need for existing numbers and also that the amount of patents can create some limitations for the optimization process, like claims for the simplification for the model. The computations should picture out the number of how many patents should be discarded so that the portfolio would be more efficient. Attention should also be paid to the form of representation of derived results.

The budget constraints are flexible depending on the income and other benefits created by the patents. The budget level can be changed in case of specific reasons like when the patents could create more income than expected. The costs are also uncertain. When the patents are granted there falls due a fixed fee, but in the application process there can for instance arise claims about the invention to be patented.

One important option would be to create such an overview on the patent groups and highlight those groups which need more patents. More investments can be needed even if some patents are discarded from a technology group. That is because when the poorest patents are discarded and the new investments are for new, better patents.

6.2 Preparations for the Optimization

6.2.1 Assumptions

Before the data can be analyzed, a couple of assumptions are needed. These include assumptions about the private value of the patent as well as presumptions of the development of patents' value over time. The figures of this section are only educated estimates so relocating them to other environments can be difficult and lead to unwanted results. The effect of them will be discussed and analyzed more in specific later on.

Patents from different technology groups can be compared against each other based on their value in technology group and value of technology group. For each technology group, the high, base and low estimates are counted as a column sum that multiplies the proportion of a technology group in a business division with the future scenarios of that particular business division. The column sum is also multiplied by the proportion of essential patents owned by the company. If the business divisions are assumed to be separate, so that the development in one division does not affect the development in other divisions the expected future scenario can be calculated from the base scenarios. Additionally, some boundaries for these estimates can be calculated from the low and high future scenarios.

6.2.2 Scenario Building

For each technology group the business prospects are counted down to particular estimates. Also the proportions of patents becoming essential are counted together in one technology group, because they describe how the value of the technology group is created. With the help of both the estimates as well as the private value of patents the optimal prospects of keeping the patents are evaluated. With the help of the estimates the value of patents in different technology groups can be compared against each other. Also the difference of the number of patents to be kept can be set against each other and that way information can be obtained on how the number of patents behaves depending of the future scenario.

When considering how the expected value and variance can be calculated from a combination of separate distributions (X and Y), following rules for expected value and variance hold:

$$E\{X+Y\} = E\{X\} + E\{Y\}$$
$$E\{X \cdot Y\} = E\{X\} \cdot E\{Y\}$$
$$Var\{X+Y\} = Var\{X\} + Var\{Y\}$$

The first rule is valid in all cases, even if the distributions are not separate. In this case the scenarios of different business cases are built in a way that there exist different interdependencies between the estimates. The expected values are still quite the same, but the existing trust into limits for variance are lost. The range still represents some information on the limits to which the expected development can lead to.

Formally, the estimates could be defined as $s_{\mathrm{bi}}^{\mathrm{low}}$, $s_{\mathrm{bi}}^{\mathrm{base}}$ and $s_{\mathrm{bi}}^{\mathrm{high}}$, where i = 1 ..., n, n = number of business divisions, the estimates would be for the technology groups , and , where j = 1 ...m, m being the number of technology groups, being the proportion of technology group j in business division i and p_{tj}being the share of essential patents in technology group j of the whole world. Then the estimates for technology group j would be counted the following way: $s_{\mathrm{tj}}^{\mathrm{base}} = p_{\mathrm{tj}} \sum_{i=0:n} (s_{\mathrm{bi}}^{\mathrm{base}} \cdot p_{\mathrm{bitj}})$

The estimates for low and high scenarios could be calculated the same way and they represent the boundaries for the estimates. These scenarios are then divided to the patents based on their proportions of becoming essential patents.

6.2.3 Current Scenario

The estimates for market growth (Figure 17) are given for the whole set of standardization US patents. There are three different estimates, where high stands for the optimistic view of the market. The base estimate is the expected rates of market growth. The low estimate is a pessimistic view of how the markets develop during the examined period. The growth is starting with a delay and it is much smaller than in the other scenarios. These estimates are created as a holistic view of experts and they are used to test the created algorithms. The estimates have been created to suit the technology group under study.

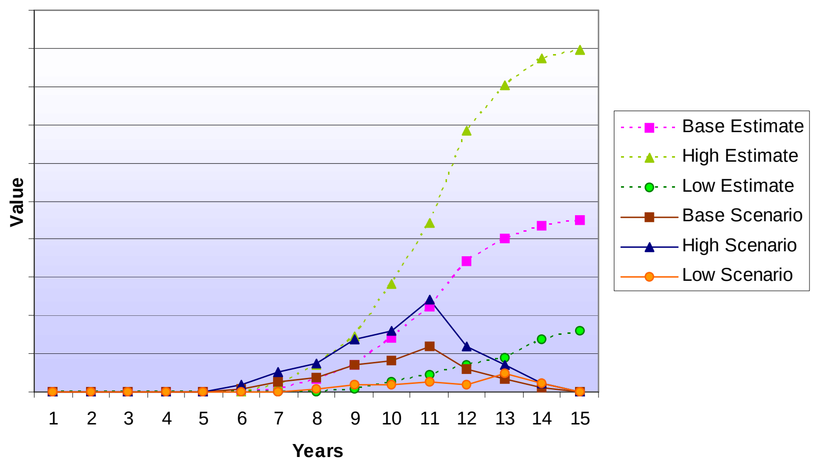

Figure 17: Scenario estimates

In this case the income created from the patents is expected to come from licensing actions. The scenarios are linked with future where they describe development the value of the unlicensed potential. The estimates and scenarios can change when other companies license the standard, because after a payment for using the patents the potential value decreases. After licensing the patents to all other companies there is no reason to keep the patents valid unless it is presumable that new entrants will join the market in the near future.

The scenarios for the value potential have been created from the market estimates by calculating the differential in growth of the estimates. They peak at the time when the market growth is the highest and after that they decline again. The reason for the decline of value potential is the forthcoming maturity stage of that industry where there are only few companies starting the business with the need to license.

6.3 Tool in Action

6.3.1 Program

The program has been programmed with the program language Java and version 5.0. The main methods can be found in the Appendix A. Running the algorithm does not take much time and results are created instantly. The program is a very early type of a prototype and it does not contain an actual interface. That means that the wanted changes need to be written directly into the code, which is not very handy. That way the main program stayed quite small and it was quick to make new modifications into the code when needed. This suited for the study quite well, because it was possible to test different approaches quite easily.

The patent data format is an Excel-file which contains information about the patents introduced in the Chapter 3. That data is then copied into a plain text file, which the program reads. The data is already processed into tables so it does not need to be cleaned for the evaluation and optimization process.

6.3.2 Optimization Results

The algorithm returns a list of kept patents in each period for the tested scenario. Additionally, it provides a list of the discarded patents, which includes information about when the patents are actually discarded. The results of current discarding strategy can be seen in Figure 18.

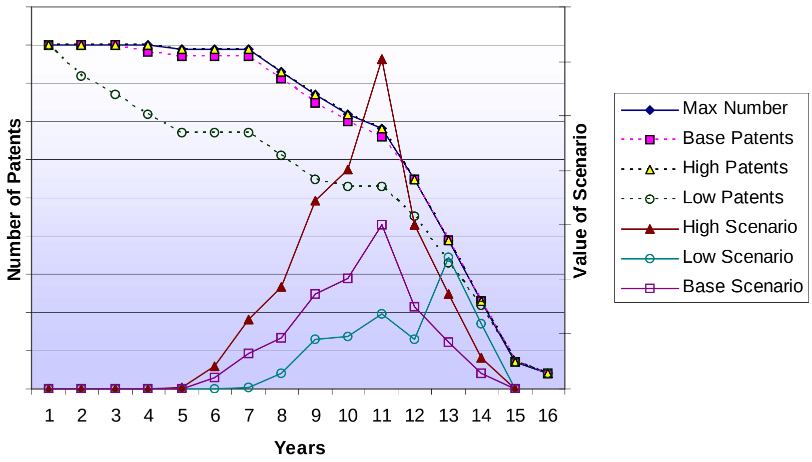

Figure 18: Discarding strategies

There are many ways to interpret the results of the scenario analysis. One option is to examine the results of the worst and best case and analyze then the sensitivity of the results. Different scenarios can be weighted and the actual discarding strategy can be produced based on them. Miranda and Proenca (1998) present a measure that combines the fitting of all scenarios into one actual strategy. In this case the biggest interest lies in the overall amount of discarded patent and a list of discarded patents, which can be bigger than the actual need. This is because the patents are further examined and the decision about discarding patents is concluded later on.

With the initial set of scenarios, the results show that there are almost no patents to be discarded in the high scenario. The decreasing overall number is a result of maturing patents. In the base scenario there are two patents that could be discarded and in the worst case there are more, 22 patents in total. This still is quite an interesting set, because it could be studied further on to define whether or not the patents should be discarded. This set of patents is listed in Table 6.

Patent Number	Patent Rating	Patent Age	Discarding Period (years form now)
2XX01	5S	11.35455	0
7XX94	5S	11.89439	0
1XX62	5S	10.59565	1
2XX95	5S	11.18754	0
1XX59	5S	10.68332	1
1XX02	2S	10.56003	1
1XX81	2S	8.308093	3
1XX01	2S	10.13823	1
7XX95	2S	9.039599	2
2XX68	2S	7.138229	0
1XX59	2S	9.077956	2
1XX15	2S	9.538115	2
1XX17	2S	7.203983	0
2XX38	2S	7.23138	0
2XX52	2S	7.757408	0
1XX31	1S	8.447704	3
3XX74	1S	6.469622	1
1XX08	1S	7.124531	0
7XX35	1S	9.538115	2
1XX01	1S	8.02864	3
1XX01	1S	9.425787	2
1XX45	1S	8.598389	3

Table 6: Table of patents to be explored more deeply

The discarded patents are almost all of quite the same small rating and old age with a few exceptions. The coloured lines describe the patents that would be discarded also in the base scenario. The decisions are not radical, but in a case with larger set of patents, systematization in the selection is needed. It is quite natural, that the weakest patents are discarded first, but additionally to the existing model, there could be constraints about the minimum number of patents in a certain technology group. Putting the patents to some order manually is not a very efficient way to manage the strategy of discarding patents. It can be also difficult to keep up the information about when the patents are discarded, which is easy to see using the program. The decision maker is mostly interested about the patents that need to be discarded almost instantly. The decisions about patents being kept can be considered later with the help of updated estimates.

The program can also discard patents with a high rating in case when the patents are old, like the first lines in the list. That kind of actions are justified in a case when it takes some time in the scenario before any or almost no revenue is created from the portfolio. In that case the patent can expire before it has created enough revenue to cover the costs.

The algorithm does not directly describe what kind of patents should be added into the portfolio. Of course, patents with higher ratings are preferred when keeping and adding patents. The program can still be used in two ways for adding purposes. Firstly, it can provide an overview on the existing technology groups, which helps to discover the sectors which need more patents to be valuable. Additionally, the same approach can describe how many patents exist during each period. That leads to finding the fields where not enough patents exist to create revenue at the time the scenario reaches its peaks.

The other way would be minimum requirements for a patents age/value-combination, which is here referred as the value threshold. It was already briefly discussed in section 5.2.3 and it presents the minimum value for a patent to be kept in the portfolio. The threshold value can be combined with the 3 (35) and from there evaluate the conditions needed for new patents. The threshold functions of the used scenarios are illustrated in Figure 19. These thresholds can also be used to describe how sensitive the results are to the estimated probabilities to become essential i.e. it shows the magnitude of needed value, which matters in discarding the patents.

In Figure 19 are defined the thresholds that are needed for the patents to be kept. In the low scenario all old patents need to be better than rating two to be kept. All the trends grow slightly as the current age decreases, which is due to the fact that they have less time to be valid during the estimated peek in the scenario. The needed proportion thresholds also differ a bit from age to age depending when the payments come due. Another peak in the figure comes from the patents with the age of one, which can depend on the length of the last period to be paid. Therefore, patents can not be discarded soon when the estimates start to decrease.

Figure 19 also shows that the probabilities of the first ratings affect the outcome of the program, because they define the order of which patents are discarded first.

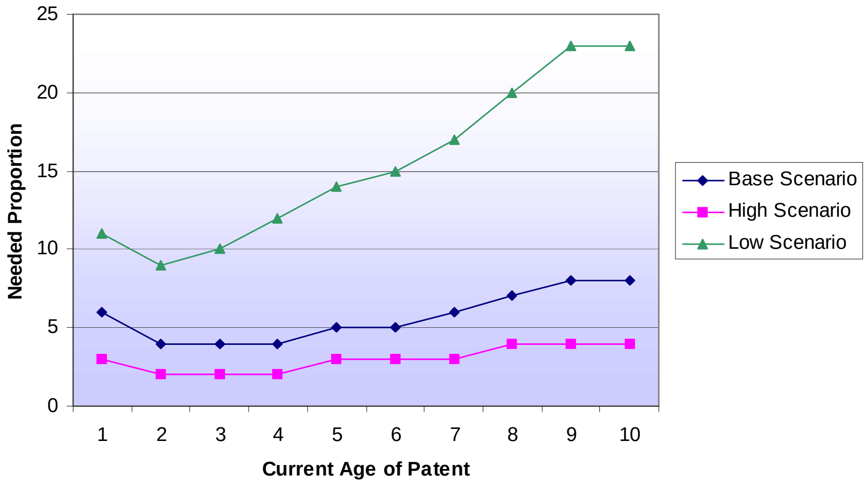

Figure 19: Thresholds of requirements

The probabilities of the highest rated patents do not get affected as much from the discarding algorithm because their probabilities are way much higher than the needed thresholds. The number of highly rated patents still matters a bit in the whole discarding process, because the algorithm counts the proportion for each patent by dividing its value with the sum of all probability scores. The more there exists patents with high ratings, the lower is the proportion of lower rated patents. This is still quite a natural way of action, because due to the synergy effect in the portfolio, lower rated patents mean more to those groups which contain in total fewer patents or fewer highly rated patents.

6.3.3 Analysis of the Results

The discarded patents can be roughly grouped into two main groups. One consists of the patents with low ratings while the other group consists of patents that are so old that they actually expire before the growth of the scenario takes place. The first group would be the natural choice to discard patents, only the number of discarded patents would be a difficult choice for the decision maker. The program can support that kind of decision making, because it shows the needed numbers of discarded patents for the different estimates. The second group with old and highly rated patents are a bit more difficult to pick out manually from the patent data, because it is quite difficult to estimate the coming revenues for the rest of the life span of the patent.

The patents also contain risks, which should be taken into notice and needs for profitability. The probabilities for patents for becoming an essential patent for a standard can be too positive, which also can justify the keeping of the lower rated patents. Only a fraction of the patents declared for a standard are essential ones. The study of one patent family suggested that approximately 21 % of the declared patents are actually essential (Goodman and Myers, 2005). Even though the actual estimates support the keeping almost all the patents, there is still interest to understand what and when some patents are supposed to be discarded for the grounds of not being essential or valuable enough. That's why the algorithm is used for a bit of different scenarios. The linking to the shape of original scenario is done by multiplying it with proportion of the total essential patents.

The algorithm can also be used to find out the different levels of estimated scenarios so that they would support keeping the patents. This means that the discarding strategy is tested with the program and then improved to provide the wanted results, which would help to estimate what kind of scenarios would be needed to justify a certain discarding strategy.

There were almost no patents to be discarded in two of the scenarios. This result could be critizised. One reason for it would be that the existing estimates have not been linked with the patent costs this way before. It can be possible that all the costs or uncertainties are still not included in the model. The program calculates the profits created by each patent and then discounts it with the needed internal rate of return. One option would be to additionally calculate the return on investment created by each patent and organize the patents based on that measure.

The order of the discarded patents is defined with Table 3 (page 35). The thresholds reflect the minimum needs for value for holding the patents. Changes in the values around the threshold values could change the final result radically. Higher or much lower ratings would not be directly influenced from small changes that much. The value differences are quite high between lowly and highly rated patents, so the results are not very sensitive to the initial values defined in Table 3.

6.3.4 Evaluation of the Tool

The probabilities of patents development into essential patents are the biggest approximations in current study. There is only little history data, so finding patterns for supporting existing trends is difficult. Bayesian networks would provide a mathematically more correct framework, but on the other hand the number of needed probabilities is multiplex compared to the amount of currently estimated probabilities. The other variables and concepts are more justifiable. Calculating net present value is quite a common tool in investment science. Estimates on the patents private value based on an expert opinion is also a good indicator, even though it never can represent an absolute truth. Because of that, an improvement for the reliance on the rating could be improved by describing the justification of the rating into the patent data.

The main algorithm and the algorithm for finding the value thresholds are quite easy to extend to other cases. Their main principles are very common, so that they can be used in other contexts, even outside patent world.

6.4 Chapter Conclusions

This chapter was about implementing the actual guidelines and optimization into practice. In the first sections the needed scenarios were created. In the last subchapters the actual optimization took place. The analysis showed that there are only a small proportion of patents needed to be discarded. This can be for instance due to the active management of the portfolio or picking up a representative set of patents for the optimization. Scenarios can be analyzed in many ways, but in this examination the interest was in creating a list of discarded patents. The list could be bigger than the actual discarding, because the patents were futher analyzed before the actual decision of discarding. The algorithm also provided the timing when each patent should be discarded in case it was discarded.

There were a number of assumptions behind the logic of the algorithm. Patents were treated in the scenario thinking so that they needed to cover only the costs created by the patent, and for instance the costs of management of risk premiums were not included into the cost factors. On the other hand, only the direct value or value expectation are taken into consideration, even though the portfolio might be also valuable in other uses.

The results of the algorithm show that only few patents are needed to be discarded. In practice there can be a need of discarding more patents, because the old low-rating patents are not very profitable, because the actual growth in the scenario happens in the last half of the periods. The results also indicate that it would be wise to invest more into the patents of current technology groups, because all patents are expired at the time where the income is expected to be the biggest. Discarding patents is not exclusive of investing into patents, because the types of patents are different; old patents expire quite soon and they do not have so much probabilities to become essential whereas new patents consist of a totally different group, which can have lots of potential.

7 Discussion

7.1 Discussion about the Model and Algorithm

7.1.1 Usefulness of the Algorithm

The algorithm does not tell anything of the actual purpose or use of the patent. Hence, the selected group of discarded patents should be considered only as a proposal that should be studied more carefully in deciding which patents should be removed. The selection of the most probable patents to be discarded helps the decision maker's work because it decreases the number of explored patents into a fraction of the size of the original portfolio. The systematic approach gives also a better overview on the whole portfolio.

The algorithm is quite versatile, since there exists a possibility to extend the algorithm also to other purposes. The needs for the algorithm are the value scenario, value function, cost function as well as a method for organizing the objects to be optimized. Additionally, there can be specified a set that defines how the scenario should be built which for this case are the linkages between business divisions and technology groups. The algorithm can also be used with reversed purposes; different scenarios can be tested to check what kinds of estimates are needed to support the number of patents to be kept.

There exist still some deficiencies that should be mentioned. The synergies inside the patent groups cannot be widely covered in this study. Also one might question the division of patents based on their technology groups. In some cases the connections between patents could be emphasized more or the groupings could be made for instance based on the final usages. In reckognizing links between patents, some studies also consider some sort of citation analysis (see e.g. Hall et al., 2005). Unfortunately, including these kinds of connections into the program would increase the complexity greatly and also the total approach would need be considered carefully all over again.

7.1.2 Main Assumptions and Open Issues

Every model is a simplification of the real situation and has several basic assumptions behind it. The usefulness of the model can be estimated based on the right depth in details. It is important that the essential details are outlined. Going to very small details is not always necessary or even desirable, because they can make it more difficult to understand the whole picture.

There were also some limitations and problems with the current model. One of the biggest questions was how the discarding or adding patents affected the proportion of the essential patents of the company. It was assumed that the discarded patents were originally so low rated that discarding them did not influence the proportions between the companies, because the proportions were divided based on the proportion of essential patents.

Another assumption was that the companies did not invest tremendously into their portfolio of the similar type during the estimated scenario. This is not a very practical approach, because the empirical case showed that most patents are expired at the end of the scenario. That would state that it is likely that at least some companies invest more into the technology under study, because if most of the patents expire before the scenario reaches its main peak the most revenues will be lost.

There are only two characteristics on which the optimization was based on. Both these attributes are important, but one might still question the fact that the optimization totally relies just on these two attributes. Individual attributes could be changed because of a mischief of some sort, which would change the outcome radically. It would be wise to have more attributes to support the selection process. Fortunately, the potential patents to be discarded are studied more carefully after the selection process, which makes that problem less severe. Still it would be justified to include some reasoning behind the rating to help to check the patent later on.

The examined system was assumed to be isolated from the rest of the world. The amount of patents owned by different companies was expected to be quite stable. There are no big investments, the ratings of the patents do not change and the moves of the competitor's do not influence the business scenarios and the division of the income of a standard. The discarding of patents was expected not to influence much to the proportion of the standard owned by the company. This could be argued reasonable, because the first patents to be discarded were with very low potential of becoming essential patents, and the proportions between companies was defined based on the ownership of essential patents in a standard.

7.1.3 Extendibility of the Results

The main ideas and frameworks can be extended to other cases quite easily. To extend the optimization principles to other patent portfolios, one needs to have some sort of valuation scores for the patents as well as the scenarios for estimating the income created by the patents.

Validity of the results could be improved with another set of data that could be compared with the results of the primary group. Unfortunately, those kinds of comparisons were not possible because there were no such data available to be used in current study. There are still three alternative strategies, which can be compared against each others. They were the results of the low, base and high scenarios.

The model can be used in evaluating also other countries than US. In other countries the payments come on a yearly basis, but it does not affect the working of the algorithm. The main issues can be used also with other patents, even though one needs to consider, how the value is composed of. For instance the patents used in differentiation can differ in value determinants. The main issues like the core of the algorithm can be extended also to other contexts, like valuation of other types of IPR. All that is needed for using the model are specified groupings of the object in the portfolio, estimations for the groupings and an inner logic that defines how the estimations are divided between the objects.

7.2 Discussion about the Study

7.2.1 Evaluation of the Study

Yin (1994) defines the criteria for the judging the quality the of a study as follows: construct validity, internal validity, external validity, and reliability. For construct validity operational measures should be used for the concepts being studied. For internal validity causal relationships should be established, whereby certain conditions are shown to lead to other conditions as distinguished from spurious relationships. External validity describes establishing a domain to which a study's findings can be generalized. Reliability demonstrates that the operations of a study – such as the data collection procedures – can be repeated with the same results.

For constructing validity it is advised to use multiple sources of evidence, establish a chain of evidence and have a key informants review the report (Yin, 1994). For current study the literature has been explored extensively to provide correct information, the different steps of the process have been explained and the intermediate results have been discussed with industry experts. For internal validity this report has been constructed in such a way that the causal relationships are easy to understand and justify. This also helps to repeat the current study if needed. The extendibility of the results has been already discussed in the previous subsection.

Reliability describes the repeatability and consistency of the results (Uusitalo, 1997). In this study it means that when other factors stay the same, the program should give also same kind of results. Also when the main principles are maintained the tool should provide same kind of results. This has been tested with the analysis of how the changing for instance the probabilities affects the final solution. The reliability of the study can be improved by maintaining the chain of evidence (Yin, 1994). This need was quite hard to accomplish, because there was only little knowledge or actual data on the needed indicators so many assumptions needed to be made. These assumptions were described in detail to create understanding why the choices were made as they were which also helped to create repeatability for the study.

Action research was a suitable approach because the iterative process was a very efficient way for constructing new practices. In every stage of the research there were so many directions in which the research could be continued. The intermediate results and discussions also helped to guide the development process through the study. In action research the researcher has a big role during the process. Therefore the researchers can intervene to the results of the study. To avoid the excessive influence the study discussed several times with other people and the results have been documented as objectively as possible.

In the research the cooperation with the managers of the case company played a high role. One might wonder what the incentives of the company are and how they affect the outcome of the study. What comes to the incentives of the case company there are no doubts that they have quite the same intentions because they benefit from the understanding of how their large patent portfolio should be managed. The initial portfolio affected highly to the actual optimization process, because it defined the initial constraints. Still, the model is quite general and it could be used in other cases.

7.2.2 Comparison to Other Studies

There were only two studies that could be found that are close to the studied subject. Sohlman (2002) studied the economic value of patent portfolio. It comes close because the purpose of this study is to maximize the value. In that study she explored cases of two patent families. She used a simple scoring method and evaluated additionally the added value of the explored cases. She divided the managing process into three levels: product level, patent family level and patent level while assessing the value of the patent groups. The other study is made by (Lin et al., 2006), who investigated how the composition and diversity of the portfolio can create synergy, and, thus contribute to the firm performance. They developed a two-level measure to describe diversity and thereafter compared different portfolios against each other. In this study the decision making was divided into three levels, but these levels were different, containing the scenario estimates for business groups, dividing them into technology groups and further on to individual patents. The studies also differ because this study was about managing a large patent portfolio while Sohlman explored and analyzed only two patent families.

Breitzman and Mogee (2002) wrote about the different applications of patent analysis. They introduced different frameworks and metrics that can be used for analysing patents for different purposes, but they did not explore the presented tools in practice so it is difficult to compare it with current study.

Patent selection problems could be compared with project selection problems. Archer and Ghasemzadeh (1999) define the project portfolio selection problem as a periodic activity, where a portfolio is selected from the proposal and existing projects so that they fit to existing objectives without exceeding available resources and violating other constraints. Almost same applies also to patents so patent selection problems could be compared to the studies of project selection studies. There are for instance the studies of Archer and Ghasemzadeh (1999), Ghasemzadeh and Archer (2000), and Liberatore and Titus (1983), just to name a few. Their emphasis was in presenting different frameworks and guidelines that simplify the selection of projects in a project portfolio. The pieces of advice were verbal so translating them into an actual tool would have almost impossible. Also several key characteristics differ in managing patents instead of projects, so comparing the studies with each other is difficult due to the lacking connective factors.

Liesiö et al. (2007b) and Doerner et al. (2004) had a more mathematical approach to the subject and presented ways to optimize the final selection. These kinds of approaches were more interesting even though the presented tools were a bit too sophisticated for current needs. Their approach was more centered to the mathematical approach and reasoning than this study. The approach of current study was a bit more difficult to justify and analyse, because there were no existing results of the studies of the same sort and there were not so many different options or cases to try out. Compared to the mathematical project management approaches, this study was a bit more extensive, because it presented both the managing in the conceptual level as well as building the systematics for supporting the decisions of management.

7.3 Chapter Conclusions

This chapter included the evaluation of current study and its results. The created framework and model were considered to be useful and closely related to the practice. The model and the algorithm were expressed as quite general, which helps to extend them to the rest of the portfolio, other patent portfolios and even other types of IPR. All that is needed are specified groupings, estimations for the groupings and an inner logic that defines how the estimations are divided between the objects.

The different aspects on validity were discussed in the view of current research. The literature has been explored extensively to provide correct information, the different steps of the process have been explained and this thesis has been constructed carefully to improve the validity of the study. The repeatability of the results was already covered in the analysis of the results section in the previous chapter.

Current study was also compared with some other studies of the same field. It was stated that the comparisons to other studies were quite difficult, because there were not so many studies with the same approach than this one.

8 Summary and Conclusions

8.1 Summary

8.1.1 Summary of the Concluded Work

The main objective for current study was to systemize the process of adding and discarding patents. The main emphasis was in the selection process for the patents to be removed in a large patent portfolio. The study also concentrated into US patents used for standardization purposes. The study was conducted as a constructive action research, where the main guidelines and processes were produced and evaluated iteratively and the intermediate results were discussed with industry experts. The theoretical part of the study concentrated on the patent management literature as well as the mathematical background for creating the actual tool. The empirical part was made up of trying to fit the created guidelines and optimization tool into actual practice with an existing patent portfolio.

The first part of the study and this report was about understanding the main characteristics and trends behind the management process. The main interest was to map the essential parameters for the optimization process and understand their reciprocal relations. It was also important to reflect the world behind the decisions. The theoretical background was combined with the practise when the actual portfolio was represented. The patent management part and the information on the existing portfolio were then used in the evaluation of different mathematical tools to be used in the actual optimization program. The same chapter additionally introduced also the backgrounds for the tool to be developed.

After the evaluation process of different mathematical methods, the study presented a model for optimizing the patent portfolio. The model included an optimization algorithm, which picks out patents to be selected for further evaluation in the discarding process. The algorithm also helps to picture how the existing portfolio can answer to the future scenarios, which helps to estimate the needs for new investments. Finally, the created model and the concluded study were discussed and evaluated. The answers to the research questions are discussed in the next section.

8.1.2 Answers to the Research Questions

Systematic management of a large patent portfolio The intention of this study was to systemize the adding and discarding patents of a patent portfolio. The main model was presented in Chapter 5 and it included also an algorithm that can be used for the actual optimization. The main research problem can also be divided into three sub questions, and the approach is covered more in detail in the following sections.

The main characteristics in the management of a large patent portfolio

The main characteristics in the management of a large patent portfolio were explored in chapters two and three. They were constructed from the scientific literature and discussions with experts. The value of the patent grows exponentially so that few patents are very valuable while the most patents are almost worth nothing. In overall, it is beneficial to manage patents in large portfolios, because there exists quite many uncertainties in the validity of a patent and that uncertainty is decreased by having more patents of the same type. The patent portfolio brings a company more freedom to operate, licensing and cross-licensing opportunities, as well as influence in business environment. Most decisions concerned with patents are exclusive; a patent attached to a standard cannot be used for differentiation or the other way round. The chapter three presented a framework (Figure 15, page 40) which introduced the different factors affecting the decisions about the overall patent portfolio. Chapter 5 presented the main principles for organizing patents on based of which it is possible to define a strategy which defined which patents should be discarded and what the time span of the discarding process was.

The systematics for adding or discarding patents in the portfolio

The principles of defining how patents should be added or discarded were explored in chapter four and five. Chapter four concentrated on the mathematical side; the tools that can be used in the actual optimization process. In chapter five the tools were built together and the main model and algorithm was represented. Section 5.1 presents the main guidelines of the optimization process and Section 5.2 presents the actual algorithm in pseudocode.

The selection process for discarding patents was quite thoroughly in the Chapters 3-6. The visualization of both discarding strategy and estimations help to detect the needs for investing in new patents. Sections 5.2.3 and 6.3 presented also a score which helps to estimate the requirements for new patents. What comes to the adding of new patents into the portfolio, the scores that represents the lowest value possible for maintaining patents help to create an overview. A really low score is a good indicator that it would be wise to invest more to that group of patents.

How did the approach work in practice?

The applicability of the defined principles and algorithms were tested in Chapter 6. The approach worked quite well in practice. The algorithm could produce a list of patents that could be examined more in detail for making decisions about discarding them. The program also produced limits which helped to define what kind of conditions for patents are needed to cover their costs. There were also some limitations and problems with the current model. One of the biggest questions was how the discarding or adding patents affected the proportion of the essential patents of the company. It was assumed that the discarded patents were originally so low rated that discarding them did not affect the proportions between the companies. Another assumption was that the companies did not invest much to the studied portfolio during the estimated scenario. This is a more difficult problem to handle, because the practical case showed that most patents are expired at the end of the scenario. If most of the patents are expired before the scenario reaches its main peak it is quite logical to invest more money to new patents of the same kind.

8.2 Main Findings

8.2.1 Contribution to Existing Knowledge

Patent portfolio optimization has not been discussed widely in scientific literature. It is the gap in the existing knowledge where current study tries to provide some answers. This study described one set of principles for managing a large patent portfolio, which is already valuable itself. The approach can be of course further discussed. Current study also provided a framework that defined the main determinants for the making decisions about the keeping or discarding patents from a portfolio.

Important finding is the approach of how patents could be conceptually managed and not the actual program code. The optimizing program is just a prototype: it is created for testing the basic ideas in practise rather than being an actual program that could be used for decision making purposes. This characteristics can be seen for instance the interface of the program, which is not designed for continuous use. As the whole, ideas presented in the code can be used when making a working program.

The main optimization algorithm is a modification of the Greedy algorithm, which is one of the basic algorithms in computer science. This study has brought the algorithm a new purpose of use in the management of intellectual property. The core of the algorithm is built as in a way that it can be easily extended to be used also in other cases if they contain groupings, estimations for groupings and an inner logic based on which the estimates can be divided down to individual objects.

8.2.2 Implications to Managerial Practices

This study presented a framework for managing large patent portfolios which helps to clarify the main systematics in the management of a large patent portfolio. The framework and guidelines help to concentrate on the most relevant issues in the management process. The study also presented an actual algorithm that can be used for selection of discarded patents from the portfolio. It does not make the choices for the decision maker, but it can decrease the number of patents to be explored. This can help the evaluation process of the decision maker in practise. Additionally, it is much easier to get an overview of the portfolio and make the discarding decisions based on it. The program can also help to recognize the need of new investments in a specific scenario. These improvements can help the management process in practise.

This study constructed guidelines for managing the adding and discarding processes of the portfolio. These were quite specific and closely related to the practice. The main principles were tested with the optimization of a part of the patent portfolio, and it seemed to work fine. It would not take much more effort to try to optimize also the rest of the portfolio with the algorithm.

8.3 Recommendations

What comes to the existing portfolio, there are some propositions for developing the existing data. It was difficult to estimate the development of the patent during time, because there was not much historical information on the subject. Additionally, it was difficult to see the reasoning behind the different ratings of the patent. Therefore it would be advisable to collect historic data and add justifications for the rating of the patent. Historical data would help to find existing trends and explore the development of the portfolio afterwards. Historical information cannot give the exact pattern how new patents develop for certain, but they give information on how they can develop, which can be used to get more knowledge on the existing patent portfolio. Reasoning for the patent rating would help to return to the patent later on and evaluate its usefulness more quickly. The changes to the ratings would also be more understandable that way.

The optimization algorithm presented a set of patents that could be discarded. These patents could be studied further on for making the final decision about keeping or discarding the patents. The scenarios also showed that there are only few patents left at the time when the revenue is expected to be the highest. Hence, it would be recommendable to study the possibilities to invest more to the patents of the studied group.

Systematization of the patent managing process can be helpful for decision support. The tool produced in this study was only a prototype, which was used to test different approaches and practises. It cannot be directly used by managers facing the issues of discarding patents or adding patents to the portfolio. The construction of an actual program could be useful for the practice, because it would simplify the evaluation process of the patents and it would also be easier to create an overview on the studied portfolio.

8.4 Topics for Further Study

In this study the synergy effects were covered only briefly. It would be interesting to study a portfolio in which the synergy effects of the patents play a bigger role than in this study. That is because the synergy effect actually creates limitations and constraints for the optimization process. It would also be interesting to test the algorithm with a bigger set of data with different estimations. Also the different discarding and adding strategies of existing players could be studied more in detail. For instance the effects of the competitors choices affect the optimal discarding study would be an interesting field for a new study.

The reasons for adding patents into the portfolio have not been studied much so a deeper analysis about adding patents so that they fit the existing patent strategies could be useful. Competitive environment is important factor in the patent management. Strategy games in which there are several players with own patent portfolios and expectations would help to indicate the optimal patent strategy for a more holistic view on the subject.

The examined system was assumed to be isolated from the rest of the world and the development of the patents was supposed to be quite stable. There are no big investments, the ratings of the patents do not change and the moves of the competitor's do not affect the business scenarios and the division of the income of a standard. These are all factors that could be studied more in details to understand the underlying phenomenon better. The development of one patent affects highly to the development of the whole portfolio, big investments can affect the royalty division between the companies and the moves of competitors also can have a big influence on the optimal discarding and adding strategy. Studying these factors would provide understanding on how sensitive the given results are from the conditions in the competitive environment.

References

Andriessen, D. (2004). *Making Sense of Intellectual Capital: Designing a method for the valuation of intangibles*, Elsevier, USA.

Archer, N. P., Ghasemzadeh, F. (1999). "An Integrated Framework for Project Portfolio Selection," *International Journal of Project Management*, vol. 17, no. 4, pp. 207–216.

Avison, D., Lau, F., Myers, M., Nielsen, P. A. (1999). "Action Research," *Communications of the ACM*, vol. 42, no. 1, pp. 94–97.

Bekkers, R., Verspagen, B., Smits, J. (2002). "Intellectual property rights and standardization: the case of GSM," *Telecommunications policy*, vol. 26, pp. 171–188.

Breitzman, A. F., Mogee, M. E. (2002). "The Many Applications of Patent Analysis," *Journal of Information Science*, vol. 28, no. 3, pp. 187–205.

Cohen, W. M., Nelson, R. R., Walsh, J. P. (2000). "Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (Or Not)," in *NBER Working Paper Series*, vol. 7552, pp. 1–31.

Corana, A., Marchesi, M., Martini, C., Ridella, S. (1987). "Minimizing Multimodal Functions of Continuous Variables with the "Simulated Annealing" algorithm," *ACM Transactions on Mathematical Software*, vol. 13, pp. 262–280.

Cormen, T. H., Leiserson, C. E., Rivest, R. L. (1997). *Introduction to Algorithms*, 18th edn., MIT Press, Massachusetts, USA.

Doerner, K., Gutjahr, W. J., Hartl, R. F., Strauss, C., Stummer, C. (2004). "Pareto Ant Colony Optimization: A Metaheuristic Approach to Multiobjective Portfolio Selection," *Annals of Operations Research*, vol. 131, pp. 79–99.

Eisenhardt, K. M. (1989). "Building Theories from Case Study Research," *The Academy of Management Review*, vol. 14, no. 4, pp. 532–550.

Feldman, R. P., Rees, M. L., Sonsini, W., Townshend, B. (2000). “The Effect of Industry Standard Setting on Patent Licensing and Enforcement,” *IEEE Communications Magazine*, vol. 38, no. 7, pp. 112–116.

Flythström, J. (2006). “Impact of Patent Licensing Policies on Technology Business,” Master’s thesis, Helsinki University of Technology, Espoo, Finland.

Frain, T. (2006). “Patents in Standards & Interoperability,” World Intellectual Property Organization, 29 November 2006, also available as: http://www.wipo.int/patent/colloquia/en/2006/11/pdf/frain_paper.pdf, referenced on 27.6.2007.

Gallini, N. T. (1992). “Patent Policy an Costly Imitation,” *The Rand Journal of Economics*, vol. 23, no. 1, pp. 52–63.

Ghasemzadeh, F., Archer, N. P. (2000). “Project portfolio selection through decision support,” *Decision support systems*, vol. 29, pp. 73–88.

Goffe, W. L., Ferrier, G. D., Rogers, J. (1994). “Global optimization of statistical functions with simulated annealing,” *Journal of Econometrics*, vol. 60, pp. 65–99.

Goodman, D. J., Myers, R. A. (2005). “3G Cellular Standards and Patents,” in *Wireless Networks, Communications and Mobile Computing*, vol. 1, pp. 415–420.

Hall, B. H., Jaffe, A., Trajtenberg, M. (2005). “Market value and patent citations,” *The Rand Journal of Economics*, vol. 36, no. 1, pp. 16–38.

Hall, B. H., Ziedonis, R. H. (2001). “The patent paradox revisited: an empirical study of patenting in the U.S. semiconductor industry, 1979-1995,” *The Rand Journal of Economics*, vol. 32, no. 1, pp. 101–128.

Hanne, T. (2001). *Intelligent strategies for meta multiple criteria decision making*, Kluwer Academic Publishers, Massachusetts, USA.

Hörmann, W., Leydold, J., Derflinger, G. (2004). *Automatic Nonuniform Random Variate Generation*, Statistics and Computing, Springer Verlag, Germany.

Jaffe, A. B., Lerner, J. (2004). "Patent Prescription: a radical cure for the ailing[US patent policy]," *IEEE Spectrum*, vol. 41, no. 12, pp. 38–43.

Johnson, D. S., Aragon, C. R., McGeoch, L. A., Shevon, C. (1989). "Optimization by Simulated Annealing: An Experimental Evaluation; Part 1, Graph Parititioning," *Operations Research*, vol. 37, no. 6, pp. 865–892.

Kaplan, R. S. (1998). "Innovation Action Research: Creating New Management Theory and Practice," *Journal of Management Accounting Research*, vol. 10, no. 1, p. 89.

Kasanen, E., Lukha, K., Siitonen, A. (1993). "The constructive approach in management accounting research," *Journal of Management Accounting Research*, vol. 5, p. 243.

Kortum, S., Lerner, J. (1999). "What is behind the recent surge in patenting," *Research Policy*, vol. 28, no. 1, p. 1.

Koski, H. (2002). "Technology policy in the telecommunication sector; Market responses and economic impacts," *Tech. Rep. 8*, European Comission, also available as: http://ec.europa.eu/enterprise/library/enterprise-papers/paper8.htm, referenced on 6.5.2007.

Lanjouw, J. O. (1998). "Patent Protection in the Shadow of Infringement: Simulation Estimates of Patent Value," *The Review of Economic Studies*, vol. 65, no. 4, pp. 671–710.

Lemley, M. A., Shapiro, C. (2005). "Probabilistic Patents," *Journal of Economic Perspectives*, vol. 19, no. 2, pp. 75–98.

Leppiniemi, J., Puttonen, V. (2002). *Yrityksen rahoitus*, Ekonomia, 2nd edn., WSOY, Porvoo, Finland.

Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G. (1987). "Appropriating the Returns from Industrial Research and Development," *Brooking Papers on Economic Activity*, vol. 1987, no. 3, Special Issue on Microeconomics, pp. 783–831.

Levitin, A. (2003). *Introduction to Design & Analysis of Algorithms*, Addison Wesley, USA.

Liberatore, M. J., Titus, G. J. (1983). "The Practice of Management Science in R&D Project Management," *Management Science*, vol. 29, no. 8, pp. 962–974.

Liesiö, J., Mild, P., Salo, A. (2007a). "Preference programming for robust portfolio modeling and project selection," *European Journal of Operational Research*, vol. 181, no. 3, pp. 1488–1505.

Liesiö, J., Mild, P., Salo, A. (2007b). "Robust Portfolio Modeling with Incomplete Cost Information and Project Interdependencies," Also available as: http://www.sal.hut.fi/Publications/pdf-files/mlie06.pdf, referenced on 6.5.2007.

Lin, B.-W., Chen, C.-J., Wu, H.-L. (2006). "Patent Portfolio Diversity, Technology Strategy, and Firm Value," *IEEE Transactions on Engineering Management*, vol. 53, no. 1, p. 17.

Mansfield, E., Schwarz, M., Wagner, S. (1981). "Imitation Costs and Patents: An Empirical Study," *The Economic Journal*, vol. 91, no. 364, pp. 907–918.

Mazzoleni, R., Nelson, R. R. (1998). "The benefits and costs of strong patent protection: a contribution to the current debate," *Research Policy*, vol. 27, no. 3, p. 273.

Miranda, V., Proenca, L. M. (1998). "Probabilistic choice vs risk analysis - conflicts and synthesis in power system planning," *IEEE Transactions on power systems*, vol. 13, no. 3, pp. 1038–1043.

Pakes, A. (1986). "Patents as Options: Some Estimates of the Value of Holding European Patent Stocks," *Econometrica*, vol. 54, no. 4, p. 755.

Parchomovsky, G., Wagner, R. P. (2005). "Patent Portfolios," *University of Pennsylvania Law Review*, vol. 154, no. 1, pp. 4–16, also available as: http://ssrn.com/abstract=874445, referenced on 6.5.2007.

Pearl, J. (1986). "Fusion, Propagation, and Structuring in Belief Networks," *Artificial Intelligence*, vol. 29, pp. 241–288.

Pitkethly, R. H. (2001). "Intellectual property strategy in Japanese and UK companies: patent licensing decisions and learning opportunities," *Research Policy*, vol. 30, pp. 425–442.

Reilly, R. F., Sweichs, R. P. (1998). *Valuing Intangible Assets*, McGraw-Hill Books, USA.

Schankerman, M. (1998). "How Valuable is Patent Protection? Estimats by Technology Field," *The RAND Journal of Economics*, vol. 29, no. 1, pp. 77–107.

Schankerman, M., Pakes, A. (1986). "Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period," *The Economic Journal*, vol. 96, no. 384, pp. 1052–1076.

Scherer, F. (1965). "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions," *The American Economic Review*, vol. 55, no. 5, pp. 1097–1125.

Scherer, F., Harhoff, D. (2000). "Technology Policy for a World of Skew-distributed Outcomes," *Research Policy*, vol. 29, pp. 559–566.

Schmoch, U. (1999). "Impact of international patent applications on patent indicators," *Research Evaluation*, vol. 8, no. 2, pp. 119–131.

Shapiro, C. (1985). "Patent Licensing and R & D Rivalry," *The American Economic Review*, vol. 75, no. 2, pp. 25–30.

Shear, R. H., Kelley, T. E. (2003). "A researcher's guide to patents," *Plant Physiology*, vol. 132, no. 3, pp. 1127–1130.

Sherry, E. F., Teece, D. J. (2004). "Royalties, evolving patent rights, and the value of innovation," *Research Policy*, vol. 33, no. 2, pp. 179–191.

Sohlman, P. (2002). "A Tool for Determining the Economic Value of Patents," Master's thesis, Helsinki University of Technology, Espoo, Finland.

Soininen, A. (2003). "Suomen ICT-sektorilla toimivien yritysten patenttistrategioita koskevien haastattelujen tulokset," in *Digital Economy Core Project (De Core): structures of mobile digital economy*, editor A. Soininen, Helsinki Institute of Information Technology, pp. 110–123, also available as: http://www-old.hiit.fi/de/core/HIIT_DE_Core_Final_Report_20041231.pdf, referenced on 6.5.2007.

Soininen, A. (2004). "Patent Strategies in the ICT Industry," *Tech. rep.*, Helsinki Institute of Information Technology, also available as: http://www-old.hiit.fi/de/core/HIIT_DE_Core_Final_Report_20041231.pdf, referenced on 6.5.2007.

Soininen, A. (2005). "Open standards and the problem with submarine patents," in *SIIT 2005 Proceedings*, IEEE, pp. 218–231, also available as: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1563810, referenced on 6.6.2007.

Spall, J. C. (2003). *Introduction to stochastic search and optimization: estimation simulation, and control*, Wiley, New Jersey, USA.

Susman, G. I., Evered, R. D. (1978). "An Assessment of the Scientific Merits of Action Research," *Administrative Science Quarterly*, vol. 23, no. 4, pp. 582–603.

Taha, H. A. (1992). *Operations Research An Introduction*, 5th edn., Macmillan Publishing Company, New Jersey, USA.

Teece, D. J. (2000). "Strategies for Managing Knowledge Assets: the Role of Firm Structure and Industrial Context," *Long Range Planning*, vol. 33, pp. 35–54.

USPTO (2006). *U.S. Patent Statistics Chart Calendar Years 1963-2006*, U.S. Patent and Trademark Office, also avaialable as: http://www.uspto.gov/web/offices/ac/ido/oeip/taf/us_stat.htm, referenced on 3.9.2007.

Uusitalo, H. (1997). *Tiede, tutkimus ja tutkielma: johdatus tutkielman maailmaan*, 4th edn., WSOY, Helsinki, Finland.

Webber, A. M. (2000). "New Math for a New Economy," *Fast Company*, vol. 31, p. 214.

Westbrook, R. (1995). "Action Research: a new paradigm for research in production and operations management," *International Journal of Operations & Production Management*, vol. 15, no. 12, pp. 6–20.

WIPO (2007). *PCT Applicant's Guide*, World Intellectual Property Organization, also available as: http://www.wipo.int/pct/guide/en/, referenced on 4.5.2007.

Wright, D. J. (1999). "Optimal patent breadth and length with costly imitation," *International Journal of Industrial Organization*, vol. 17, pp. 419–436.

Yamada, H. (2006). "Patent Exploitation in the Information and Communication Sector - Using Licensing to Lead the Market," *Science and Technology Trends Quarterly Review*, vol. 19, pp. 11–21.

Yin, R. K. (1994). *Case Study Research: Design and Methods*, Applied social research methods series, 2nd edn., SAGE Publications, Thousands Oaks, CA, USA.

Zeleny, M. (1982). *Multiple Criteria Decision Making*, McGraw-Hill Inc, USA.

A Appendix: Parts Of Program Code

The most important methods are listed below. First is the main optimization method and after that is the method that divides the proportions of scenario to individual patents.

```
/**
* Optimizes the portfolio
* @param scenario scenario values for periods in table form
* @param patents patent table
* @param proportion is the proportion of essential patents owned by the company
*/
public double optimize(double[] scenario, Patent [] patents, double proportion){

        int [] keptPatents = new int[scenario.length];
        double [] patentValues = calculateValues(patents);
        double [][] patentProportions = countProportions(patentValues, proportion);
        ArrayList<Integer> discardedIndeces = new ArrayList<Integer>();
        ArrayList<Patent> discardedPatents = new ArrayList<Patent>();
        ArrayList<Integer> discardedPeriods = new ArrayList<Integer>();
        int period;
        ArrayList<Double> prevCosts;
        //counting the period where each patent expires
        int [] discardedPeriod = countAging(patentTable, scenario.length);
        double patValue;
        double patCosts;
        double patTotalValue;
        double portfolioValue =0;
        int per;

        for(int pat = patentTable.length-1; pat >= 0; pat--){

                period = discardedPeriod[pat];
                patValue = 0;
                patTotalValue = 0;

                while(period >= 0){
                        prevCosts = previousCosts(patentTable[pat].getAge(), period);
                        for(per = period-(int)prevCosts.get(2).doubleValue(); per <= prevCosts.get(3).doubleValue();per++){

                                patValue += (patentProportions[per][pat]*(period+1)*scenario[per])/Math.pow(1.15, per);
                        }

                        patCosts = prevCosts.get(1).doubleValue()/Math.pow(1.15,period-(int)prevCosts.get(2).doubleValue());
                        patTotalValue += patValue - patCosts;
                        if(patValue < patCosts) {//discard patent?

                                if(patTotalValue < 0){//patent to be discarded in current period
                                        patTotalValue = 0;
                                        discardedPeriod[pat] = period-(int)prevCosts.get(2).doubleValue();
                                        //discard patents

                                        discardedPatents.add(patentTable[pat]);
                                        discardedPeriods.add(discardedPeriod[pat]);
                                        discardedIndeces.add(pat);
                                }

                        }
```

```
                        //change to next period
                        period -= (int)prevCosts.get(2).doubleValue()+1;

                }
                portfolioValue += patTotalValue;
        }

       //discarded patents now listet in discPat-table and periods in discardedPeriods

        return portfolioValue;

}
```

Patent proportion calculations

```
/**
* @param patentValues the values in patent table from the initial age/rating table
* @param proportion the proportion of essential patents
*/
public double[][] countProportions(double [] patentValues, double proportion){

        double[][] proportions = new double[15][patentValues.length];
        double[] totalValues = countTotalValues(patentValues);

        for(int period = 0; period < 10;period++)
                for(int i = 0; i < proportions[0].length; i++){

                         proportions[period][i] = patentValues[i]*proportion*(period+1)/totalValues[period];
                }

        //the end of the 10 years the probability to develop into essential
        //does not evolve anymore
        for(int period = 10; period < proportions.length;period++){
                for(int i = 0; i < proportions[0].length;i++){
                        proportions[period][i] = proportions[9][i];
                }
        }

        return proportions;
}
```