A Framework to Determine the Potential for Success of New Medical Robotic Products

Assessment by Cooper Scoring Model and TOPSIS Analysis

Student:
J.R. Wiyandini

Supervisors:
J.M. Hummel, Dr. (University of Twente)
K. Markiewicz (University of Twente)
A. van Breemen (ASML)

ASML

UNIVERSITY OF TWENTE.

MASTER THESIS – HEALTH SCIENCES

A Framework to Determine the Potential for Success of New Medical Robotic Products

Assessment by Cooper Scoring Model and TOPSIS Analysis

Name: Jelita Ratna Wiyandini
Student number: S1323334
E-mail: jeje.jelita@gmail.com
Date: August 2014

ASML UNIVERSITY OF TWENTE.

Primary supervisor:
Dr. J. M. Hummel
Assistant professor
Health Technology and Services Research | University of Twente

Secondary supervisor:
K. Markiewicz
PhD candidate
Health Technology and Services Research | University of Twente

External Supervisor:
A. van Breemen
(Business Development/Product Marketing Manager)
ASML

Executive Summary

Background - At the early years of the 21st century, the introduction of innovative medical technology was in an increasing trend. One of the emerging medical technologies that are currently available in healthcare fields are robotic devices. Medical robotic systems have already brought a lot of improvisations in existing medical procedures such as the development of less-invasive medical procedures to produce fewer side effects and faster recovery times. Introducing innovation in healthcare such as idea, practice, or product is widely recognized as a complex process. As innovations are central to business prosperity, the industries and companies try to rapidly develop new technologies to create new and fierce competition. ASML – a mechatronic company, saw a potentially promising business within this field. ASML needs to have some certain indication if the type of new medical robotic products that they are going to produce will have a chance to succeed on the healthcare market. Therefore, this research project is conducted in a collaboration between ASML and University of Twente. ASML wants to analyze the most attractive surgical robotics present on the market to discover new medical robotic products with a large market and low entry barriers.

Objective/Research Question - To assess the likely success of medical robotic innovations; supporting the investment decision of ASML in medical robotics. Four research questions are formulated in order to achieve the research objectives: *1. Which diseases or treatments have the largest clinical market?; 2. Which medical robotic products are currently available in healthcare?; 3. Which diseases or treatments that have the largest clinical market could be successfully addressed by medical robotic products?; 4. Which medical robotic devices for which diseases or treatments fit the core competences of ASML?*

Methods - A thorough literature review was undertaken in order to identify the size of market for new medical robotic device, as well as to find out which diseases that will be better and have more value to patient if the treatments were supported by robotic devices. Afterwards, an interview with expert was conducted in order to validate the findings from literature review. Finally, a scoring model based on the work by Cooper (1985) in combination with success factors in healthcare field by Fleuren (2004) was used. To do the scoring, we had to collect information from internet about several medical robotic devices that have been successful in entering the healthcare market. Afterwards, the scoring model was quantified using TOPSIS method to calculate the likelihood of success of the alternative medical robotics.

Results – After taking the literature review by using several internet search engines and doing an interview with an expert for validation, we found out five diseases and treatments as the largest clinical market. We also found out nine robotic cases as alternatives to be compared in the Cooper scoring models. Those nine robotic cases are Da Vinci System, the Flex System, SPORT, and SPIDER for minimally invasive surgery procedures, ARTAS for hair transplantation, Sensei and Magellan System for intravascular surgery, Cyberknife System for radiosurgery, MAKOplasty for knee and hip replacement surgery, and PRECEYES for eye surgery (microsurgery). Finally, after scoring each alternative by Cooper scoring model and quantifying it with TOPSIS analysis, we got top four robotic alternatives that had the highest results and could be considered by ASML in order to support the investment decision of ASML in medical robotics.

Conclusion/Recommendation – The assessment by Cooper scoring models and TOPSIS analysis method resulted four alternatives as the most ideal devices that could bring success to ASML including Da Vinci, SPORT, Cyberknife, and PRECEYES. However, we chose Da Vinci as the final recommendation for ASML based on the rough calculation of total gross revenue per year that were influenced by several factors such as the number of target group and the estimated selling price. There are three key points that have to be highlighted by ASML in order to enter such market: (a) cost, (b) technology or functionality, and (c) intellectual property. Accordingly, we recommend ASML to develop a surgical robotic device that has an advanced technology, less expensive, and easy to operate.

Acknowledgements

My special thanks goes to my first supervisor: Marjan Hummel. She is a really nice person, who is very helpful yet patient in supervising me day by day. She is one of the most important persons for me in doing this thesis project. I also thank my second supervisor: Kasia Markiewicz. Even though we met in the last time of this project, but your advice and feedback was very meaningful for my thesis writing. My gratitude also goes for my external supervisor: Albert van Breemen. If he did not push me to make some progresses every week, maybe this thesis would not finish on time. Also, thanks to Sophie van der Voort, the bachelor student that worked together with me in this project. She did a great job and always helped me when I needed it.

I thank my beloved parents that separated miles away with me, but never stop supporting and praying for me. Also my beloved little brother and sister, Hendra and Tari for their constant encouragements. They are really the true love of my life that I am grateful for.

I am also very thankful for friends and colleagues that always support and cheer me up during my study journey: (a) my very best friend here, Cikos and Karen, who have always been supporting me through my ups and downs; (b) my best friend in Master class, Jamie, who has been very kind to me in every way; (c) A*nak Rantau* friends: Rindia, Citra, Anggasta, Inov, Riza, Iwan, and the others; (d) The Bandids members whom I always had fun with when I needed an escape from thesis madness; (e) *Warung Rahardjo* family: Okta, Kang Opik, Ari, Mas Tyo, and Mas Apri, who always shared laugh, warmness, and also food every time I needed it; (f) all PPI Enschede friends; (g) Tiwi, Kopi, Acong, Salome, and all high school best friends, I cannot wait to meet you all; (h) all my best friends from Dentistry Unpad. I might be forgotten to put some names in this piece of paper, but I always remember you and I am grateful for your presence, dear all my friends.

After all, my deepest gratitude goes to Allah that has written this beautiful destiny for me. His blessing for me is uncountable and priceless. He surrounds me with beloved people that supports every steps and decisions I made in life. *Alhamdulillah*. Thank you Allah for this beautiful journey, and for Your surprise in this summer. I know, Your timing is never wrong.

Enschede, August 2014

Table of Contents

Table of Tables

Table of Figures

1. Introduction

The first chapter provides an introduction of this study. It consists of: the background of this project in section 1.1, a brief description of the ASML Company in section 1.2, a description of the problems that would be tackled in this study in section 1.3, the main research objective and research questions in section 1.4 and 1.5 respectively, and finally the research design that consists of the methods to answer the research questions is formulated in section 1.6.

1.1 Background

At the early years of the 21st century, the introduction of innovative medical technology was in an increasing trend. Innovations in medical technology are growing rapidly. It is driven by scientific and economic interests and value to public health (Bakker & Roszek, 2007). One of the emerging medical technologies that are currently available in healthcare fields are robotic devices. To date, robots are being used in many domains such as manufacturing, services, healthcare, defense, and space. Medical robotic systems have already brought a lot of improvisations in existing medical procedures such as the development of less-invasive medical procedures to produce fewer side effects and faster recovery times. It also could improve worker productivity, as well as risk-benefit and cost-benefit ratios (*A Roadmap for U.S. Robotics*, 2013).

During the last quarter of the 20th century, there has been a shift of paradigm in the surgical approaches. Many procedures have reduced the invasive techniques because of the adverse events. The trauma involved in gaining access to the intended area is considered to be the main cause of pain, discomfort, and other morbidity rather than the surgical procedure itself (Mack, 2001). Thus, less invasive medical procedures are the paradigm that is happening in surgical procedures, nowadays.

The idea behind the development of surgical robotics was the premise that higher speed and accuracy could be achieved in surgery (Gomes, 2011). Higher speed could make the surgery faster, and higher accuracy will make the recovery faster and will lower the chance of adverse effects as well. Sol, Garos, van der Helm, & de With (2012) confirmed those statements by reporting that the quick recovery after treatment is economically attractive since it impacts to shorten hospitalization, early rehabilitation, a quick return to normal activities, and also reduced labor time for the hospital staffs. Therefore, the developments in minimally invasive surgery (MIS) seems to be the most important innovations and trends in healthcare industry recently, and robotic are expected to impact the field of MIS.

Introducing innovation in healthcare such as idea, practice, or product is widely recognized as a complex process. There are several positive or negative factors affecting this process. However, sometimes changes do not occur because the health professionals could not accept it, or there is no financial support to implement these changes (Fleuren, Wiefferink, & Paulussen, 2004). Cooper (1994) defined success factors of new product as the drivers of the product to succeed, and how these drivers can be translated into managerial actions. As innovations are central to business prosperity, the industries and companies try to rapidly develop new technologies to create new and fierce competition, and the ultimate winner are the management that could improve the effectiveness and time efficiency of their new product (R. G. Cooper, 1994).

ASML – a mechatronic company, saw a potentially promising business within this field. By the end of 2013, they came to University of Twente to ask for a work collaboration to analyze the chance of success of a new medical robotic products that they were about to produce. Eventually, this project was started on February 2013 involving one master student and one bachelor student.

1.2 Company Profile

ASML is a world leader in the manufacturing of advanced technology systems for the semiconductor industry. ASML was founded in the Netherlands in 1984. ASML's corporate headquarter is located in Veldhoven, the Netherlands. The manufacturing sites as well as research and development facilities are located in Connecticut, California, Taiwan, and the Netherlands. Technology development centers and training facilities are located in japan, Korea, the Netherlands, Taiwan, and the United States. Overall, ASML has more than 70 locations in 16 countries.

ASML manufactures complex machines that are critical to the production of integrated circuits or chips and have become the worldwide leading provider of lithography systems for the semiconductor industry since 2002.

The complexity of producing integrated circuits with more functionality increases in each generation. The company design, develop, integrate, market, and service advance systems used by customers to create chips that power a wide array of electronic, communications, and information technology products. ASML is also committed to provide customers with leading edge technology that is production-ready at the earliest time.

1.3 Problem Description

As an expert in mechatronic – a design process that includes a combination of mechanical engineering, electrical, telecommunication, control, and computer engineering, ASML upholds the complexity design of the machines to have a competitive advantages in market in order to prevent competitors to easily enter the area of business. Currently, ASML is exploring the opportunity to expand their product focus to the robotics field on the basis of product complexity and differentiation.

At first, there were three robotic fields that were included into ASML's consideration such as manufacturing robotics, professional service robotics, and medical robotics. According to the company presentation from February 2014, ASML stated that there were three trends of innovation in robotics currently: (1) innovation that has low cost computation, sensors and actuators, (2) innovation that is driven by mechatronic and system integration, and (3) innovation that needs software and cloud computing. Only point number two and three that was fit with ASML's profile. They argued that medical robotics has complex technology that fits ASML's core competency as mechatronic company. Besides, the medical robotics have high average sales price (ASP) and a large growing market that fits ASML as a large scope company. Thus, ASML decided that medical robotics was the area that fit its profile the best.

However, ASML needed to have some certain indication if the type of new medical robotic products that they are going to produce will have a chance to succeed on the healthcare market. This consideration was strengthen by the conclusions drawn by Cooper t (1985) that a company will always face difficulties and uncertainties in launching new products, and in average there are only 60 from 100 companies succeed in the market when launching new products (R. Cooper, 1985; Crawford, 1979; Hopkins, 1980). Hence, ASML considers to do market analysis first before starting the development of new robotic products to see the market's need and size for such products, as they do not want to end up regretting spending millions of dollars on something not-profitable and unworthy.

Therefore, this research project was conducted in a collaboration between ASML and University of Twente. ASML wanted to analyze the most attractive surgical robotics present on the market to discover new medical robotic products with a large market and low entry barriers. After that analysis ASML would like to start developing the technology that has the biggest capabilities to make a difference in healthcare and also the highest profit potential for the company. This project was also conducted in the collaboration with a bachelor student that concentrates on the analysis of the economic attractiveness of medical robotic products for ASML.

1.4 Main Objective

To assess the likely success of medical robotic innovations; supporting the investment decision of ASML in medical robotics.

1.5 Research Questions

In order to achieve the main objective of this research, four research questions are formulated as follows.

1. Which diseases or treatments have the largest clinical market?
2. Which medical robotic products are currently available in healthcare?
3. Which diseases or treatments that have the largest clinical market could be successfully addressed by medical robotic products?
4. Which medical robotic devices for which diseases or treatments fit the core competences of ASML?

1.6 Research Design

With regard to research questions, some methods are being proposed to answer those questions.

RQ 1: "Which diseases or treatments have the largest clinical market?"

To identify the size of the market for new medical robotic products, first the incidence of the disease must be specified and after that the costs of the disease treatment, as a healthcare expenditure in US and UK. A literature review will be conducted to get the necessary information by using internet search engines such as Pubmed, Google Scholar, and Google. The findings will be validated through an interview with expert in robotic and healthcare field. Finally, the results will be combined and the conclusion for the most promising market will be made.

A chart overview as shown in Figure 1 was made regarding this study design. This analysis leads to the new product development and contains of two steps. Step 1: analysis of the major healthcare expenditures on diseases. This process aims to find out the clinical market for the product, as abovementioned. In order to enter the market, we can do either the incremental changes with the existing medical procedures, or make the radical changes with creating new medical procedures. Step 2: analysis of existing medical robots and the presentation of the robots. This process aims to find out the competition of the products. The presentation of medical robots were assessed by the ability to provide the medical technology requirements such as manipulation (instruments, radiation, drugs), vision (x-ray, MRI, echo, camera), and diagnostics system.

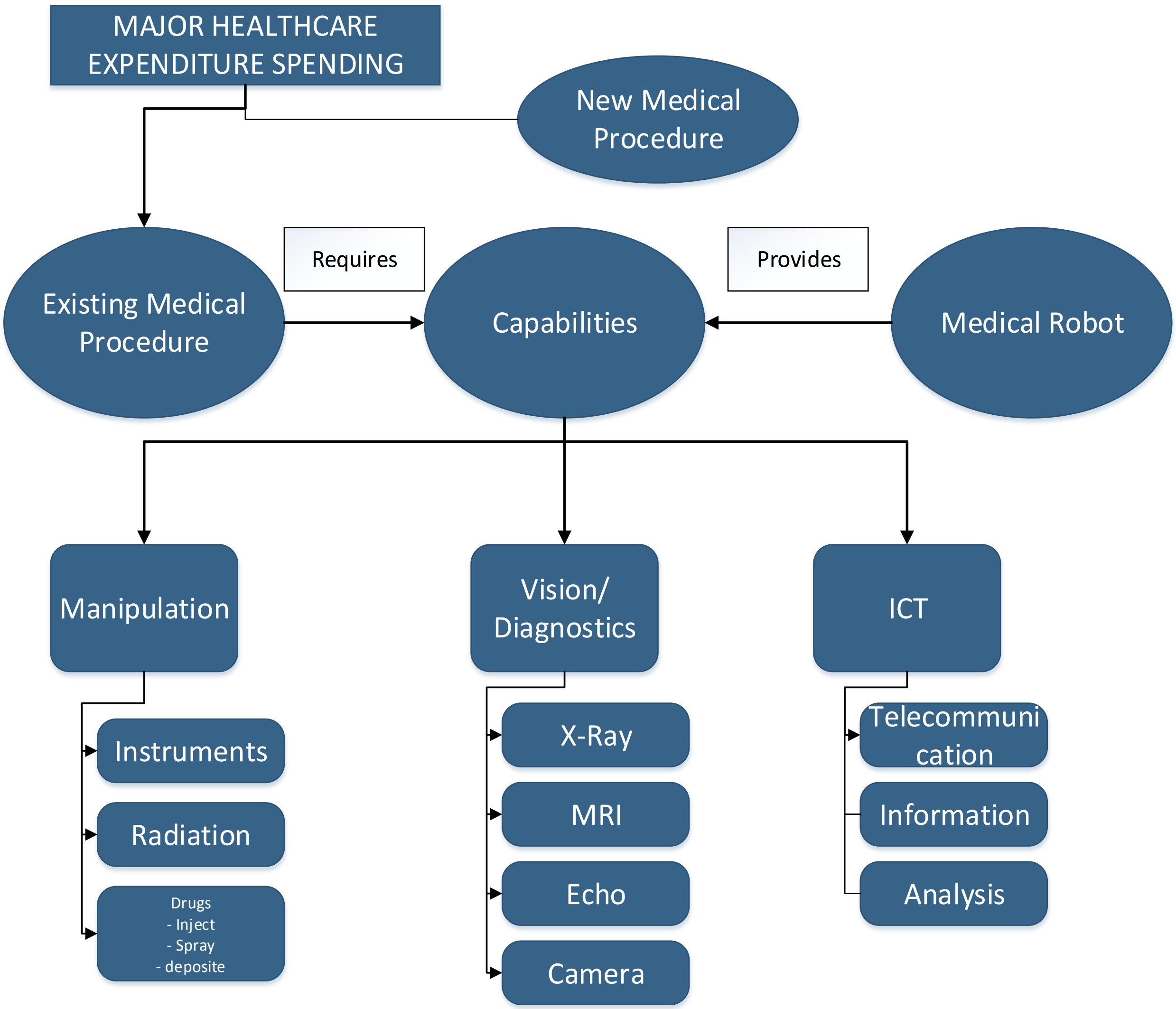

Figure 1 An overview of analysis leading to the new product development

RQ 2: "Which medical robotic products are currently available in healthcare?"

The next step is to collect information about medical robotic products that are currently available in the healthcare market through using internet search engines: Pubmed, Google Scholar, and Google. The results of this step will be used as comparison variables in Cooper scoring model.

RQ 3: "Which diseases or treatments that have the largest clinical market could be successfully addressed by medical robotic products?"

After figuring out the answers of the first and second RQs, we classify the diseases that could be better treated and have more value to patients if supported by robotic devices. We called this step as product-market combinations (PMC). To find out the answers of this question, a literature review will also be undertaken and interview with an expert will be held. We will interview Prof. Ivo Broeders - a robotic professor and surgeon, to validate our findings based on his experience as a practitioner. Afterwards, the results will be used as the basic information for Cooper scoring model that will be done in the next phase.

We used a scoring model developed by Cooper (year) to estimate the likelihood of success for a new medical robotic products when entering a specific market. This model has already been validated and used in many firms to predict whether a new product will be succeed or fail in market. To do the calculation, we first have to validate the model of several cases of robotic devices that have been successful in entering the healthcare market. Subsequently, we scored the likelihood of success of a new robotic product that ASML wants to produce.

Afterwards, the scoring model will be quantified using TOPSIS method. TOPSIS is an abbreviation of Technique for Order Performance by Similarity to Ideal Solution and a part of multi-criteria decision analysis (MCDA). We used TOPSIS to calculate the likelihood of success of the alternative medical robotics, based on the scores we given on Cooper scoring model. A higher calculation result suggests a higher likelihood of success. We chose TOPSIS in order to screen technological opportunity to gain general overview. Besides, this method requires only a minimal number of inputs from the user and its output is easy to understand, which is fit with this research project situation.

Combining Cooper scoring models and TOPSIS analysis has never been done before. Original Cooper scoring model needs questionnaires to score the factors and sophisticated qualitative analysis that involving some experts in it, which is not possible for this project. Thus, we decided to use more simple approach, and TOPSIS seems to suit the condition of this project.

RQ 4: "Which medical robotic devices for which diseases or treatments fit the core competences of ASML?"

This last question is addressed when we can predict for ASML if a new robotic product is likely to become successful. In essence, the answer of this question is the conclusion based on the results, primarily of the third research question. Accordingly, the recommendation to ASML will be made.

1.7 Overview of the study

This study is divided into seven chapters. The first chapter is the introduction describing the project's background, company profile of ASML, study problem, research objective, research questions, research design, and the overview of this study. The second chapter provides an overview of theoretical framework regarding trends in medical technology, minimally invasive surgery (MIS), and the surgical robotics. Afterwards, the calculation methods of this research project is explained in chapter three, together with Cooper scoring model and TOPSIS analysis. Chapter four explains the answer for the first research question regarding the promising healthcare market for medical robotics. Current medical robotic products will be explained in chapter five, in order to answer second research question. The third and fourth research question regarding Cooper scoring model will be answered and analyzed in chapter six. Final chapter provides the discussion of the study results and the conclusion together with the recommendation for ASML.

2. Theoretical Framework

The second chapter provides a summary of literature review related to the new medical robotic products that ASML wants to produce. This chapter is divided into three sections. Section 2.1 consists of general information about current trends in medical technology as an introduction to robotic devices. Section 2.2 describes the minimally invasive surgery, which is being a dominating trend recently in surgical procedures. Subsequently, section 2.3 describes the surgical robotics, which explaining the relation between minimally invasive surgery and robotics.

2.1 Trends in Medical Technology

Generally, technology is addressed as the utilization or application of science for social's benefits (Bakker & Roszek, 2007). Innovation in medical technology are growing rapidly, driven by scientific and economic interests and value to public health (Bakker & Roszek, 2007). Medical technology consists of medical devices, in-vitro diagnostics, medical imaging equipment, and e-health solutions that are used to extend life and increase healthy life years, to reduce symptoms, and to prevent disease progression (MedTech Europe, 2012). These new and emerging medical technologies will improve the results and outcomes of the treatments such as faster recovery times and better prognosis, but on the other hand some new issues related to risks like requirements for training and education, will emerge (Bakker & Roszek, 2007).

Bakker and Roszek (2007) reported that among others a new trend in the medical technology development is visible: converging technologies, which means combining different types of medical technologies and the crossing of borders between traditional categories of medical products. They also stated that the traditional demarcation boundaries such as medical devices, pharmaceutical products, or human tissues could be cut by new generations of medical technologies. Furthermore, they said that the combination between the development and perfection of minimally invasive surgery (MIS) techniques and these new generations of devices could offer patients better prognosis, improved treatments, and faster recovery times.

2.2 Minimally Invasive Surgery

Surgery is all diagnostics or therapeutic interventions that disrupt the body integrity or restructure the continuity of the body tissues (Weber et al., 2008). Generally speaking, surgery is a procedure that involves cutting and penetrating the tissues. There are so many ways to categorize hundreds of different types of surgery such as based on the aim, the urgency, the seriousness, the field, and the approach of surgery (The Better Health Channel, 2014).

During the last quarter of the 20th century, there has been a shift of paradigm in the surgical approaches. Many procedures have reduced the invasive techniques because of adverse events caused by it. The trauma involved in gaining access to the intended area is considered to be the main cause of pain, discomfort, and other morbidity rather than the surgical procedure itself (Mack, 2001). Therefore, minimal invasive surgery (MIS) becomes the focus of surgical approaches recently because of its superior outcomes in improving survival rate, fewer complications, and faster return to functional health and productive life (Mack, 2001). Below is the comparison of open surgery and MIS technique from Weber et al. (2008):

Table 1 Differences between open surgery and MIS

Open Surgery	MIS Technique
Big exposure, more trauma	Smaller exposure, less trauma
The postoperative pain depends mostly on the size of surgical wounds	Less postoperative pain
Harmful to keep the body cavity open for a long time (vaporization, drying, etc.)	Cosmetic advantages
Susceptible to secondary injuries during exposure	Shorter postoperative healing period and duration of being hospitalized
Increasing possibility of later adhesions	Less postoperative adhesions
The bigger the wound is, the higher possibility of postoperative complications (infections, hernia, etc.)	Reduced number of wound infections and hernia

We could see from Table 1 that MIS has more advantages compared to open surgery procedure, so the shift toward MIS procedures is understandable. One important key in MIS is visualization, since the opening area is very small (about 2 inch), it limits surgeons to see the operation field. Mack (2001) in his article stated that the technology of the late 20th century made MIS a reality rather than isolated event. This technology, facilitated some shifts in MIS technique, so that for the first time the surgeon did not have to look directly at the target structure but viewed it digitally as enhanced images that was able to provide a better visualization because of the magnification and illumination.

MIS is also started to be implemented in cardiac surgery. Even though open cardiac surgery has been performed successfully in this past 40 years with generally good results, the procedure of opening the sternum and spreading the rib cage to gain access to the heart contribute significant morbidity (Mack, 2001). Cardiac surgery is different with other surgeries because it needs the heart-lung machine which could add further morbidity. Thus, to eliminate the adverse events, MIS in cardiac surgery is started to be implemented. A total endoscopic approach was tried to be implemented, but then was prohibited later because of the complexities involved with cardiac surgery (Mack, 2001). However, they did not stop and started evolving into current procedure in which multivessel bypass is performed on a beating heart through a median sternotomy incision to eliminate the heart-lung machine and moreover, the procedure on a beating heart could improve the outcomes (Mack, 2001).

According to explanation above, the application of MIS procedure to more complex surgeries will require the new technology and techniques. Much effort is being expended to improve endoscopic and MIS techniques. For example, to facilitate a totally endoscopic approach on a beating heart, there is an interest in using vascular anastomosis with connectors, coupling devices, glues, and sealants, to replace the suturing procedure (Mack, 2001). A potential alternative for that technique is the utilization of precision enhancement, such as robotic devices.

2.3 Surgical Robotics

2.3.1 Robotics

Robotic is complex systems that depends on many advances technologies and challenges which require significant research and development process. The term robotics was invented by Karel Capek, a Czech playwright, in 1920. He related “robot” with Czech word “robota” which means serf labor and used for every machine that can freeing man from tedious and heavy work (Camarillo, Krummei, & Salisbury, 2004). This history managed to set the perception of robots as artificial humans persist among us. In fact, the modern perception of robotics profoundly leans on developments in computer and mechatronics, whereas automation of physical work is still being its core function (Butter et al., 2008). Another specific definition of robotics based on Robotics and Automation Society of the Institute of Electronics and Electrical Engineers that is written on the report of the workshop of A Roadmap of U.S. Robotics (2013):

> Robotics focuses on systems incorporating sensors and actuators that operate autonomously or semi-autonomously in cooperation with humans. Robotics research emphasize intelligence and adaptability to cope with unstructured environments. Automation research emphasize efficiency, productivity, quality, and reliability, focusing on systems that operate autonomously, often in structured environments over extended periods, and on the explicit structuring of such environments. (p.8)

In a simplification it means that a robot is not always a machine that look like human physically and do the automation of human work, but rather a computerized machine that leans on mechatronics that can assist human in automation their work.

To date, robots are being used in many domains such as manufacturing, services, healthcare or medical, defense, and space. In manufacturing domain, robotics is a key that can bring revolutionary impact to it by automating dirty, dull, and dangerous tasks since US workers no longer aspire to low factory jobs and the cost of US workers keeps rising as well (*A Roadmap for U.S. Robotics*, 2013). Meanwhile, service robotics assist people in their daily lives at work, at home, for leisure, and also assist people with mental and physical limitations (*A Roadmap for U.S. Robotics*, 2013). Robotics system developed for military applications and defense named as unmanned systems. These systems offer several assistances in military operations such as environmental sensing, precision targeting, and precious strike (*A Roadmap for U.S. Robotics*, 2013). Generally speaking, unmanned systems offer versatility, functionality, and the capacity to reduce risks to human life (*A Roadmap for U.S. Robotics*, 2013). Robot applications in space have brought us a lot of valuable information regarding the Solar System and beyond. Human owe these robots for traveling through dark and deep space in order to observe, measure, and visit distant worlds (*A Roadmap for U.S. Robotics*, 2013). The last and the most important one for this project is robotics in healthcare domain, or medical robotics. Medical robotic systems have already brought a lot of improvisations in existing medical procedures such as develop medical procedures to be less invasive so that could produce fewer side effects and faster recovery times, improve worker productivity, and improve both risk-benefit and cost-benefit ratios as well (*A Roadmap for U.S. Robotics*, 2013).

2.3.2 Medical Robotics

> Robotics for medicine and healthcare is considered the domain of systems able to perform coordinated mechatronic actions (force or movement exertions) on the basis of processing of information acquired through sensor technology, with the aim to support the functioning of impaired individuals, rehabilitation of patients, care and medical intervention of patients and also to support individuals in prevention programs (Butter et al., 2008, p.12)

According to that definition, medical robotics are considered to have a huge value in healthcare in terms of health, societal, and economic benefits. Robotics can offer solutions for a significant proportion, especially for patient groups with certain needs such as amputees, stroke sufferers, or cognitive or mental disability patients (TNO Quality of Life, 2008). Moreover, according to the article of *A Roadmap for U.S. Robotics* (2013) robotic devices are already affecting more fields in healthcare such as telerobotic systems to perform less invasive surgery with more precise and accurate movement, haptic devices as form of robotics to train medical personnel with simulations, rehabilitation robots to assist therapy for patients who require rehabilitation. Furthermore, robotics technology can be used to acquire data from biological systems with undoubted accuracy, and it also has a role in enhancing basic research regarding human health (*A Roadmap for U.S. Robotics*, 2013).

There are several medical robotics that are being introduced in healthcare market, however, based on the report of panel discussion and consultation with experts and stakeholders by TNO Quality of Life (2008), there are only six representative areas that can be regarded for further investigation: (1) smart medical capsules, (2) surgical robotics, (3) intelligent prosthetics, (4) robotized motor coordination analysis and therapy, (5) robot-assisted mental and social-therapy, and (6) robotized patient monitoring systems. Regarding to this project, we will only focus on surgical robotics.

2.3.3 Surgical Robotics

The idea behind the development of surgical robotics was the premise that higher speed and accuracy could be achieved in surgery (Gomes, 2011). Higher speed could make the surgery faster, and higher accuracy will make the recovery faster and lower the chance of adverse effects as well. Sol, Garos, van der Helm, & de With (2012) on the healthcare roadmap report strengthen those statements by reporting that the quick recovery after treatment is economically attractive since it impacts to shorter hospitalization, early rehabilitation, a quick return to normal activities, and also reducing labor time for the hospital staffs. Therefore, the developments in minimally invasive surgery (MIS) seems to be the most important innovations and trends in healthcare industry recently, and robotic can be expected to impact the field of MIS.

The initial concept of surgical robotic is an operation from a site remote that could transpose surgical and technical expertise from one site to distant site (Mack, 2001). The use of robotics can overcome the limitations of MIS procedure that faced by the surgeons. Surgical robotics have a goal to create a completely integrated system that converts information to action, so that it is able to translate large hand movements to precise instrument tip movements (Mack, 2001). Thus, surgeons could do they work precisely even though in limited viewing area because the surgical robotics could eliminate several disadvantages of manual procedures such as hand tremor, enhance dexterity, provide sensory feedback and motion scaling (Mack, 2001).

Mack (2001) as his article described the enhancement of dexterity was reached by placing a microprocessor between the surgeon’s hand and the tip of the instrument. He added that all tasks that are seemed not possible to be done by manual procedure, are possibly done by the assist of robotic devices. Hand tremor could be reduced significantly by using motion scaling, in which precision and eventually haptic feedback could be enhanced, allowed surgeon to do many tasks that impossible to be done today. Dexterity enhancement by robotic assistance is being a focus on eye surgery (microsurgery), MIS surgery, and endoscopic cardiac surgery (Mack, 2001).

Subsequently, Mack (2001) wrote that technologies that will impact surgery are those that allow procedures to be performed through natural orifices rather than a MIS approach. The development of x-ray delivery by remote site under image guidance (e.g. MRI and ultrasound) will permit the ablation of tumors of prostate, breast, liver, and lung without the necessity of incision (Mack, 2001). Moreover, he added that the advancements in microchip and wireless technology may allow the development of some robotic devices such as the swallowable cameras, implantable sensors and medical records, microrobots for completing surgical procedures, and magnetically controlled implants that could be navigated remotely.

According to the information above, we concluded that new and emerging medical technologies will improve the results and outcomes of the treatments such as faster recovery times and better prognosis. The combination between the development and perfection of minimally invasive surgery (MIS) techniques and new medical technologies could offer such advantages to patients. One of the potential alternatives for new medical technologies is the surgical robotic devices. The use of robotics can overcome the limitations of MIS procedure that faced by the surgeons. With this trend, surgical robotics could have a promising market in the future of healthcare.

3. Methods

The third chapter provides an explanation of the methods that is used in assessing and analyzing all robotic cases in order to find the most likely success one related to ASML. This chapter is divided into three sections. Section 3.1 provides the background theory about success factors for new innovations, which will be used as criterion in Cooper scoring model. Section 3.2 describes about the basic idea and theory of Cooper scoring model that will be used to score each robotic case based on some criterion. Afterwards, the theory, steps, and formula of TOPSIS to analyze the scoring model will be explained in section 3.3.

3.1 Background

Built upon difficulties and uncertainties of new products development on a certain firm, Cooper (1981) found the idea of conducting initial screening as the first selection stage in the new product process. He stated that the screening stage is the initial GO/NO GO decision of a new product, which the decision will be either an initial but tentative commitment to the new product project or an outright rejection of the proposal (R. G. Cooper, 1981). According to Cooper (1985), there are four main approaches to initial screening, include:

1. *Benefit measurement models*
   Systematics procedures that require a well-informed respondent or group to provide subjective inputs regarding characteristics of the project under consideration. This model relies more on subjective assessment and fit with corporate objectives. Included in this category: checklists and scoring models. In the latter, rating of a project's attributes are sought and combined in a weighted fashion to yield a numerical project score (Bakker & Roszek, 2007; R. Cooper, 1985).
2. *Economic models*
   Economic model is like a conventional investment decision that uses computational approaches (e.g payback period, breakeven analysis, return-on-investment, discounted cash flow methods). This model uses techniques probability analysis to accommodate the uncertainty of data. Nonetheless, this models suffer at the idea screening stage because they require considerable financial data as inputs when often relatively little is known about the project. Thus, such models are more relevant for "known" projects or later stages of new product process (R. Cooper, 1985).
3. *Portfolio selection models*
   In portfolio selection model, the screening decision is viewed as part of the total resource allocation problem. The objective of this model is to develop a portfolio of new and existing projects in order to maximize an objective function, yet subject it to a set of resource constraints. This model is rarely used, because these mathematical models require substantial data inputs, including financial data on all projects, timing information, resource needs, and availabilities (R. Cooper, 1985).
4. *Market research approaches*
   Market research approaches is limited to relatively simple consumer products (e.g. package goods). In this model, marketplace is the critical criteria for the GO/KILL decision. Thus, it makes sense to use a variety of market research techniques (ranging from consumer panels and focus group to perceptual and preference mapping) to screen product ideas (R. Cooper, 1985).

From those initial screening models, Cooper stated that benefit measurement approaches are generally recommended for new product idea screening because only a tentative commitment and gross distinctions are required. Also, since available information of this project is limited, benefit models become the logical screening tool (R. Cooper, 1985). However, besides some advantages this model also have some disadvantages. Based on Cooper article on 1985, the advantages and disadvantages of this models are as shown in Table 2.

Table 2 Advantages and disadvantages of scoring models

Scoring Models	
Advantages	Disadvantages
Helps make a highly judgmental decision more objective	Relies on the subjective ratings of managers, hence the data input may not be very reliable
Systematizes the review of projects	Often seen as oversimplifications, since they attempt to reduce a complicated decision situation to a product score
Forces managers to subject each project to a consistent and large set of review criteria	Checklist question used and weighting for each criteria are arbitrarily determined
Focuses attention on the most relevant issues	Dependent among variables
Requires management to state goals and objectives clearly	
Easy to understand and use	
Generally applicable	

Cooper wrote some articles about the factors that separate between the successes and the failures of new products. The comparison studies between successes and failures had been done by several researchers, but always come out with some vague and inconsistent operational definitions regarding the new product. Moreover, since the evidence of conceptual model finding is hard to find, the inconsistency of the variables that some particular researcher chose to measure seemed to be greater (R. Cooper, 1979).

Thus, Cooper in 1979 did an extensive investigation regarding what separates successful from unsuccessful new industrial products using multivariate methods. He identified the dimension underlying success and failures, then demonstrated the dominant role of product strategy and the need for a strong market orientation, clearly. After went through the research process, Cooper (1979) concluded three keys for new products to be successful in the market. First single most important dimension is **product uniqueness and superiority**. Unique and superior products are typically innovative and new to the market, fulfill customers' needs better than competitors, economically beneficial to the customers, and have higher quality compared to competing products (R. Cooper, 1979). A company must seek for differential advantage from the product, as it is the core and central strategy in most industrial new product ventures.

The next critical role player in new product outcome is **market knowledge and marketing proficiency**. To be strong in this dimension, the market-oriented activities have to be proficiently undertaken, especially the sales force and distribution effort (R. Cooper, 1979). The commercial viability of a new product that rests in the hands of its potential customers is one of the obvious points that needs to be reinforced. Therefore, an effective market launch together with a solid understanding of the marketplace is vital to the successful of a new product (R. Cooper, 1979).

The third most important dimension of new product is **technical and production synergy and proficiency**. A project is called synergy and proficiency when the firm has a particularly strong and compatible technical engineering and production, as well as resource base (R. Cooper, 1979). Actually, those technical and production facets that are important to new production success has been taken for granted for so long. One important thing we should keep in mind is that this technical dimension does not stand alone as other critical dimension to new product success (R. Cooper, 1979).

However, based on his research Cooper (1979) also stated that there are also other dimensions that are negatively related with the success of new product, or in other words, barriers to the success. First is new product with high pricing, compared to the competitors, with no economic advantage to the customer. Then, a product that is in a dynamic market with many new products are being introduced. Beside its receptiveness to new ideas and facilitating new product introduction, the dynamic market can become a trap area consists of problems and hidden obstacles, and a breeding area for competitive one-upmanship (Calantone & Cooper, 1977). The third barrier is being in a competitive market where customers are already satisfied. This intense product competition often ends with deadly outcomes for the new product launched into the market (R. Cooper, 1979).

There are also other additional dimensions that works as complementary dimensions but worth to be considered for supporting the success of new product. Two similar dimensions are marketing and managerial synergy, and strength of marketing communications and launch effort, that complement the more important determinant of success, market knowledge and marketing proficiency (R. Cooper, 1979). The synergy of people and skills is critical to new product success, as well as the strength of marketing communications such as advertising, promotion, and distribution effort (R. Cooper, 1979). Another dimension is market need, growth, and size. Surprisingly, it does not always have to be high need, high growth, and large size market that determine the new product success. Instead of having an up-hill battle in such lucrative market, some companies could be attracted into smaller, less lucrative market that gives them the opportunities to successfully launch their new product (R. Cooper, 1979). So, we can conclude that high growth, high need, and large markets do not really play a pivotal role in new product successes.

3.2 Cooper Scoring Models

Accordingly, Cooper built a new version of scoring models, called NewProd, which has several important differences with scoring models at that time. NewProd model is basically a scoring model that based on the premise that a project's desirability, attractiveness, or eventual success can be predicted by examining the profile of the project (R. Cooper, 1985). It can be used as a Go/Kill decision or to prioritize a series of possible new products, or in other words to separate potential winner projects from potential loser projects in an early stage to save company's money and resources (R. Cooper, 1985). As in most scoring models, NewProd evaluators rate the project under consideration on a large number of criteria using zero-to-ten rating scales. According to Cooper (1985), there are six dimensions that influence the outcome of the screening procedure such as market criteria, product advantage, product economic advantage for the user, synergy criteria, newness to the firm, technological resource compatibility, and project descriptors.

There are two things that are captured in market criteria. The first thing is the magnitude of the market such as the market size, need, and growth. The second is the market competitiveness, because entering the market when competitiveness is low is better than when it is high (R. Cooper, 1985). Speaking of product marketability, Cooper (1985) argued that it is critical to achieve differential advantage by accentuating the product superiority, since it is the most important factor in the success equation. The other important marketability factor is how the product could be economically advantage to the users (R. Cooper, 1985).

Project-company fit dimensions, which are included synergies in managerial skills, marketing skills, financial resources, and production resources, are also important to product outcomes (R. Cooper, 1985). The last dimension, project descriptors, is a group of factors that have no link to product outcomes. It is only one entered the success equation, but in a fairly weak manner, named product scope (R. Cooper, 1985). Accordingly, we summarized all those dimensions and some important criteria in it on the Figure 2.

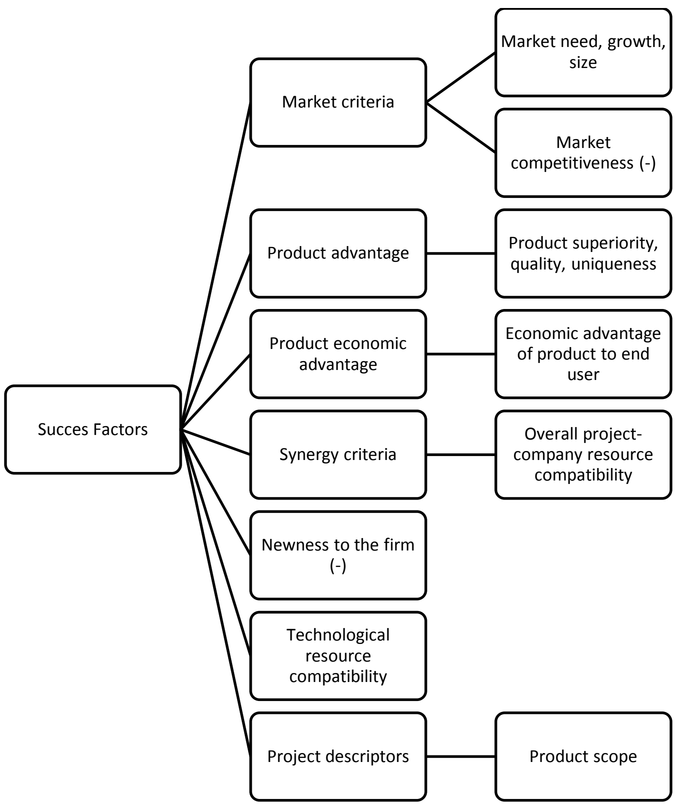

Figure 2 Dimensions of Cooper scoring models

All of those eight key success factors and dimensions were related to product outcomes in a significant way. Cooper (1985) analyzed it with multiple regression and linear discriminant analysis, and selected the first one to be used in the model because it was marginally better. Table 3 below summarized the information about the key dimensions, their coefficients in the success equation, and some variables that are included in each factor, based on Cooper article on 1985.

Table 3 Cooper scoring model's key factors, regression coefficients, and variables

Key Factors	Regression Coefficient	Variables on Factors
Product superiority / quality	1.744	Product is superior to competing products Product has unique features for user Product has higher quality than competitors Product does unique task for user Product reduces customers' costs Product is innovative (first of its kind)
Economic advantage to the user	1.138	Product reduces customers' costs Product is priced lower than competing products
Overall company-project fit	0.801	A good fit between needs of project and company resource base in terms of: - Managerial skills - Marketing research skills - Salesforce/distribution resources - Advertising/promo resources - Financial resources - Engineering skills - R&D resources Production resources
Technological compatibility	0.722	A good fit between needs of project and company resources base in terms of: - R&D resources and skills - Engineering resources and skills
Newness to the firm	-0.354	Product takes the firm into new areas for firm, such as: - New product class to company - New salesforce/distribution - New type of users' need served - New customers to company - New product technology to firm - New production process to firm
Market need, growth and size	0.342	High need level by customers for product class large market ($volume) Fast growing market
Market competitiveness	-0.301	Intense price competition in the market Highly competitive market Many competitors Many new products enter the market Changing user needs
Product scope	0.225	A market derived new product idea Not a custom product (more mass appeal) A mass market for product (as opposed to one or a few customers)

However, since we are doing it in healthcare area, we would collaborate the scoring model with the success factor determinants for new products in healthcare based on article of Fleuren, Wiefferink, & Paulussen (2004). Based on their research, there are four determinants in healthcare that affect the likelihood of success of a new product including (1) characteristics of the socio-political context, such as rules, regulation, legislation, and patient characteristics; (2) characteristics of the organization, such as staff turnover and the decision making process; (3) characteristics of the user, such as knowledge, skills, and perceived support from colleagues; and (4) characteristics of the innovation, such as complexity or relative advantages. Thus, we added one more success factor into the model named healthcare compatibility fit, which reflected the fitness of the robotic devices with surgeon skills and available space. This is in accordance to the theory that the user and the characteristic of innovation play an important role in the innovation process and as a part of an organization they involvement will affect a larger environment, including the socio-political context (Fleuren et al., 2004).

3.3 TOPSIS Analysis

TOPSIS is an abbreviation of Technique for Order Performance by Similarity to Ideal Solution and a part of multi criteria decision analysis (MCDA) (Ishizaka & Nemery, 2013). Refer to that article, MCDA is a stepping stones methods and techniques to find a compromise solutions in order to support the decision maker in their unique and personal decision process. MCDA is a discipline that combines mathematics, management, informatics, psychology, social science and economics to produce a tactical or strategic decision, depends on the time perspective of the consequences (Ishizaka & Nemery, 2013).

We saw TOPSIS analysis as a method to calculate the weighted scores of each robotic case for every success factor. As mentioned before, the weight of these success factors are already determined by Cooper. A higher calculation result suggests a higher likelihood of success. TOPSIS as the analysis tool was chosen because this method requires only a minimal number of inputs from the user, and the outputs is easy to understand. Actually, the only subjective parameters are the weights associated with criteria. Nonetheless, in our case, we have coefficient regression from Cooper model that can be used to determine the weight of each criteria, so it became more objective than the original one. In order to determine the best solution, the fundamental idea is to see which one has the shortest distance to the ideal solution and the furthest distance from the anti-ideal solution (Hwang & Yoon, 1981; Lai, Liu, & Hwang, 1994).

The TOPSIS method consists of five computation steps. The first is gathering performances of the alternatives on the different criteria. Subsequently, we normalized those performances to make the measurements of different units (e.g. dollars, years, etc.) comparable. We use the ideal normalization, where if the criterion has to be maximized, each performance is divided by the highest value in each column, and if the criterion has to be minimized, then each performance is divided by the lowest score in each column. The third step is to construct weighted normalized decision matrix by multiplying the normalized scores by their corresponding weights. Afterwards, the weighted scores will be used to compare each action to an ideal and anti-ideal virtual action. One of the ways to define these virtual actions is by collecting the best and worst performance on each criterion of the normalized decision matrix. The next step is to calculate the distance for each action to the ideal action and the anti-ideal action. Finally, the last step is to calculate the relative closeness coefficient (C_a) of each action. The value of closeness coefficient is always between 0 and 1. C_a approaches 1 when an action is closer to the ideal than the anti-ideal, and it approaches 0 when an action is closer to the anti-ideal than to the ideal. In this case, we will compare and analyze the final results of the closeness coefficient of each robotic case to figure out which robotic case is the most ideal for ASML to successfully enter the market.

4. Promising Healthcare Market

The fourth chapter provides the answer of first research questions about the market: "which diseases or treatments have the largest clinical market?" This chapter is divided into three sections. Section 4.1 describes the method used to answer above mentioned research question. The results will be described in section 4.2, which is divided into two sub-section: 4.2.1 provides the result of highest expenditure diseases and 4.2.2 provides the result of the most frequent surgeries happened in four years. Eventually, section 4.3 combines all the results after validated by expert interview, as a guidance for next step.

4.1 Methods

We performed a literature study to find secondary data about the largest and most promising clinical market. We divided the searching into two types, the highest expenditure diseases and the most frequent surgeries. In order to find recent statistical data, we used Google and Scopus to find articles in English. Search terms included: the highest expenditure diseases, the most costly diseases, the most frequent surgeries, the most common surgeries, US surgery data.

We believe that every country has different sequence of the highest expenditure diseases. Therefore, to ease comparing the data, we put all the data in table, so that we could compare the sequences of data among each country based on the article we found. Afterwards, we counted which disease that has the most appearance as the highest disease in every country, then we will have our own order of the highest expenditure disease worldwide.

Meanwhile, the data of the most frequent surgeries has different way to proceed. We collected all the data form US database surgeries, because those are the only database that gave the complete data of all of the surgeries that were conducted in US in 2007-2010. We screened those databases and selected top five of the most frequent surgeries every year and put it in the table.

Finally, to validate all the literature findings with practical situation, we conducted an interview with an expert named Prof. Ivo Broeders. He is a surgeon and also a professor in robotics and minimally invasive surgery at University of Twente. We presented all of our findings in front of him and asked for his opinion. Afterwards, we combined our literature findings with expert opinion as a guidance for next step of this research.

4.2 Results

4.2.1 The Highest Expenditure Diseases

There are several articles found during this search, but mostly in US and in Europe. We found difficulties in finding the data of developing countries in English. Lack of English data in developing countries and different health situation gave us insight that introducing robotic devices is less feasible for developing countries compare to developed one. For this reason we decided to focus on developed countries.

As we mentioned above, after finding the data from several articles regarding the highest expenditure diseases, we put all the data into a table (Appendix 1), to see which diseases that appear as the top five of the most costly diseases among all. We found nine articles that contain of six articles about US, and three articles about European Countries such as the Netherlands, France, Germany, Spain, Sweden, and UK, with the year ranging from 2004 until 2012 (Appendix 2).

US Articles

All six articles have heart diseases as the most costly diseases in US, even though two mentioned it more specific like angina pectoris and congestive heart failure (Cohen S. (2012); Ehrlich et al. (2010); Goetzel et al. (2003); Olin and Rhoades (2005); Soni, A. (2007); Soni, A. (2011)). However, each article has different order regarding the second until the fifth place. Three articles have cancer and trauma related disorders as the second and the third highest expenditure diseases respectively. In the fourth place, there are four out of six articles mentioned about intellectual disability. Finally, the fifth highest expenditure disease has pulmonary conditions as its place as mentioned by three articles.

Based on information above we can conclude that the order of the highest expenditure diseases in US are as follows:

1. Heart disease
2. Cancer
3. Trauma related disorders
4. Intellectual disability
5. Pulmonary conditions

EU Articles

As mentioned above, there are three articles that give the comparison data about the highest expenditure diseases in European countries. Heijink at al. wrote two articles in 2006 and 2008 which compared ten and five developed countries respectively. Aiming to have an insight of the highest expenditure diseases in Europe, we decided to compare six countries in Europe including France, Germany, the Netherlands, Spain, Sweden, and UK. Every country has its own pattern of their diseases expenditure. This article used percentage of total healthcare costs to determine which disease has the highest expenditure. Four out of six countries have circulatory or heart disease as the first highest expenditure diseases, which is in accordance with US. In the second place, two countries placed digestive system diseases, while other countries have it on the third and fourth place. Subsequently, intellectual disability, respiratory system diseases, musculoskeletal diseases and cancer also take place in every of each country for the highest expenditure diseases.

Meanwhile, another article from Polder and Achterberg (2004) discussed and compared diseases expenditure between men and women only in the Netherlands in 1999. According to the data, the first highest expenditure diseases among men in the Netherlands is intellectual disability, whereas in women it placed in the third position. It is because the healthcare system in the Netherlands comprises living arrangements as well as provisions related to social-welfare. Meanwhile, the first highest expenditure disease among women in the Netherlands is symptoms and ill define, means there are many visits to GP or to acute care facilities when no diagnosis is available yet. Next diseases that has the highest expenditure in the Netherlands are cardiovascular diseases, digestive system diseases, and nervous and sensory system diseases as well as musculoskeletal diseases.

It is rather difficult to combine all the highest expenditure from all six countries, because every country has different sequence even though the diseases are more or less the same. Thus, we combined all the findings into one form of sequence based on which diseases that most frequently appear in each country. Accordingly, we got the sequence of the highest expenditure disease in EU countries as follows:

1. Circulatory/Heart diseases
2. Intellectual disability
3. Digestive system diseases
4. Respiratory system diseases
5. Musculoskeletal diseases

Accordingly, currently we have two types of order of the highest expenditure diseases in the US and in the EU countries. In order to have the insight about the highest expenditure diseases in developed countries, we combined the final order of US and EU countries. It was easy to determine the first place, because both US and EU have heart diseases as the first highest expenditure diseases. Subsequently, second place in US is cancer, while EU has intellectual disability. We eliminated intellectual disability and trauma-related disorders from the sequence because it seems like the robotic companies could not do much and explore further in this area. Thus, we have three diseases left and since respiratory system diseases is present in both sequence, we decided to put it as second highest expenditure diseases. Afterwards, we placed cancer, digestive system diseases, and musculoskeletal diseases as the third, fourth, and fifth highest expenditure diseases respectively. The final order of the highest expenditure diseases in US and European countries can be shown in Table 4 below.

Table 4 Final order of highest expenditure diseases in US and Europe

US	EU	Combine
Heart diseases	Heart diseases	**Heart diseases**
Cancer	~~Intellectual disability~~	**Respiratory system diseases**
~~Trauma related disorders~~	Digestive system diseases	**Cancer**
~~Intellectual disability~~	Respiratory system diseases	**Digestive system diseases**
Respiratory system diseases	Musculoskeletal diseases	**Musculoskeletal diseases**

4.2.2 The Most Frequent Surgeries

We collected number of surgical procedure in US in 2007 until 2010 from the National Center for Health Statistic Organization in US. The database consists of fifteen types of surgeries and divided into some groups with codes based on the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) (see Appendix 11). After screening the databases, we got cardiovascular system surgeries, obstetrical procedure, digestive system surgery, musculoskeletal system surgeries, and female genital surgeries as the top five of the most frequently conducted surgeries in US in 2007-2010. The number of operation on the cardiovascular system is approximately as high as obstetrical procedure. The difference is that the number of cardiovascular surgeries is increasing steady year by year, while obstetrical procedure is a little bit fluctuated because it increased in 2008 and decreased in 2009, then increased again in 2010. The next most frequently conducted surgeries is digestive system surgeries which showed an increasing trend during 2007 until 2009 and then declined in subsequent year.

Operation on the musculoskeletal system showed the best trends among all because it increased significantly year by year. Within four years, the number of patient with this kind of surgery increased for more than one million. The last surgery procedure that is most frequently conducted in US is the operation on the female genital. Although the number is not that high and the trend is also fluctuated.

All of those information is presented in the chart (Figure *3*) so that we could easily see the trend of all those top five diseases year by year.

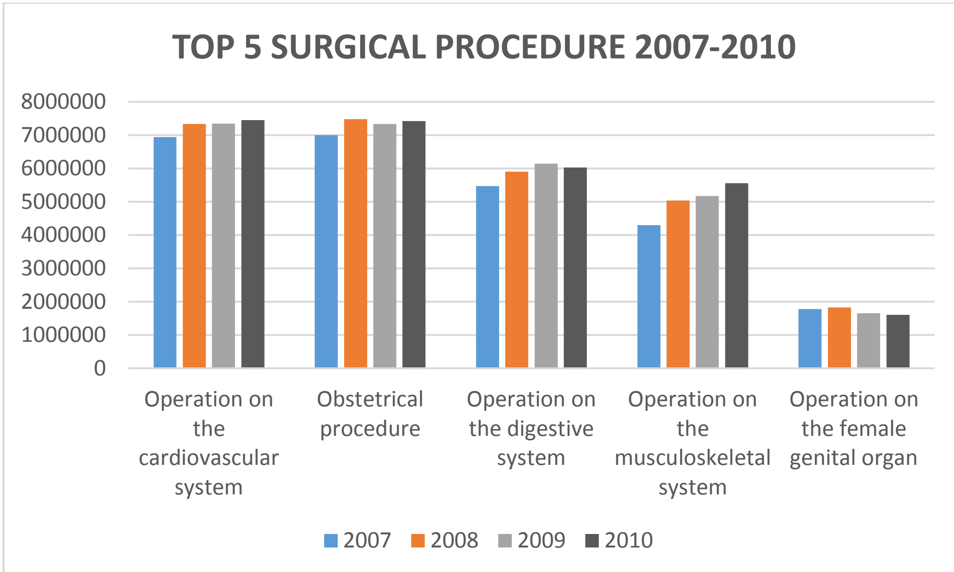

Figure 3 Chart of the top five surgical procedure 2007-2010

4.3 Market Validation and Conclusion

In this section, we will describe the validation of all information above by interviewing Prof. Ivo Broeders, a surgeon and a professor in robotics and minimally invasive surgery, then we will conclude what kind of diseases or treatments that might give the best opportunity for new medical robotic devices to enter. “Defining the market is indeed the first thing to do to start a research in new technologies”, Ivo said. We showed our first finding regarding the top five highest expenditure diseases and he argued that it was a vague data. Since we are focusing on surgical robotic devices, relying on this data is not a wise idea because the health expenses here are not always about invasive medicine expenses. However, we could still use this data as rough filters and as a check if we are in the right path or not.

Subsequently, we showed him our second finding regarding the top five most frequently conducted surgical procedures in US. As abovementioned, we have cardiovascular system surgeries, obstetrical procedure, digestive system surgery, musculoskeletal system surgeries, and female genital surgeries as the top five of the most frequently conducted surgeries in US in 2007-2010. However, from those five procedures, only four that can be taken into consideration to be classified into main types of surgery. As a surgeon, Ivo thought that obstetrical procedure, which means all kind of procedures regarding childbirth, is not appropriate to be intervened by robotic surgical devices. So, we excluded this type of surgery, and there are four remaining surgical procedures.

Afterwards, Ivo said that there is different technology required for every type of surgery, hence we classified those surgical procedures based on their technological intervention. We classified them into three main types of surgery, first is endovascular surgery (cardiac surgery), second is endoscopic or endoluminal surgery (digestive system surgery and female genital organ surgery), and the last is musculoskeletal surgery. However, Ivo stated that there is one more surgical procedure type that has a promising market, called microsurgery. This is the type of surgery that requires an operating microscope to operate small body parts such as ear, eye, nerves, and blood vessels.

Thus, now we have four types of surgeries that could be considered as the most promising market for new medical robotic devices. Those are:

1. Endovascular surgeries
2. Endoscopic surgeries
3. Musculoskeletal surgeries
4. Microsurgery

Surprisingly, those four types of surgeries are still in accordance with several highest expenditure diseases. Endovascular surgeries are invasive procedures in cardiac system diseases and endoscopic surgeries are invasive procedures in digestive system diseases, while musculoskeletal surgeries are obviously invasive procedures for musculoskeletal diseases.

Microsurgery is every surgery that is performed on very small structures, such as blood vessels and nerves, and need a visual guiding from a microscope (Sherk, 2014). Microsurgery is very hard and technically demanding surgery. It has a critical definition of success, for instance in transplantation surgery, when the blood is able to keep on circulating so that the transferred tissue remains viable, then the microsurgery is succeed (Sherk, 2014). Many surgical procedures can utilize the techniques of microsurgery such as surgery on the inner ear, vocal cords, corneal transplants, glaucoma, vasectomies, tubal ligations (female sterilization), tissue reconstruction (reconstructive surgery), and reattachment of disrupted or amputated body parts (Sherk, 2014). Moreover, microsurgery can also be lifesaving treatments, since it is able to treat vascular abnormalities in brain and remove cancerous tumors.

Accordingly, we saw microsurgery as other option of surgical robotic devices market. Currently, there is still no dominant player in that market, so the entry barrier is rather lower than other three areas. However, we still need further analysis about current robotic products and the compatibility of ASML regarding the technology needed. Those issues will be analyzed and explained in next chapters.

5. Current Medical Robotic Products

The fifth chapter provides the answer of second research questions about the current cases of robotic products: "Which medical robotic products are currently available in healthcare?" This chapter is divided into two sections. Section 5.1 describes the method used to answer this research question. The results will be described in section 5.2, which is divided into eight sub-section that describes eight cases of current surgical robotic products.

5.1 Methods

We performed a literature study to find data about current surgical robotics that already in the healthcare market. Afterwards, we did an internet based research to find information regarding the robotic companies. We finally ended up with nine robotic cases, which each case has uniqueness and specific characteristic compared to other cases.

Those nine robotic cases are Da Vinci System, the Flex System, SPORT, and SPIDER for minimally invasive surgery procedures, ARTAS for hair transplantation, Sensei and Magellan System for intravascular surgery, Cyberknife System for radiosurgery, MAKOplasty for knee and hip replacement surgery, and PRECEYES for eye surgery (microsurgery). Several important things we search on the internet regarding the robotic cases are company profiles, technological capabilities (mechatronic, imaging, ICT), and the disease or condition that is indicated to use the robots. Subsequently, we put all of our findings into a table to compare it and give the information to ASML to assist them regarding the scoring model, especially the technological compatibility factor (Appendix 4).

5.2 Results

5.2.1 Intuitive Surgical

Intuitive Surgical Company as the global technology leader in minimally invasive robotic-assisted surgery developed *da Vinci* Surgical System to enable surgeon to operate through a few small incisions from a nearby ergonomic console, which will be translated into precise, real-time, robotic movements (Intuitive surgical, 2014). There are four interactive robotic arms that will go through the incision into the human body, which one of these arms consists of a camera with 3D HD vision system. Meanwhile, other three arms consist of tiny wristed instruments with seven degrees of motion that could move greater than human hand (Intuitive surgical, 2014). Therefore, *da Vinci* enables surgeons to operate with enhanced vision, precision, dexterity, and control. Generally speaking, *da Vinci* systems is designed to provide surgeons with the capabilities of traditional open surgery while enabling them to operate through a few small incisions (Intuitive surgical, 2014).

The original prototype of the *da Vinci* System was built in 1980s under contract of the U.S. Army for remotely performing battlefield surgery (Intuitive surgical, 2014). Nonetheless, Intuitive Surgical at that time realized that this technology had possible commercial application which could accelerate the application of minimally invasive surgical approach to a broader range of procedures. Accordingly, in 1999 Intuitive Surgical launched *da Vinci* systems which then became the first robotic surgical system cleared by FDA for general MIS surgery a year later (Intuitive surgical, 2014). In following years, the FDA approved the *da Vinci* surgical system for thoracoscopic (chest) surgery, which contains of cardiac procedures performed with adjunctive incisions, as well as urologic, gynecologic, pediatric, and transoral otolaryngology surgery procedures (Intuitive surgical, 2014).

Figure 4 Da Vinci System (console and robotic arms)

Da Vinci could assist minimally invasive surgery in several parts of body. First is cardiac surgery, a procedure that refers to any surgical procedure on the heart and its supporting structures (da Vinci Surgery, 2013). They also mentioned in their website that there are two specializations of cardiac surgery that is done by *da Vinci*, mitral valve prolapse and coronary artery disease. Second type of surgery that can be done by *da Vinci* is colorectal surgery, which consists of colectomy and low anterior resection (da Vinci Surgery, 2013). In this case, the colorectal condition is meant by diseases in colon and rectum including colon cancer, rectal cancer, diverticulitis, and inflammatory bowel disease (da Vinci Surgery, 2013). Thoracic (chest) surgery, which refers to any type of surgery that performed on organs and tissues in chest cavity, is also one of type of surgeries that could be done by *da Vinci* systems. According to their website, *da Vinci* systems could assist the lobectomy procedure that refers to remove a lobe of the lungs, usually in the case of non-small lung cancer. Other type of surgery that could be assisted by *da Vinci* systems is head and neck surgery, which refers to oral and throat cancer patients (da Vinci Surgery, 2013). Furthermore, *da Vinci* systems could also assist surgery for women who face gynecologic conditions such as fibroid tumors, endometriosis, heavy menstrual bleeding, cancer, and pelvic prolapse (da Vinci Surgery, 2013). Urologic surgery, which usually conducted for operating bladder cancer, kidney cancer, kidney disorder, and prostate cancer, could also be assisted by *da Vinci* systems (da Vinci Surgery, 2013). Eventually, *da Vinci* is also used to assist general surgery procedures including bariatric surgery (operation for obese people), Heller Myotomy (surgery for patients with swallowing disorder), and cholecystectomy (surgery to remove gall bladder) (da Vinci Surgery, 2013).

5.2.2 Restoration Robotics

Restoration Robotics Inc. developed ARTAS Robotic System to enable hair restoration physicians with the power of advanced imaging and precision robotics (Restoration Robotics, 2013). The ARTAS Robotic System harvests follicular units with low transection rates and dissects follicular units accurately and consistently thousands of times in a single session (Restoration Robotics, 2013). ARTAS Robotic System has four key special capabilities such as high-resolution digital imaging for accuracy, image-guided robotic alignment for speed and precision, minimally invasive dissection, and intuitive operation to make the procedure easier to perform (Restoration Robotics, 2013). Generally speaking, ARTAS Robotic System could help the surgeon to optimize the procedure of hair transplantation with speed and precision far beyond manual techniques for efficient and consistent results. By far, ARTAS Robotic System has already treated 35 million men in US with hair loss (Restoration Robotics, 2013).

Figure 5 Left: The ARTAS Robotic chair; Right: The monitoring screen. (Rashid, 2014)

5.2.3.Medrobotics

The Medrobotics Company has built a highly articulated and flexible multi-linked robotic system to assist minimally invasive surgery procedure especially for many body parts that are difficult or even previously impossible to reach by hand (Medrobotics corporation, 2014). This snake-like robot, which is named The CardioARM, was developed to enable surgeons to perform complex procedures of intrapericardial surgery through a beating heart without opening the chest cavity (Neuzil et al., 2013). This device is built with 50 rigid cylindrical links serially connected by three cables, which two of the adjacent links could rotate approximately 10 degrees relative to each other (Ota et al., 2009). The key features of this device is called “follow-the-leader” mechanism that means the user only has to give inputs to one distal tip of the robot, then the other links will follow its location (Ota et al., 2009). In order to control the links, the operator uses a joystick together with a button to move it forward or backward with maximum speed up to 20 mm/s (Ota et al., 2009). Images from fiber camera on one of the links will be displayed on the monitor that located near the surgeon (Ota et al., 2009).

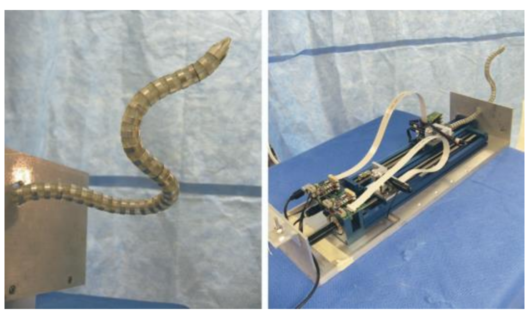

Figure 6 CardioARM, the snake-like robot from MedRobotics Company

5.2.4 Hansen Medical

Hansen Medical built robotic devices for intravascular system with the vision of empowering and protecting physicians while providing enhanced care for the patients (Hansen Medical, 2014). They divided the products into two types: robotic for electrophysiology (Sensei® Robotic system) and robotic for peripheral vascular intervention (Magellan ™ Robotic System).

The Sensei Robotic System

Electrophysiology is a branch of cardiology that deals with the treatments for heart rhytm disorders such as catheter ablation and cardiac devices implanation (Hansen Medical, 2014). The Sensei® Robotic system for electrophysiology have some key features to make the electrophysiologists' job easier and saver such as force sensing for stabilizing the catheter, potential for reduced fluoro time for physicians, and instinctive 3D control (Hansen Medical, 2014). They argued that this system provides navigation of flexible catheters, which can produce stability and control in interventional procedures. Generally speaking, the Sensei® Robotic Catheter System is a device that combining advance level of 3D catheter control and 3D visualization, which could provide accuracy and stability during electrophysiology procedures.

Figure 7 The Sensei robotic system

The Magellan Robotic System

Meanwhile, The Magellan ™ Robotic System is designed for multi-specialty peripheral vascular procedures which could provide stability (Bismuth, Duran, Stankovic, Gersak, & Lumsden, 2013). The company stated that this device could enable surgeon to cannulate target lesions through robotic control of the distal tip sheath and leader catheter, and through robotic control of guidewires as well (Hansen Medical, 2014). This device also has centralized and remote workstation where the surgeon can control the system and reduce the probability of physician radiation exposure (Riga, Cheshire, Hamady, & Bicknell, 2010). In 2009, Hansen Medical Company got the FDA clearance for Sensei® Robotic Catheter System, and two years later for Magellan ™ Robotic System (Hansen Medical, 2014). They also establish partnerships with Philips Healthcare for the development of the vascular robotic system especially on fiber optic shape sensing and localization technology.

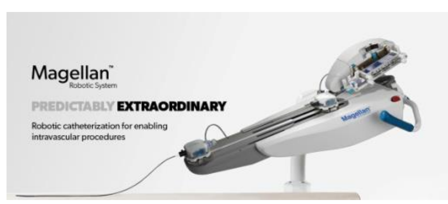

Figure 8 The Magellan robotic system

5.2.5 Accuray

Accuray is a radiation oncology company that focuses on delivering personalized innovative treatment to help cancer patients having a longer and better life (Accuray, 2014). They developed two types of oncology robotic systems, The CyberKnife® System and The TomoTherapy® System.

Figure 9 The Cyberknife

Accuray claimed that The Cyberknife System is the first, and only, non-invasive robotic radiosurgery system for treating cancerous and non-cancerous tumor in any body-parts (Accuray, 2014). It may be used for patients that have inoperable or surgically complex tumors and as a replacement of conventional surgery because its accuracy could produce a shorter and more intense course of radiation (Accuray, 2014). The Cyberknife is a frameless robotic radiosurgery system, which means it does not require a rigid frame for precise targeting (Huscher, Mingoli, Sgarzini, Mereu, & Gasperi, 2012). It has two main elements: (1) a small linear particle accelerator to produce the radiation, and (2) a robotic arm to deliver the energy to any part of the body from any direction (Huscher et al., 2012). This system has two key features that differs it from other oncological therapy methods, the first is that the radiation source is installed on a general purpose industrial robot, so that it allows the device to radiate patient in a certain desired distance and different angles without moving both the patient and the device. The second feature is the X-ray imaging cameras as a real time guidance system (Huscher et al., 2012).

5.2.6 MAKO

As an innovative medical device company, MAKO Surgical Corp. contributed to medical sector development by introducing a less invasive method for knee resurfacing and a new procedure for total hip arthroplasty called MAKOplasty®(MAKO Surgical Corp., 2014). MAKOplasty Partial Knee Resurfacing is designed to relieve pain and restore motion ability for adults diagnosed by early to mid-stage osteoarthritis that has not evolved all three parts of the knee (MAKO Surgical Corp., 2014). Meanwhile, MAKOplasty Total Hip Arthroplasty is designed for patients who need total hip replacement with high accuracy and precision level that could restore mobility and active lifestyle faster (MAKO Surgical Corp., 2014). This MAKOplasty procedure is empowered by two kind of robotic systems named RIO® Robotic Arm Interactive Orthopedic System and proprietary RESTORIS® family of implants (MAKO Surgical Corp., 2014). Tarwala & Dorr (2011) reported that the MAKO robotic guided navigation is a valuable innovation in total hip replacement since it is able to provide precise quantitative information about the component position and biomechanical reconstruction of leg length and offset. They also argued that this device has a fail-safe mechanism for acetabular preparation and cup implantation.

Figure 10 The MAKOplasty

MAKOplasty procedure assists the surgery through a robotic arm that is controlled by the surgeon. This device provide tactile feedback and real-time 3D CT-scan imaging to guide the operation, so that it can result in an accurate and proper implant position while conserving healthy bone (MAKO Surgical Corp., 2014).

5.2.7 Titan Medical

Currently, Titan Medical Inc. is developing a robotic surgical system named SPORT that is expected to be commercially available in 2015. SPORT (Single Port Orifice Robotic Technology) is a minimally invasive surgery device that will allow the surgeons to perform the surgery within a single and small hole in the body (Titan Medical Inc., 2014). This device consists of two main compartments, the first is a single-port surgeon controlled robotic platform that includes a 3D vision system and other interactive instruments for performing MIS procedures, and the second is a surgeon workstation that enable the surgeon to control the instruments as well as viewing the 3D endoscopic images from a console (Titan Medical Inc., 2014). Titan Medical stated that this minimally invasive surgery robot will focus on assisting general surgery (gall bladder and appendix removal) and surgery of ear, nose, and throat, rather than entering common medical procedures for which robotic systems are used such as hysterectomies and prostatectomies.

Figure 11 The SPORT (Single Port Orifice Robotic Technology)

5.2.8 Transenterix

Transenterix is a company that also focuses on minimally invasive surgery, especially on MIS surgery. They claimed themselves as the pioneer in using flexible instruments and robotics to improve the outcomes of minimally invasive surgery (TransEnterix, 2014). Transenterix is a relatively new company, since it is founded on 2007. Hence, to strengthen the company in medical market, on 2013 Transenterix announce the merger with SafeStitch, a medical device company focused on the development of technologies that manipulate tissues for the treatment of obesity and other intraabdominal abnormalities through endoscopic and minimally invasive surgery (TransEnterix, 2014).

This company has two medical robotic devices, The Spider Surgical System that has been approved by FDA and is currently available in medical market, and Surgibot System that is still under development (TransEnterix, 2014). We will only take one case that has already proven by FDA, Spider Surgical System.

Spider Surgical System is a flexible MIS platform that allows multiple instruments to be used through one incision, usually on belly button (TransEnterix, 2014). Thing that differs it from conventional MIS is its flexibility, since the conventional one used rigid instruments that limit the optimum process of the surgery. One of the key features of this device is the instrument delivery tubes (IDTs), which could accommodate a range of flexible instruments (TransEnterix, 2014). Other key feature is the true left and true right instrumentation that could eliminate the awkward cross arms movement, so that a single surgeon could operate the device more naturally from an open platform with multiple working channels (TransEnterix, 2014).

Figure 12 The Spider Surgical System

5.2.9 PRECEYES

Medical Robotic Technology in collaboration with Eindhoven University of Technology developed robotic technology for medical applications, that focused on cure sector such as vitreo-retinal (VR) eye surgery and minimally invasive surgery (Medical Robotics, 2014). The VR eye surgery robotic device or PRECEYES was started to build on 2006, by a PhD candidate at that time, Thijs Meenink. He built a smart eye-surgery robot that allows eye surgeons to operate easier with greater precision on the retina and the vitreous humor of the eye, or called VR-surgery (Eindhoven University of Technology, 2011). This kind of surgery needs high precision and steady hand movements, since it is performed minimal invasively with 0.5mm needle shaped instruments on a delicate micrometer range thick tissue (Eindhoven University of Technology, 2011). However, as Meenink finished his PhD research at Eindhoven University of Technology on 2011, the development of PRECEYES was continued by Medical Robotics Company.

PRECEYES consists of master and slave part. A surgeon remains fully in control to the robot by operating it from the master using two joysticks, meanwhile the slave as two robotic arms copy the movements of the master and operating in the real field. The robotic arms included the 0.5mm needle-like instruments that consists of forceps, surgical scissors, and drains. One of the advantages of this robot is that the needle is designed to enter the eye always at the same location, so it could prevent damage to the surrounding eye tissue (Eindhoven University of Technology, 2011).

Another uniqueness of this device is the 'instrument changer', where the slave part could change instruments, for instance forceps to scissors, within only a few seconds. PRECEYES also could provide haptic feedback as well as high precision movement, since surgeon control the tiny instruments via joystick where every particular centimeter of the joystick movement is translated into only one millimeter at the tip of the needle (Eindhoven University of Technology, 2011). An ophthalmologist from AMC Amsterdam, Prof. dr. Marc de Smet stated in the website that the robotic eye surgery is the next step in the evolution of microsurgery in ophthalmology, and will lead to further development. The robot eye surgery devices are not available yet in the market, and this robot is claimed to be the first one (Eindhoven University of Technology, 2011).

Figure 13 The PRECEYES

6. Scoring Results and Analysis

The sixth chapter provides the answer of third research questions about: "which diseases or treatments that have the largest clinical market could be successfully addressed by medical robotic products?" This chapter is divided into two sections. Section 6.1 describes about the scoring procedure and results by using Cooper scoring models. Afterwards, the TOPSIS analysis regarding the Cooper models will be described in section 6.2.

6.1. Cooper scoring models

This scoring model is used to compare the criteria of each robotic case and its compatibility with ASML. As mentioned above, this scoring model consists of nine criteria that has each own weight based on the coefficient regression. The criteria are divided into two types, product-related criteria and company-related criteria. The first type consists of product superiority, economic advantage to the user, market need/size/growth, and product scope. Meanwhile, the company-related criteria, which in this case is ASML, consists of company-project fit, technological compatibility, familiarity to the firm, and market competitiveness. In order to make it more in accordance with healthcare market, we decided to modify this model by adding one more criteria namely healthcare technology fit. We realized that we need to consider new medical product with current situation of healthcare such as surgeon skills and space availability. We thought that this criteria was as important as company-fit project, so we decided to put the same weight and made some little adjustment with other factors' weight to keep the total amount of all weight remains one.

There were three contributors filled this scoring model including a compatible person from ASML to fill company-project fit, technological compatibility, and familiarity to the firm, a bachelor student that focused on the scoring for product superiority and economic advantage to the user, and this thesis writer who scored the remaining factors. The scoring procedures and results per criteria is described below.

1. Product superiority (0.25)

Sophie van der Voort, a bachelor student of Health Science at University of Twente, did this calculation to fulfil her bachelor thesis project.

This is the most important factor of this model since it has the highest weight among all (0.25). A new product should be superior to competitors' products in terms of meeting customer needs. It also has to have unique features that competitors do not have. Basically, the healthcare products were produced to make the patients' health better. Therefore, the quality of the products should be proven in advance. For instance, in the US all products in healthcare market have to be accepted by FDA before entering the market, so that the quality is already above the threshold. Thus, in order to measure how much health benefits the robots can provide, we would like to measure their impact on quality of life of the patients. We calculated the effectiveness of the robots by using the quality adjusted life years (QALY). The QALY is the sum of a state of health and the number of years that someone is living in that state of health (Cosh, Girling, Lilford, McAteer, & Young, 2007). The state of health is expressed in a utility value and has a scale of 0 (death) to 1 (perfect health).

Accordingly, we used this formula to calculate the QALYs:

$$\Delta QALYs = \Delta utility\ x\ period\ of\ time\ with\ that\ health\ state$$

This calculation gave us an overview of the QALY gap between the current treatment and the robotic treatment as follows:

Table 5 QALYs gap between current treatment and the robotic surgery

Robots	QALY gap
SPORT	2.62
DaVinci Robot	2.61
Preceyes	1.31
Cyberknife	1.12
ARTAS	1.12
MAKOplasty	0.84
Spider	0.64
Medrobotics	0.33
Sensei/Magellan	0.075

The results showed that all treatments with those robotic devices gathered more QALY compared to current conventional treatments. We could see in Table 5 that SPORT robotic systems has the highest QALY gap (2.62), followed by da Vinci (2.61) and PRECEYES (1.31). The higher QALY gap, the better the treatment was, so we concluded that SPORT was the best robotic device for this factor.

2. Economic advantage to the user (0.13)

Sophie van der Voort, performed the calculation of economic advantage for the user.

This is the second most important marketability factor that has the same weight with healthcare technology fit and company-project fit (0.13). A product is called economically beneficial to the customers if it could reduce customers' costs, as its price is lower than the price of the competing products (R. Cooper, 1985). Therefore, we needed to know if the robotic device reduced or added the cost compared to the current treatment costs. First thing to do was to find out the cost of current treatment for every robotic device. Then, we used the time consumption differences between current treatment and robotic treatment to find out the cost differences. Eventually, the calculation between the current treatment cost and time were conducted to figure out the cost difference if we use the robot. The current cost were divided by the duration (minutes) of current treatment, and then multiplied with the duration difference (minutes) between current and robotic surgery.

$$\Delta cost = \left(\frac{current\ cost}{current\ duration}\right) x\ \Delta duration$$

When the duration of robot surgery was longer than current treatment, the difference (Δ) would be negative, which also impacted the Δcost. It meant that when the surgery with robot consumed longer time than with current treatment, the extra cost was needed. Otherwise, when the robotic surgery consumed shorter time, it could save the cost.

Van der Voort (2014) in her thesis explained the way of calculating the cost, as we can see in Table 6. The prostatectomy surgery by using da Vinci robot was longer than current treatment (±200 min) and the set-up and turn over time was assumed 15% from total time, so that in total the surgery time with da Viinci robot will be 230 min. Then we calculated two things, the difference between current surgery time and robotic surgery time, which in this case we got 23.28 minutes, then we put this number into the formula. Eventually we got the result that using da Vinci needed €3,049.13 extra costs compared to current treatment. Same way of calculation was applied to other robots, except SPORT and PRECEYES, since they were not in the market yet, we could not calculate the cost precisely. However, we tried to estimate the additional cost for these two robots with different way. As mentioned above, SPORT was a robot that tried to compete da Vinci, so we could assume that it has similar result with da Vinci. Meanwhile, PRECEYES was the only robots in eye surgery (microsurgery), so we could not compare it with other robots. To estimate the time and the cost, first we search in the internet about the average duration for doing VR eye surgery, and we found that it took 120 minutes to do it with current treatment. Since one of the advantages of the PRECEYES was to make the operation faster by increasing the precision and eliminating hand tremor of the surgeon, we assume that using the PRECEYES could reduce the time duration for 45 minutes, so that the total surgery time was 75 minutes. Then, we added the set-up time and turn over time about 15% from total time, so in total, the duration with robotic devices was 86.25 minutes. Next step was to find the cost of current treatment, which was easy by searching in the internet, and we got $4500 or equal with €3326. Finally, we added this number into the formula above, and we got the results that using PRECEYES could save cost until approximately €935.16.

Table 6 Additional costs based on differences in the duration needed

Robots	Current time	Robot time	∆ Time	Additional costs
DaVinci Robot	146.5	123.2	-23.28	-€ 3,049.13
MAKOplasty	127.2	124.5	2.69	€ 384.28
Spider	120.8	187.1	-66.32	-€ 3,095.41
Cyberknife	555	480	75	€ 1,282.07
Medrobotics	119	183.4	-64.37	-€ 2,402.63
Sensei/Magellan	92.3	87.7	4.62	€ 246.55
SPORT	146.5	123.2	-23.28	-€ 3,049.13
ARTAS	621	310.5	310.5	€ 3,270.00
PRECEYES	120	86.25	33.75	€ 935.16

For the results, instead of putting the costs value into the scoring model, we decided to score it to make the calculation simpler. Firstly, we determined the range score from 0 to 1 based on the highest extra costs (scored 0) until the highest cost savings (scored 1). According to Table 7, Spider has the highest extra costs (-€ 3,095.41), while ARTAS has the highest cost savings (€ 3,270.00). To calculate the score for other devices, the cost of each robot was subtracted by -€ 3,095.41, and the result was divided by the total of the minimum and the maximum costs.

$$Score = \frac{Additional\ costs\ of\ A_n - minimum\ costs}{total\ range\ between\ minimum\ and\ maximum\ costs}$$

$$= \frac{Additional\ costs\ of\ A_n - (-€\ 3{,}095.41)}{€\ 3{,}270.00 - (-€\ 3{,}095.41)}$$

Table 7 Economic advantage to user. Extra cost needed or saving cost.

Robots	Additional costs	Score
ARTAS	€ 3,270.00	1
Cyberknife	€ 1,282.07	0.687698
PRECEYES	€ 935.16	0.633199
MAKOplasty	€ 384.28	0.546656
Sensei/Magellan	€ 246.55	0.525019
Medrobotics	-€ 2,402.63	0.108835
DaVinci Robot	-€ 3,049.13	0.007271
SPORT	-€ 3,049.13	0.007271
Spider	-€ 3,095.41	0

Table 7 showed that Spider, da Vinci, SPORT, and Medrobotics were robots that needed huge extra costs and it was related to longer duration they needed compared to current treatments. Therefore, it also had low scores. Meanwhile, other robots gave the economic advantages to users by saving costs, since doing the treatments with these robots needed shorter time than current treatments. ARTAS was the highest cost-saving robots compared to other, since it could save half time of the duration, so that the reduced cost was higher as well (van der Voort, 2014). The same reason was also applied to other robots, so that we could see that the surgery time was an important determinant related to the cost. However, the experiences of the surgeons really affected the duration of the surgery. In the future, when more surgeon use robotic as routines, the skills will be improved, and the surgery time will be shorter as well. So, we can conclude that this results was flexible and could change sometimes in the future.

3. Healthcare technology fit (0.13)

This is a factor that analyzes how the product can fit with existing resources in healthcare such as surgeon, healthcare organization, and learning curve. How much effort the surgeon has to do to use the products? Because the more complex a product, the harder it is to be learnt, and it will reduce the acceptance rate among the surgeon. How this product can fit with available space in operation room, so that it can be used without building any additional room/space (efficient). The size of the product is a matter for this assessment. In order to score this factor, we will give five point scales to each sub-factor as follows:

Table 8 Scoring criteria for healthcare technology fit

Healthcare technology fit	Score (1-5)
Surgeon skills	1: Not in accordance with existing skills and learning curves. 2: Poorly in accordance with existing skills and learning curves. 3: Fairly in accordance with existing skills and learning curves. 4: Well accordance with existing skills and learning curves. 5: Excellently in accordance with existing skills and learning curves.
Space available	1: No fit with available space. Need a totally new space. 2: Poor fit with available space. Need some additional space. 3: Reasonable fit with available space, but will be better with a few space adjustment. 4: Good fit with available space. If necessary, need a little adjustment. 5: Excellent fit with available existing space.

Subsequently, after went through some comparisons and considerations based on the information we found regarding each robotic case, how it works, and how big the size is, we put the scores into the table below:

Table 9 Scoring results of healthcare technology fit

Robots	Surgeon skills	Space available
DaVinci Robot	3	4
MAKOplasty	5	5
Spider	4	5
Cyberknife	5	4
Medrobotics	3	5
Hansen	3	5
Titan Medical	3	4
ARTAS	5	5
Preceyes	4	5

Table 9 showed that MAKOplasty, Cyberknife, and ARTAS were robotics that excellently in accordance with existing skills and learning curves. It means that in operating those robotics, surgeon did not have to do many adjustment and training, because those robotics did not have much differences with current treatment procedure, even easier. This is in line with Bergeles & Yang (2014) that argued that a hand-controlled robot were more easily acceptable by the surgeons rather than console-controlled one, because they resemble familiar tools and can be directly introduced into their workflow. We decided that every robotic device that did not use console to operate, or in the other words, the surgeon still operated it directly in the patient's body, so they could still get the haptic feedback and easier to adjust. Meanwhile, in terms of space availability all robotic devices fit with current condition, there only three robots that needed a little space adjustment.

4. Company-project fit (0.13)

This is a factor that focuses on analyzing if the company has qualified skills and resources to produce the new product. This is also an important factor to product-outcomes. This factor analyzed if the project fits with the availability of managerial skills and marketing skills including marketing research, salesforce distribution, and advertising resources in it. Besides, this factor also analyzed if the company has financial and production resources including engineering skills and R&D resources to build this project.

In order to score this factor, we gave five point scales to each sub-factor as follows:

Table 10 Scoring criteria for company=project fit

Company-project fit	Score (1-5)
Managerial skills	1: Very negative (Not fit at all with existing managerial skills) 2: Fairly negative (Not fit in most areas of existing managerial skills) 3: Neutral (Slightly not fit with existing managerial skills) 4: Fairly positive (Fit in most areas of existing managerial skills) 5: Very positive (Fits really well with existing managerial skills)
Marketing skills	1: Very negative (Not fit at all with existing marketing skills) 2: Fairly negative (Not fit in most areas of existing marketing skills) 3: Neutral (Slightly not fit with existing marketing skills) 4: Fairly positive (Fit in most areas of existing marketing skills) 5: Very positive (Fits really well with existing marketing skills)
Financial resources	1: Very negative (Not fit at all with existing financial resources) 2: Fairly negative (Not fit in most areas of existing financial resources) 3: Neutral (Slightly not fit with existing financial resources)

	4: Fairly positive (Fit in most areas of existing financial resources) 5: Very positive (Fits really well with existing financial resources)
Production resources	1: Very negative (Not fit at all with existing production resources) 2: Fairly negative (Not fit in most areas of existing production resources) 3: Neutral (Slightly not fit with existing production resources) 4: Fairly positive (Fit in most areas of existing production resources) 5: Very positive (Fits really well with existing production resources)

Subsequently, we asked a qualified person in ASML that knew the real condition in ASML to fill this criteria. We gave him this scoring criteria to guide him putting the scores into the model, and the final scoring is as follows:

Table 11 Scoring results of company-project fit

Robots	Managerial skills	Marketing skills	Financial resources	Production resources
DaVinci Robot	3	4	4	3
MAKOplasty	3	4	4	3
Spider	3	4	4	3
Cyberknife	3	4	4	3
Medrobotics	3	4	4	3
Sensei/Magellan	3	4	4	3
SPORT	3	4	4	3
ARTAS	3	4	4	3
Preceyes	3	4	4	3

Table 11 showed that ASML gave all the robotics the same scores. They scored neutral for both managerial skills and production resources, means that current managerial was fit enough with this robotic project, but to make some adjustment and additional skills would be better. Meanwhile, they scored one point higher for marketing skills and financial resources fit, means that they were more ready and confident with this factors.

5. Technological compatibility (0.06)

This is a factor that focused on analyzing if the company has technological resources that is needed to produce the new product. In surgical robotic product, technological resources that is important are mechatronics, imaging technology, and ICT. We did it by figuring out what kind of technology that a product needs, and check if the company has the technological compatibility for producing it. The result will be obviously different between existing medical robotic company and ASML, because ASML is a new player in robotics. In order to score this factor, we will give five point scales to each sub-factor as follows:

Table 12 Scoring criteria for technological compatibility

5. Technological compatibility	Score (1-5)
Mechatronics	1: Not compatible 2: Slightly compatible 3: Somewhat compatible 4: strongly Compatible 5: Very strongly compatible
Medical imaging	1: Not compatible 2: Slightly compatible 3: Somewhat compatible 4: Compatible 5: Very strongly compatible
ICT	1: Not compatible 2: Slightly compatible 3: Somewhat compatible 4: Compatible 5: Very strongly compatible

As well as company-project fit, we also asked ASML to score this factor for their company. We gave them the table of technology needed from this nine cases (Appendix 3), so they could check which technology they have or they are compatible with, and which one is not. Then, the final scoring is as follows:

Table 13 Scoring results of technological compatibility

Robots	Mechatronics	Medical Imaging	ICT
DaVinci Robot	4	2	2
MAKOplasty	4	2	2
Spider	4	2	2
Cyberknife	4	1	2
Medrobotics	4	2	2
Sensei/Magellan	4	1	2
SPORT	4	2	2
ARTAS	4	2	2
Preceyes	4	2	2

Table 13 showed that ASML scored uniformly among all the robot devices, for mechatronics and ICT compatibility. The difference was, the score for mechatronics compatibility was higher than ICT, since ASML is an expert in mechatronic, so there would be no problem in fulfilling the requirements on it. Meanwhile, the scores for medical imaging compatibility was quite low, especially in x-ray related imaging. It was admitted by ASML since the first time we started this research that ASML had to put more remarks and efforts in this area.

6. Familiarity to the firm (0.06)

This is a factor for project outcomes to analyze how familiar this product to the firm. This resulted obviously different between existing medical robotic company and ASML, because the former has focused on medical market since the first time they were founded, meanwhile ASML was a non-medical company that wanted to enter medical robotic market. To ease the assessment, we divided this factor into five subfactors: familiar product class for the company, familiar salesforce distribution, familiar types of users' needs served, familiar customers to company, and familiar competitors to company. These subfactors are rather similar with company-project fit, only this one more focused on analyzing how familiar this project for the company, meanwhile the other one focused on existing resources that compatible for the project. We made it similar so that it could be comparable to each other.

In order to score this factor, we gave five point scales to each sub-factor as follows:

Table 14 Scoring criteria for familiarity to the firm

Familiarity to the firm	Score (1-5)
Familiar product class for company	1: Completely new product class 2: Moderately new product class 3: Slightly new product class 4: Moderately familiar product class 5: Completely familiar product class
Familiar salesforce distribution	1: Completely new for salesforce distribution 2: Moderately new salesforce distribution 3: Slightly new for salesforce distribution 4: Largely experienced for salesforce distribution 5: Fully experienced salesforce distribution
Familiar types of users' needs served	1: Completely new customers' needs 2: Moderately new customers' needs 3: Slightly new customers' needs 4: Largely existing customers' needs 5: Fully existing customers' needs
Familiar customers to company	1: Completely new customers 2: Moderately new customers 3: Slightly new customers 4: Largely existing customers 5: Fully existing customers
Familiar competitors to company	1: Completely new competitors 2: Moderately new competitors 3: Slightly new competitors 4: Largely existing competitors 5: Fully existing competitors

As well as company-project fit and technological compatibility factors, we also asked ASML to score this factor for their company. We gave them the information needed from this nine cases, so they could check which parts they were already familiar with, and which one was not. Then, the final scoring is as follows:

Table 15 Scoring results of familiarity to the firm

Robots	Familiar product class for company	Familiar salesforce distribution	Familiar types of users' needs served	Familiar customers to company	Familiar competitors to company
DaVinci Robot	1	1	1	1	1
MAKOplasty	1	1	1	1	1
Spider	1	1	1	1	1
Cyberknife	1	1	1	1	1
Medrobotics	1	1	1	1	1
Sensei&Magellan	1	1	1	1	1
SPORT	1	1	1	1	1
ARTAS	1	1	1	1	1
Preceyes	1	1	1	1	1

That was quite clear from Table 15 that this surgical robotic industry was quite new and unfamiliar for ASML. This was a common condition for a new company or an old company that wanted to enter a new market. In order to enter the surgical robotics market, ASML has to improve both management and boardrooms in system integration to aid better strategic decisions for new product as written in the article of Cambridge Consultants (2010) regarding the MIS company.

7. Market need/size/growth (0.14)

This is a factor that focused on analyzing how big and how promising the market is. We divided this factor into three sub-factors. First, to determine how big the market and demand is, we have to enter the data about the size of target group, the number of patient that go through that treatment each year. This data had been collected by bachelor student that also involved in this project, Sophie van der Voort (2014). Afterwards, another way to determine the size of the market is by considering the reimbursement rate of each treatment. We got all the reimbursement data from MediCare reimbursement database, US. Eventually, we also have to enter the data about the trend of the diseases or treatments year by year, to know whether this market is growing or not.

Table 16 Scoring criteria for market growth

Factor	
Fast growing market	1: decreased dramatically 2: decreased 3: up and down 4: steadily increased 5: steadily increased dramatically

Regarding the market size and need, we got all the data from the US and the UK database. Meanwhile, for the growing market data, we got from surgery database in the National Center for Health Statistic

Organization in US from 2007-2010 as shown in Table 17, except for hair transplantation and cancer treatment.

Table 17 Market growth data from National Center for Health Statistic Organization in US (2007-2010)

No.	Procedure	2007	2008	2009	2010
1	Operation on the cardiovascular system	6942000	7333000	7347000	7454000
2	Obstetrical procedure	7003000	7483000	7340000	7424000
3	Operation on the digestive system	5474000	5903000	6146000	6027000
4	Operation on the musculoskeletal system	4300000	5043000	5177000	5561000
5	Operation on the female genital organ	1785000	1827000	1662000	1609000
6	Operation on the eye	79000	83000	69000	81000

Based on International Society of Hair Restoration Surgery (ISHRS) data on 2011, the number of hair restoration procedures in 2010 was approximately 279,381; up 11% from 2008; and up 66% compared to 2004. Meanwhile, for cancer treatment data we used the information from American Cancer Society, Surveillance and Health Services Research (2014) as shown in Figure 14. We used the expected cancer survival rate, which will raise until two million people on 2024.

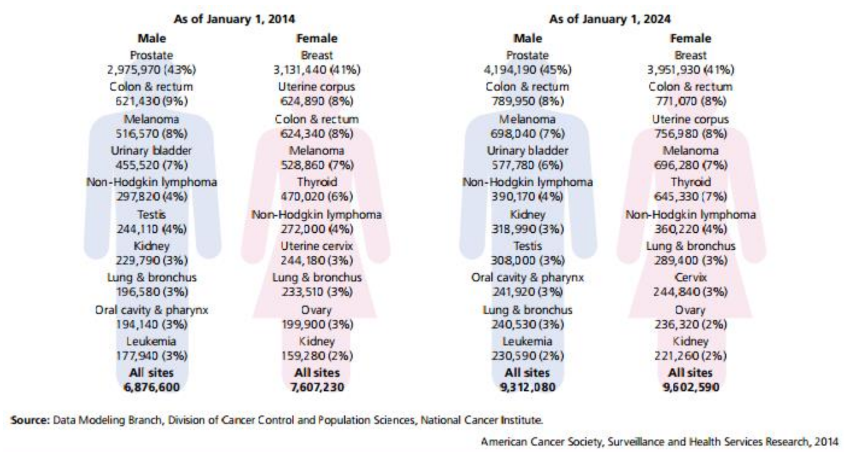

Figure 14 Market growth data for cancer treatment
Source: American Cancer Society, Surveillance and Health Services Research (2014)

Subsequently, after all the data needed were collected, we put it into the scoring model. The growing market was assessed based on the scoring criteria given above. The result is as follows:

Table 18 Scoring results of market need/size/growth

Robots	Size of target group	Reimbursement rate	Growing market
DaVinci Robot	24237391	$744	3
MAKOplasty	4226564	$1350	5
Spider	24237391	$744	3
Cyberknife	1431064	$21530	4
Medrobotics	29976027	$34000	4

Sensei&Magellan	4359073	$7000	2
SPORT	24237391	$744	3
ARTAS	129605294	$10000	5
Preceyes	325739	$995	3

Table 18 showed that ARTAS had the largest size of target group, followed by Medrobotics, while Da Vinci, Spider, and SPORT had same number of group target size since they were in the same market, MIS. The size of target group of ARTAS was so large because it was based on the number of bald men that was quite high especially in UK and US. Meanwhile for the reimbursement rate, Mediacare US gave the highest rate for group of cardiac surgeries, so in this case Medrobotics got the highest one since it focused on cardiac MIS. There was an exceptional for ARTAS, since it was not a life-threatening surgeries, and focused more to esthetic, there was no reimbursement rate for this type of surgeries. Thus, we used the average price of this treatments that we found based on internet search. The last scoring results within this criteria is the trends of how this market growing. We could see in the table xx that MAKOplasty and ARTAS got the maximum score because the number of treatment was done in those markets increased year by year. The declining trend of market growth was showed in Sensei&Magellan robots, which focused on cardiac catheterization.

8. Market competitiveness (0.05)

This is a factor to analyze how high the competition is to enter such market, in terms of players. In this factor, we would like to see how the competition environment is going on within such market, whether the market has one dominant player with strong patent, or no existing player at all, which means we explore a quite new market as the first player. In order to score this factor, we will give five point scales to this factor as follows:

Table 19 Scoring criteria for market competitiveness (players)

Factor	Score (1-5)
Market competitiveness	1: One dominant player with strong patent 2: A few strong players 3: Several equal players 4: A few equal players 5: No existing player

Subsequently, after considering all the data that we had already collected in advance regarding all the type of robotic cases, the diseases, and the treatments, we eventually could see how the competition environment was looked like in such market and could make an assessment based on the scoring criteria above. Thus, we put the result into the table below:

Table 20 Scoring results of market competitiveness

Robots	Market competitiveness
DaVinci Robot	2
MAKOplasty	2
Spider	2
Cyberknife	1

Medrobotics	2
Sensei&Magellan	2
SPORT	2
ARTAS	2
Preceyes	4

Table xx showed that among all, only PRECEYES got the highest score, means that it was still a really new market and there was only a few player that tried to be in market. However, all the robots had a few strong player in the market except Cyberknife. Cyberknife is the only radiosurgery robots in the market by far. This type of market was hard to be entered since the only player might be having a strong patent, and all the users had already trusted this robotics brand.

9. Product scope (0.04)

This is a factor and the least important one that focused on analyzing whether the product could reach wide scope or not. The product that was intended to mass use rather on individual use and customized, gave better score. As we know, medical robotic devices are obviously a mass market, not a customized one, so that the score was high for every cases. In order to score this factor, we will give five point scales to each sub-factor as follows:

Table 21 Scoring criteria for product scope

Factor	Score
Product scope	1: Fully individually customized and one or few customer(s) intended product 2: Slightly customized and few customers intended product 3: Moderately mass intended and not customized product 4: Largely mass intended product 5: Completely mass intended product

In order to make the assessment, we reviewed the data we had regarding each robotic case and scored it as follows:

Table 22 Scoring results of product scope

Robots	Product Scope
DaVinci Robot	4
MAKOplasty	4
Spider	4
Cyberknife	4
Medrobotics	3
Sensei&Magellan	4
SPORT	4
ARTAS	4
Preceyes	4

Actually, we could see from the table that all robots had same scores, means the robots were built as largely mass intended product, except Medrobotics. We put lower score for this robot, because it was only intended for very specific cardiac diseases, even not all cardiac diseases could be treated by this robot. Nonetheless, all the robots were still in the category of mass intended product, only the amount of coverage was different. Eventually, we put all the scoring above into one table of Cooper scoring model (Appendix 5), so that we can easily analyze it with TOPSIS methods that will be described in the next section.

6.2 TOPSIS Analysis

As describe in chapter three, TOPSIS method is used to find which robotic case is the most ideal one for ASML to be succeed. The reason behind why we chose TOPSIS as the analysis tool is because this method requires only a minimal number of inputs from the user, and the outputs is easy to understand. Theoretically, determining the weight is supposed to be the only subjective factor in this method, but not in this case because we adopted the coefficient regression from Cooper model to determine it.

TOPSIS has five computation steps, which the first one is gathering performances of the alternatives on the different criteria that had already been done in Cooper scoring model. Then we moved into second step, to normalize those performances so that the measurements of different units (e.g. dollars, years, etc.) could become comparable. We used the ideal normalization, and since all the criteria had to be maximized, each performance is divided by the highest value in each column.

For example, the performances of n alternatives a with respect to m criteria i are collected in a decision matrix $X = (x_{ai})$. Then the formula for ideal normalization is

$$r_{ai} = \frac{x_{ai}}{u_a^+} \text{ ; for } a = 1, \ldots, n \text{ and } i = 1, \ldots, m,$$

where $u_a^+ = \max (x_{ai})$ for all $a = 1, \ldots, n$;

$$r_{ai} = \frac{x_{ai}}{u_a^-} \text{ ; for } a = 1, \ldots, n \text{ and } i = 1, \ldots, m,$$

where $u_a^- = \min (x_{ai})$ for all $a = 1, \ldots, n$.

Therefore, our first step is to find the highest value in each column by using excel formula =MAX(Fn:Mn). The results of this step can be found in Appendix 6. Subsequently, we translated the ideal normalization formula $r_{ai} = \frac{x_{ai}}{u_a^+}$ into excel formula and the results for each robotic case can be found in Appendix 7.

Subsequently, after we had the ideal normalization value, we constructed a weighted normalized decision by multiplying the ideal normalized scores r_{ai} by their corresponding weights w_i. We translated the formula of this step ($V_{ai} = w_i \cdot r_{ai}$) into excel formula by multiplying priorities column with sub-weight column and we can see the results in the Appendix 8.

Afterwards, the weighted scores will be used to compare each action to an ideal and anti-ideal virtual action. One of the ways to define these virtual actions is by collecting the best and worst performance on each criterion of the normalized decision matrix. So, that for the ideal action we have

$$A^+ = (v_1^+, \ldots, v_m^+)$$

And for the anti-ideal we have

$$A^- = (v_1^-, \ldots, v_m^-)$$

Where $v_i^+ = \max_a(v_{ai})$ if criterion *i* is to be maximized and $v_i^- = \min_a(v_{ai})$ if criterion *i* is to be minimized. This formula was translated into Excel formula on each criterion of the normalized decision matrix, and the results can be seen in Appendix 9.

The next step is to calculate the distance for each weighted normalized action to the ideal action ($d_a^+ = \sqrt{\sum_i (v_i^+ - v_{ai})^2}$) and the anti-ideal action ($d_a^- = \sqrt{\sum_i (v_i^- - v_{ai})^2}$). We translated the formula into Microsoft excel formula, and the results is as seen in Table 23. A good results of this calculation was the one that had the low value of d_a^+because it means it had a close distance with ideal solution, and the one that had a high value of d_a^- because it means it has a wide distance with the anti-ideal solution.

Table 23 The value of the distance to the ideal and anti-ideal action for each robot

Robots	d_a^+	d_a^-
DaVinci Robot	0.1496	0.2430
MAKOplasty	0.1835	0.1557
Spider	0.2396	0.0614
Cyberknife	0.1237	0.1947
Medrobotics	0.2597	0.0604
Sensei&Magellan	0.2544	0.1319
SPORT	0.1496	0.2439
ARTAS	0.1491	0.1768
Preceyes	0.1432	0.1812

Finally, we could calculate the relative closeness coefficient of each action to find out which robotic cases that are the closest to ideal action, by using the formula $C_a = \frac{d_a^-}{d_a^+ + d_a^-}$, we got the final results as written in Table 24 below.

Table 24 Final results: the most ideal robot in sequence

Rank	Robots	C_a
1	SPORT	0.7165
2	DaVinci Robot	0.6203
3	Cyberknife	0.5667
4	ARTAS	0.5425
5	PRECEYES	0.4995
6	MAKOplasty	0.3662
7	Sensei&Magellan	0.2154
8	Spider	0.2040
9	Medrobotics	0.1970

Table 24 showed us which robotic device was the most ideal one to be considered by ASML as guidance in order to invest in medical robotic products in the future. Surprisingly there was SPORT leading in the first place, followed by da Vinci, and then by Cyberknife. SPORT and da Vinci were competing really tight here, with same scoring value for each criteria. Nonetheless, there were one differentiator among them, the QALYs gap of SPORT was a little bit higher than da Vinci (Table 5). There were some reasons, firstly the fact that SPORT only needed one incision while da Vinci still needed multiple incisions impacted to the recovery period and scars left. The old da Vinci was reported to be able to do single incision surgery, but the technique of the robot was not supported enough, especially for the wrist control (Fox, 2015). Secondly, the da Vinci did not have tactile feedback, so the surgeon had to learn it more complicatedly and needed more training, because it did not suit the background education they had (Fox, 2015). Actually, the SPORT was made to improve all the shortage in da Vinci, so it was fair enough if it was better than da Vinci. However, we needed to consider about the fact that SPORT had not been in the market until now, so that the calculation about economic advantage would be rather invalid compared with da Vinci, since there were no data regarding the extra costs and clinical outcomes studies.

To make a balance view, we would like to describe high and low point of other robotic cases based on their results in the scoring model. As a remark, since the “product superiority (QALYs gap)” factor had the highest weight, so the score in this factor had the greatest influence in final results. Sitting at the third position, Cyberknife actually had quite high score in most factors. The QALY gap was high and it had a promising market that was growing year by year. However, since Cyberknife is the only robot in its market that do the radiosurgery, Cyberknife could monopolize it so that new players would find difficulties to enter such market, and it made the score very low. Besides, even if the market was growing, the target group was not as high as other robots, so the score also fell in this factor. However, Cyberknife was a promising market in terms of reimbursement rates, since it had a quite high price and was the second highest among all. In the fourth position we had PRECEYES that also had high QALYs gap and in accordance with surgeon skills, since this robot was aimed to overcome the obstacles that surgeon faced in operating eye, such as precision and hand tremor. The trends in the market for eye surgeries was not really good, since the graphic showed ups and downs number of eye surgeries conducted year by year. Nonetheless, it was the only robot that had a positive score in terms of market competitiveness, since currently there is no player in it, even PRECEYES has not entered the market yet, so it was very open and promising market for companies that want to enter it.

Next position held by ARTAS, which had average score in other factors, but lower score in QALYs gap compared to the top four cases. Actually, ARTAS was not the only player in this market, there was another player that made the competitiveness was a little bit lighter, because it means that ARTAS did not monopolize the market and the patent. However, ARTAS had a quite high number in terms of reimbursement rates factor, but actually since it was not a life threatening case, we put the public rate for hair transplantation rather than the reimbursement rates, and it was the third highest number after Medrobotics and Cyberknife. MAKOplasty as the robots that helped knee and hip surgeries is in the next position following ARTAS. The QALYs gap is lower, but it had a high score for healthcare technology fit especially in surgeon skills. To operate this robot, surgeons did not need to do a lot of training and adjustment because the robot was positioned inside the body by the surgeon to ensure the cutting took place only in the pre-specified districts. Same with ARTAS, it had a promising market that growing year by year. Spider had a good score in surgeon skills compatibility compared to other robots in MIS field, because surgeon did not work in the console, but directly held the devices. So they still could get the haptic feedback, and this was a positive values compare to console-control robots. However, the trend in MIS market was not as good as other market since it had ups and downs trend year by year, so we scored it lower than other.

The three lowest scores were held by Sensei&Magellan, Spider, and Medrobotics. As we could see, two of them were robots for heart diseases treatments, which the QALYs gaps with current treatments were not so high. Medrobotics scored higher than Sensei&Magellan because it had higher reimbursement rates since the operation was more complex than the other one, and it aimed for wider target while the latter was for specific heart disease treatment (catheterization). However, the other shortage of Sensei&Magellan in ASML's perspective was the imaging system, since they were not compatible in that area. The last robot was Spider, another MIS robot device that did not need a console to operate. However, this robot scored low because the QALYs gap with the current treatments was low, although the other factor scored same with other MIS robots, even in terms of fitness with space available it scored perfect, because it was a small device that had similar size with manual tools that were used in current treatments. According to the thesis of van der Voort (2014), Spider had longer operation time than current treatment, and the accuracy was not as good as current treatment, so it affected the QALYs gap.

7. Discussion, Conclusion, and Recommendation

The main goal of this study is to assess the likely success of medical robotic innovations, in order to support the investment decision of ASML in medical robotic. Accordingly, four main research questions were made to achieve the goal such as which diseases or treatments have the highest healthcare expenditure? Which medical robotic products are currently available in healthcare? Which diseases or treatments that have the most healthcare expenditure could be successfully addressed by medical robotic products? Which medical robotic devices for which diseases or treatments fit the core competences of ASML? The aim of this chapter is to discuss all the findings based on the theoretical framework, and give some recommendation to support the investment decision of ASML in medical robotic. This chapter starts with a discussion of the main findings in section 7.1. Section 7.2 gives some conclusions, and recommendations for ASML together with future research are given in section 7.3.

7.1 Discussion

This research project analyzed the most ideal medical robotic innovations that have the likelihood of success based on our literature findings, interview with experts, and scoring model analysis. The aim is to give some recommendations to ASML in order to support investment decision of this company in medical robotics. The findings described in previous chapters highlight several issues that need further discussion, namely (a) the product-market combination (PMC) and (b) the most ideal PMC.

(a) The product-market combinations (PMC)

First of all, defining the market was the first thing to do to start a research in new technologies. We defined the market for this project as the diseases and treatments that have the highest costs and the most frequent ones worldwide. However, we decided to focus for searching and collecting data from US and European databases because it was easier to find complete data in English. Furthermore, different health situation between developing countries and developed countries gave us insight that introducing robotic devices is more feasible for developed countries compare to developing ones.

In determining the top five highest healthcare expenditure, we decided to only include diseases that need invasive treatment as the market for new medical robotics. This decision is in accordance with a report of surgical workshop by Cambridge Consultants (2013), which concluded that surgical intervention sits at the core of the world's healthcare system, both clinically and financially. Moreover, surgical intervention nowadays heavily dependent on a small number of highly skilled surgeons that requiring extremely complex and costly centralized infrastructure (Cambridge Consultants, 2013). That is the reason why surgery is in two situation, as a clinical necessity and a huge cost center and bottleneck for every healthcare organizations in the world. As mentioned before, we first determined the market based on the highest expenditure diseases, and then continued with further search about the most frequent surgeries conducted in 2007-2010 (Figure *3*). Surprisingly, those four types of surgeries are still in accordance with several highest expenditure diseases (Table 4). Endovascular surgeries are invasive procedures in cardiac system diseases and endoscopic surgeries are invasive procedures in digestive system diseases, while musculoskeletal surgeries are obviously invasive procedures for musculoskeletal diseases.

Analyzing a market needs an exact number of its size, to have an insight of how big it is. Thus, we subsequently collected the data about the most common surgeries that are done within particular time. There were three surgeries that were being the most frequent surgeries conducted in US in 2007-2010, namely cardiovascular surgery, endoscopic surgery, and musculoskeletal surgery. We could see that those results were in line with our findings in the highest healthcare expenditure, which made this findings more reliable for the next step. However, an interview with Prof. Ivo Broeders made us decide to add microsurgery as another promising market for robotics. Those four markets were in accordance with current trends in surgical treatments, called minimally invasive surgery (MIS). There has been a shift of paradigm in the surgical approaches in terms of the invasive techniques, from the open surgery to the MIS, in order to reduce adverse events. This statement was in line with article of Mack (2001), which stated that MIS becomes the focus of surgical approaches recently because of its superior outcomes in improving survival rate, fewer complications, and faster return to functional health and productive life. As a type of surgeries that needed as small access as possible, MIS demanded quite high skill surgeon to do the operation. In MIS, surgeon faced several limitation both in viewing the operation area and in directly touching the intended organ.

Those condition appeared to be sufficient for the requirements of the robotic surgery. Advancements in video imaging, endoscopic technology, and instrumentation had made it possible to convert many difficult and almost impossible procedures of MIS. Mack (2001) in his article argued that robotics could create a completely integrated system that converts information to action, by facilitating potential tasks such as information gathering and networking, navigation and guidance, dexterity and enhancement, and simulation of virtual environments. Hence, this brought more confidence to do the investment in surgical robotic devices. Nine robotic cases were collected to be compared and analyzed, to give some insights for ASML to choose which type of surgical robotic market they want to enter, as early decision stage. Those nine cases represent different market and characteristic, such as robotics for MIS, robotics for MIS with snake-arm technologies, robotics for single incision surgeries, robotics for hair transplantation, robotics for cancer surgeries, robotics for cardiac catheterization, robotics for musculoskeletal surgeries, and robotics for microsurgeries, which in this case is eye surgeries.

Accordingly, we could see a product-market combination that we already expected. All nine robotic cases represent four market that was defined earlier. In order to determine which PMC is the most ideal one for ASML, we did some filters such as scoring and analysis model that would be discussed in next sub-section.

(b) The most ideal PMC

In order to get the best PMC in this market, the use of Cooper scoring models and TOPSIS analysis was appropriate as filters. The simplicity of those tools that produced easy-to-understand results was fit with the situation of this research. However, the outcomes from the scoring models and analysis showed a little unexpected thing. At first we predicted that da Vinci was the one that would be really suit with ASML competences, but in fact the final results showed that SPORT was the most ideal one, followed by da Vinci with a slightly different score, and PRECEYES at the third position. Nonetheless, SPORT has not been in the market until now, so that the calculation about economic advantage for the users would be rather invalid compared with da Vinci, but the characteristics of SPORT and da Vinci are in line with trends in surgical procedures in the future.

SPORT is a minimally invasive surgery device that will allow the surgeons to perform the surgery within a single and small hole in the body (Titan Medical Inc., 2014). This robot consists of one robotic arm including a camera and different instruments in it, which controlled by a surgeon behind a console. Titan Medical Company built this robotic devices to compete da Vinci by improving all the shortages in da Vinci systems. Da Vinci also already expanded their products by launching their newest product that worked based on single incision surgery procedures because they already saw this shifted trends (Intuitive surgical, 2014). This is in line with some theories that predicted the surgical trends would be less and less invasive, shift from minimally invasive surgery to single invasive surgery, and in the end it would be non-invasive surgery (Cambridge Consultants, 2013). This trend happened for some reasons, money was usually being the first consideration for every party. Less invasive means less wound, so that it reduced the side effect and the long stay in hospital, and eventually impacted to the total costs. However, in surgeon's point of view single incision surgery was not a favorable one. The fact that they had to handle all the instruments by one hand as well as lack of visualization limited their freedom of movement. Thus, they really needed a very flexible robotic devices that could bend smoothly inside the body through one small incision with proper imaging systems for visualization.

Speaking of imaging systems, as agreed by some experts in the workshop that was held by Cambridge Consultants (2010), a better surgical outcomes across multiple segments would be gained by integrating real-time imaging systems with the treatments. This idea emerged because providing real-time imaging while the treatment was conducted could enable better and more efficient surgical planning and peri-operative decision making. Real time imaging consisted of several sources such as CT scan, MRI, ultrasound, x-ray, 3D camera, fluorescence, and thermography. With this real time imaging systems, the expectation that surgeons' function would shift from someone who manipulating tissue or organ to a decision maker will become real. Accordingly, we concluded that the demand of future robotic was clear, to have a flexible and real time imaging robotic devices.

However, we also had to consider the accordance of the robotic technologies with current surgeons' skill. Mostly said that using a flexible endoscope was unpleasant because it felt like pushing a rope into an empty room, they lost the sense of tactile feedback, moreover when the surgeon had to operate the robot from the console. SPORT got one point higher here, because as mentioned in article of M. Fox (2014) SPORT was built to improve some shortages in da Vinci which one of them was creating the tactile feedback system for surgeons. However, adjusting the learning curve to be more visual feedback could be one of the way out from the education side. Also, a surgical robotic producer should be more concern about this issue, by improving both tactile feedback and visual feedback system.

In order to enter the market, we had to consider about how many players that had already been there and how strong they were. As we know, MIS market was monopolized by da Vinci so far, because this robot was the first player in this market. At first, da Vinci focused on cardiac surgery, but it did not work because of the complicated procedure and high costs. Then they focused their operation to general MIS surgeries, especially prostatectomy and gall-bladder surgeries because of the easiness and the number of patients, even though the reimbursement rate was not as high as cardiac surgeries. As the first founding and player in MIS robotic devices, da Vinci had a strong position in the market as the only dominant player. Once, there was a company named Computer Motion tried to enter the market with the similar product and got sued by Intuitive Surgical for nine patent infringements. Computer Motion lost the case and then was bought by Intuitive Surgical a few years later. It could describe how strong da

Vinci is in the market until now. Titan's idea to produce SPORT based on the da Vinci device's shortages was another breakthrough to enter the market. However, in terms of low entry barrier, microsurgery (eye surgery) market was the most favorable one compared to other cases. There were several player, but not really focused on the eye and not a strong one. PRECEYES was our best three ideal cases, even though it is not in the market yet, but it is considerable to enter such market, if we wanted to enter the easy one.

7.2 Conclusion

In this section we conclude all the answers from four research questions of this project.

1. Which diseases or treatments have the largest clinical market?

There are four types of surgeries that could be considered as the most promising market for new medical robotic devices. Those are:
1. Endovascular surgeries
2. Endoscopic surgeries
3. Musculoskeletal surgeries
4. Microsurgery

Endovascular surgeries are invasive procedures in cardiac system diseases and endoscopic surgeries are invasive procedures in digestive system diseases, while musculoskeletal surgeries are obviously invasive procedures for musculoskeletal diseases. Accordingly, we saw microsurgery as other option of surgical robotic devices market. Currently, there is still no dominant player in that market, so the entry barrier is rather lower than other three areas.

2. Which medical robotic products are currently available in healthcare?

Those nine robotic cases are Da Vinci System, the Flex System, SPORT, and SPIDER for minimally invasive surgery procedures, ARTAS for hair transplantation, Sensei and Magellan System for intravascular surgery, Cyberknife System for radiosurgery, MAKOplasty for knee and hip replacement surgery, and PRECEYES for eye surgery (microsurgery).

3. Which diseases or treatments that have the largest clinical market could be successfully addressed by medical robotic products?

Based on the Cooper scoring model, all treatments with those robotic devices gathered more QALY compared to current conventional treatments. It means that all the diseases or treatments could produce better patients' outcome with the involvement of robotic devices. However, costs was being the biggest obstacle in this case. Some robotics such as Spider, da Vinci, SPORT, and Medrobotics needed huge extra costs and it was related to longer duration they needed compared to current treatments. Meanwhile, other robotic products could do vice versa, since they were able to performed the treatment in shorter duration, they could save the costs as well. This was one important point that should be paid more attention in addressing the robotic device to treat particular diseases.

4. Which medical robotic devices for which diseases or treatments fit the core competences of ASML?

The assessment by Cooper scoring models and TOPSIS analysis method resulted SPORT and da Vinci surgical system as the most ideal devices that could bring success to ASML. Thus, we would like to recommend ASML to be focus on general MIS market, where these two robots are. The obstacle would be the competitiveness, since da Vinci holds very strong patent. SPORT is not in the market yet, and will be introduced to the market in 2015.

However, there is other recommendation. Sitting at the third position in the analysis, Cyberknife could also be the promising robotic devices to be considered by ASML. The biggest obstacle is the imaging system, which ASML does not have capability on it at all. But then, collaborate with a strong imaging company will be a way out to create a strong robotic device in this field.

Eventually, we still have one more choice, to invest in the market of the fourth most ideal robot based on the analysis, microsurgery. There are some strong reasons to consider this market. Firstly, we have the advantage in terms of market competitiveness, since currently there is no player in it, even PRECEYES has not entered the market yet, so the market is very open and promising for companies that want to enter it. Secondly, the future trends of robotics tends to lead to smaller devices rather than big device with console. Currently, we are heading to the era of nano-robotic, so in order to be in line with it, we would better consider about smaller devices rather than big one.

7.3 Recommendation

According to the final results, there are four alternatives that could be considered by ASML. However, we would like to give one final advice for ASML to support their investment decision in healthcare market. We recommend ASML to enter the MIS market (Da Vinci). There are some factors to support this recommendation including the number of target group and the estimated selling price, which we put into a rough calculation to predict total gross revenue per year. Based on this calculation, Da Vinci appeared as the highest one (Appendix 10).

Accordingly, there are three key points that have to be highlighted by ASML: (a) cost, (b) technology or functionality, and (c) law suits. *Cost* – in order to compete with Da Vinci, we have to make robotic products with lower price and costs. We also have to consider that in the real situation, the number of market size may shrink, which may change the cost calculation. *Technology or functionality* – other aspect to consider in developing surgical robotic devices is the future trends of surgical robotics technologies. Based on several articles, the robotics trends will lead to nano-robotics and automatization, meanwhile the surgery procedures are heading to non-invasive surgery or surgery via natural orifice. In the perspective of surgeons, future robotic trends are going toward real-time imaging system and better haptic feedback systems. *Law suits* – intellectual property of Da Vinci products will be one of the biggest obstacles in this market. ASML has to address this issue really well, considering the previous cases where Intuitive Surgical Company sued every competitor that enters their market, which always ended up with the victory on their side. As the conclusion, we recommend ASML to develop a surgical robotic device that has an advanced technology, less expensive, and easy to operate.

Further Research

We believe that this research has many shortages in some aspects, due to the limited time of the project. In this research, we only looked into the existing medical technology, meanwhile there are many others new technologies that lead into new treatment procedures that could be interesting to focus on. For instance, we knew that ASML now is also focusing on tissue printing technology, and we think that it will be interesting if ASML can perform a market analysis for that technology. In terms of robotic cases, we only selected the commercial ones, in which the information could be easily gathered from internet. Meanwhile, there are a lot of fresh and new ideas of robotics in the start-up projects in universities. Thus, we suggest another research that can deep dive into those areas. Further research is also needed to investigate market size in order to calculate a more reliable cost, so we can reach our goal in terms of developing lower price robotic device.

References

A Roadmap for U.S. Robotics. (2013).

AAOC. (2013). Total Hip Replacement. *American Academy of Orthopaedic Surgeons*. Retrieved from http://orthoinfo.aaos.org/topic.cfm?topic=a00377

Accuray. (2014). Accuray. Retrieved June 02, 2014, from http://www.accuray.com/healthcare-professionals

Bakker, G., & Roszek, B. (2007). *New and Emerging Medical Technologies*. *RIVM* (pp. 1–116). Bilthoven.

Bergeles, C., & Yang, G.-Z. (2014). From passive tool holders to microsurgeons: safer, smaller, smarter surgical robots. *IEEE Transactions on Bio-Medical Engineering*, *61*(5), 1565–76. doi:10.1109/TBME.2013.2293815

Bismuth, J., Duran, C., Stankovic, M., Gersak, B., & Lumsden, A. B. (2013). A first-in-man study of the role of flexible robotics in overcoming navigation challenges in the iliofemoral arteries. *Journal of Vascular Surgery*, *57*(2 Suppl), 14S–9S. doi:10.1016/j.jvs.2012.08.124

Butter, M., Rensma, A., van Boxsel, J., Kalisingh, S., Schoone, M., Leis, M., … Korhonen, I. (2008). *Interim Final Report report*.

Calantone, R. J., & Cooper, R. G. (1977). A Typology of Industrial New Product Failure. *Contemporary Marketing Thought*, 492–497.

Camarillo, D., Krummei, T., & Salisbury, J. (2004). Robotic technology in surgery: past, present, and future. *Am J Surg*, *188*, 25–155.

Cambridge Consultants. (2010). *Navigating Surgical Options : The Future of Minimally Invasive Surgery A Workshop Hosted by Cambridge Consultants*.

Cambridge Consultants. (2013). *Disrupting the Operation : The Surgical Landscape in 2030 A workshop hosted by Cambridge Consultants*.

Cooper, R. (1979). Original article Newprodmodel Cooper_1979.pdf. *Journal of Marketing*, *43*, 93–103.

Cooper, R. (1985). Selecting Winning New Product Projects: Using the NewProd System.

Cooper, R. G. (1981). Project Selection Model, (3), 54–61.

Cooper, R. G. (1994). New Products: The Factors that Drive Success. *International Marketing Review*, *11*(1), 60–76. doi:10.1108/02651339410057527

Cosh, E., Girling, A., Lilford, R., McAteer, H., & Young, T. (2007). Investing in new medical technologies: A decision framework. *Journal of Commercial Biotechnology*, *13*(4), 263–271. doi:10.1057/palgrave.jcb.3050062

Crawford, C. M. (1979). New product failure rates - facts and fallacies. *Research and Management*, 9–13.

Da Vinci Surgery. (2013). da Vinci...Changing the Experience of Surgery. Retrieved from http://www.davincisurgery.com/

Eindhoven University of Technology. (2011). Fast high precision eye-surgery robot helps ophthalmologists. Retrieved from http://www.tue.nl/en/university/news-and-press/news/fast-high-precision-eye-surgery-robot-helps-ophthalmologists

Fleuren, M., Wiefferink, K., & Paulussen, T. (2004). Determinants of innovation within health care organizations: literature review and Delphi study. *International Journal for Quality in Health Care : Journal of the International Society for Quality in Health Care / ISQua*, *16*(2), 107–23. doi:10.1093/intqhc/mzh030

Fox, M. C. (2015). Taking Down Goliath Part II : Why Titan Medical Represents A Formidable Contender In The Surgical Robot Market, 1–7.

Gomes, P. (2011). Surgical robotics: Reviewing the past, analysing the present, imagining the future. *Robotics and Computer-Integrated Manufacturing*, *27*(2), 261–266. doi:10.1016/j.rcim.2010.06.009

Hansen Medical. (2014). Intravasccular Robotics. Retrieved from http://www.hansenmedical.com/international/

Hopkins, D. S. (1980). *New Products Winners and Losers*.

Huscher, C. G. S., Mingoli, A., Sgarzini, G., Mereu, A., & Gasperi, M. (2012). Image-guided robotic radiosurgery (CyberKnife) for pancreatic insulinoma: is laparoscopy becoming old? *Surgical Innovation*, *19*(1), NP14–7. doi:10.1177/1553350611418990

Hwang, C. L., & Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications*. New York: Springer-Verlag.

Intuitive surgical. (2014). Intuitive Surgical. Retrieved from www.intuitivesurgical.com

Ishizaka, A., & Nemery, P. (2013). *Multi-Criteria Decision Analysis: Methods and Software* (I., p. 299). West Sussex: John Willey & Sons, Ltd.

Janz, B. A., & Yang, J. (2013). Principles of Microsurgery. Retrieved from http://emedicine.medscape.com/article/1284724-overview#showall

Lai, Y. J., Liu, T. Y., & Hwang, C. L. (1994). TOPSIS for MODM. *European Journal of Operational Research*, *76*(3), 486–500.

Mack, M. J. (2001). Minimally invasive and robotic surgery. *JAMA : The Journal of the American Medical Association*, *285*(5), 568–72. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11176860

MAKO Surgical Corp. (2014). MAKO Surgical Corp. Retrieved from http://www.makosurgical.com/

Medical Robotics. (2014). PRECEYES Medical Robotics. Retrieved from http://www.preceyes.nl/

Medrobotics corporation. (2014). Medrobotics expanding the reach of surgery. Retrieved May 30, 2014, from http://www.medrobotics.com/technology.html

MedTech Europe. (2012). The European Medical Technology Industry in Figures. *The European Medical Technology Industry in Figures*.

Neuzil, P., Cerny, S., Kralovec, S., Svanidze, O., Bohuslavek, J., Plasil, P., … Sediva, L. (2013). Single-site access robot-assisted epicardial mapping with a snake robot: preparation and first clinical experience. *Journal of Robotic Surgery*, *7*(2), 103–111. doi:10.1007/s11701-012-0343-6

Ota, T., Degani, A., Schwartzman, D., Zubiate, B., McGarvey, J., Choset, H., & Zenati, M. a. (2009). A highly articulated robotic surgical system for minimally invasive surgery. *The Annals of Thoracic Surgery*, *87*(4), 1253–6. doi:10.1016/j.athoracsur.2008.10.026

Restoration Robotics. (2013). ARTAS Robotic System. Retrieved May 29, 2014, from http://restorationrobotics.com/artas-robotic-system/

Riga, C. V, Cheshire, N. J. W., Hamady, M. S., & Bicknell, C. D. (2010). The role of robotic endovascular catheters in fenestrated stent grafting. *Journal of Vascular Surgery*, *51*(4), 810–9; discussion 819–20. doi:10.1016/j.jvs.2009.08.101

Sherk, S. D. (2014). Microsurgery. *Encyclopedia of Surgery*. Retrieved July 02, 2014, from http://www.surgeryencyclopedia.com/La-Pa/Microsurgery.html

Sol, E., Garos, C., van der Helm, F., & de With, P. (2012). Holland High Tech Healthcare 2013 Roadmap, *19*(c), 1–26.

Tarwala, R., & Dorr, L. D. (2011). Robotic assisted total hip arthroplasty using the MAKO platform. *Current Reviews in Musculoskeletal Medicine*, *4*(3), 151–6. doi:10.1007/s12178-011-9086-7

Titan Medical Inc. (2014). Titan Medical Inc. Retrieved from http://www.titanmedicalinc.com/

TNO Quality of Life. (2008). *Robotics for Healthcare*. Retrieved from www.tno.nl/robotics_for_healthcare

TransEnterix. (2014). TransEnterix. Retrieved June 03, 2014, from http://www.transenterix.com/

Van der Voort, S. (2014). *Identifying Market Opportunities for Advanced Robotics Technology: Assessment by QALY analysis and a headroom analysis*.

Weber, G., Lantos, J., Borsiczky, B., Ferencz, A., Jancso, G., Ferencz, S., … Balatonyi, B. (2008). *Basic Surgical Techniques* (pp. 1–111). University of Pecs, Medical School. doi:10.1007/978-3-540-69028-3_2

Appendix

Appendix 1

The top five highest healthcare expenditure in US and European Countries

Country	Top 5 Healthcare Expenditure					Expenditure Types
	1	2	3	4	5	
US	**Heart disease**	**Trauma-related disorder**	**Cancer**	**Mental disorder**	**COPD/Asthma**	
	$99.2 bil	$80.8 bil	$80.3 bil	$79.8 bil	$64.2 bil	total expenditure
US	**Angina Pectoris**	**Essential Hypertention**	**Diabetes Mellitus**	**Low back disorder**	**Acute myocardial infarction**	
	$235.69	$160.23	$104.32	$90.24	$69.23	per employee
US	**Heart disease**	**Cancer**	**Trauma-related disorders**	**Mental disorders**	**Osteoarthritis**	
	$90.9 bil	$71.4 bil	$67.3 bil	$59.9 bil	$56.2 bil	total expenditure
US	**Congestive Heart failure**	**Coronary artery disease**	**Osteoarthritis**	**COPD**	**Mental disorders**	
	$41,058	$16,882	$13,466	$12,619	$11,101	per patient
US	**Heart disease**	**Cancer**	**Trauma-related disorders**	**Mental disorders**	**Pulmonary conditions**	
1997	$70 bil	$55.4 bil	$53.7 bil	$36.2 bil	$35.3 bil	total expenditure
2002	$67.6 bil	$48.4 bil	$55.8 bil	$47.5 bil	$45.3 bil	total expenditure
US	**Heart disease**	**Cancer**	**Trauma-related disorders**	**Mental disorders**	**Pulmonary conditions**	
2000	$61.8 bil	$42.4 bil	$45.8 bil	$37.6 bil	$39.8 bil	total expenditure
2004	$90 bil	$62.2 bil	$58.5 bil	$52 bil	$48.7 bil	total expenditure
France	**Circulatory disease**	**Digestive syst. Diseases**	**Mental disorders**	**Nervous syst. Diseases**	**Respiratory syst. Diseases**	

1998	10.70%	10.50%	9.40%	7.40%	6.20%	% of total healthcare costs
France	**Circulatory disease**	**Digestive syst. Diseases**	**Mental disorders**	**Nervous syst. Diseases**	**Musculoskeletal syst. Diseases**	
2002	11.40%	11.00%	9.00%	8.60%	7.40%	% of total healthcare costs
Germany	**Circulatory disease**	**Digestive syst. Diseases**	**Musculoskeletal syst. Diseases**	**Mental disorders**	**Nervous syst. Diseases**	
2002	15.80%	13.90%	11.30%	10%	7.90%	% of total healthcare costs
Germany	**Circulatory disease**	**Digestive syst. Diseases**	**Musculoskeletal syst. Diseases**	**Mental disorders**	**Nervous syst. Diseases**	
2004	15.70%	14.80%	10.90%	10%	8.20%	% of total healthcare costs
The Netherlands	**Mental disorders**	**Symptoms and ill-define**	**Coronary heart disease**	**Dental problems**	**Dementia**	
Men - 1999	$1.55 bil	$1.03 bil	$584 mil	$568 mil	$448 mil	total expenditure
The Netherlands	**Symptoms, ill define**	**Dementia**	**Mental disorders**	**Pregnancy**	**Stroke**	
Women - 1999	$1.35 bil	$1.31 bil	$1.23 bil	$763 mil	$612 mil	total expenditure
The Netherlands	**Mental disorders**	**Circulatory disease**	**Digestive syst. Diseases**	**Symptoms, ill-defined**	**Musculoskeletal syst. Diseases**	
2003	15.60%	10.90%	10.20%	9.40%	7.70%	% of total healthcare costs
Spain	**Circulatory disease**	**Respiratory syst. Diseases**	**Symptoms, ill-defined**	**Digestive syst. Diseases**	**Pregnancy & child birth**	
1993	14.80%	13.50%	13.10%	8.70%	7%	% of total healthcare costs
Sweden	**Mental disorders**	**Circulatory disease**	**Respiratory syst. Diseases**	**Nervous syst. Diseases**	**Cancer**	
1991	18.40%	16.90%	7.70%	5.80%	5.60%	% of total healthcare costs

UK	**Circulatory disease**	**Mental disorders**	**Respiratory syst. Diseases**	**Digestive syst. Diseases**	**Cancer**	
1993	25.70%	14.40%	9.80%	8.30%	8.30%	% of total healthcare costs

Appendix 2

Article sources of top five highest expenditure diseases

No.	Country	Top 5 Healthcare Expenditure					Authors
		1	2	3	4	5	
1	US	**Heart disease**	**Trauma-related disorder**	**Cancer**	**Intellectual Disability**	**COPD/Asthma**	Cohen S. (2012)
2	US	**Angina Pectoris**	**Essential Hypertention**	**Diabetes Mellitus**	**Low back disorder**	**Acute myocardial infarction**	Goetzel et al. (2003)
3	US	**Heart disease**	**Cancer**	**Trauma-related disorders**	**Intellectual Disability**	**Osteoarthritis**	Soni, A. (2011)
4	US	**Congestive Heart failure**	**Coronary artery disease**	**Osteoarthritis**	**COPD**	**Intellectual Disability**	Ehrlich et al. (2010)
5	US	**Heart disease**	**Cancer**	**Trauma-related disorders**	**Intellectual Disability**	**Pulmonary conditions**	Olin and Rhoades (2005)
6	US	**Heart disease**	**Cancer**	**Trauma-related disorders**	**Intellectual Disability**	**Pulmonary conditions**	Soni, A. (2007)
7	France	**Circulatory disease**	**Digestive syst. Diseases**	**Intellectual Disability**	**Nervous syst. Diseases**	**Respiratory syst. Diseases**	Heijink, R. et al. (2006)
8	France	**Circulatory disease**	**Digestive syst. Diseases**	**Intellectual Disability**	**Nervous syst. Diseases**	**Musculoskeletal syst. Diseases**	Heijink, R. et al. (2008)
9	Germany	**Circulatory disease**	**Digestive syst. Diseases**	**Musculoskeletal syst. Diseases**	**Intellectual Disability**	**Nervous syst. Diseases**	Heijink, R. et al. (2006)
10	Germany	**Circulatory disease**	**Digestive syst. Diseases**	**Musculoskeletal syst. Diseases**	**Intellectual Disability**	**Nervous syst. Diseases**	Heijink, R. et al. (2008)
11	The Netherlands	**Intellectual Disability**	**Symptoms and ill-define**	**Coronary heart disease**	**Dental problems**	**Dementia**	Polder, J. and Achterberg, P. (2004
12	The Netherlands	**Symptoms, ill define**	**Dementia**	**Intellectual Disability**	**Pregnancy**	**Stroke**	Polder, J. and Achterberg, P. (2004
13	The Netherlands	**Intellectual Disability**	**Circulatory disease**	**Digestive syst. Diseases**	**Symptoms, ill-defined**	**Musculoskeletal syst. Diseases**	Heijink, R. et al. (2006)
14	Spain	**Circulatory disease**	**Respiratory syst. Diseases**	**Symptoms, ill-defined**	**Digestive syst. Diseases**	**Pregnancy & child birth**	Heijink, R. et al. (2006)
15	Sweden	**Intellectual Disability**	**Circulatory disease**	**Respiratory syst. Diseases**	**Nervous syst. Diseases**	**Cancer**	Heijink, R. et al. (2006)
16	UK	**Circulatory disease**	**Intellectual Disability**	**Respiratory syst. Diseases**	**Digestive syst. Diseases**	**Cancer**	Heijink, R. et al. (2006)

Appendix 3

Technologies needed for top four surgeries

Type of Surgeries	Manipulation	Vision	ICT
Cardiac Surgery	MIS: - Special elongated instruments - Endowrist instruments - Viewing scope Off-pump*: - Cardiac (tissue) stabilizers	- 3D Camera + TV monitor - X-ray/ fluoroscopy	- Control loop - Multisensory data fusion
Endoscopic Surgery	- 5-10 mm diameter instruments (graspers, scissors, clip applier) - Trocars**	- 3D Camera + TV monitor	- Control loop - Multisensory data fusion

	- Vacuum pump - Saline cleansing solutions		
Musculoskeletal Surgery	- X-ray examination to locate injured or fracture bones - Implantation (metal, ceramic, plastic prosthetic)(AAOC, 2013)	- X-Ray - CT-scan/MRI - Fluoroscopy	Computer-assisted navigation system***
Microsurgery	- Microsurgical instruments - Microsuture - Vein coupler - Sterile Doppler (Janz & Yang, 2013)	Preoperative: - CT scan - Angiography Intraoperative: - Operating microscope	- Control loop - Multisensory data fusion

Appendix 4

Overview of technological compatibility of nine robotic cases

No.	Products	Surgery Type	Capabilities
1	Da Vinci System	Minimally invasive surgery	– Surgeon can control the robot from a console, which will be translated into precise, real-time robotic movements – High-definition 3D endoscope vision system – Four interactive robotic arms – Endowrist instruments, with seven degrees of motion (even greater than human wrist), which has a specific surgical mission such as clamping, suturing, and tissue manipulation
2	ARTAS	Hair transplantation	– High resolution 3D digital imaging – Image guided robotic alignment – Minimally invasive dissection – Keyboard/patient-side control
3	The Flex® System	Minimally invasive surgery	– precise and stable platform for enhanced visualization – single site access to the body – endoscope can be directed into any shape (flexible)
4	– Magellan™ Robotic System – Sensei® X Robotic Catheter System	Intravascular surgery	– simultaneous distal tip control from a centralized and remote workstation (physician is away from radiation source) – instinctive 3D imaging control
5	CyberKnife System TomoTherapy System	Radio surgery	– delivering high doses of radiation accurately with minimal exposure of surrounding healthy tissue and organs – 3D CT imaging to ensure the accuracy of the patient position – multi-leaf collimator (MLC), a patented device that opens and closes quickly to permit, or block, the passage of radiation, dividing the radiation beams into many smaller beamslets – the patterns of movement is precisely calculated before treatment begins, so the intensity

			of the radiation beam delivered conforms to the patient's tumor – machine rotates 360° around the patient
6	MAKOplasty	Knee and hip replacement surgery	– performing knee resurfacing through 4-6 inch incision (MIS) – 3D imaging model of the knee – Surgeon-guided bone preparation for increased accuracy – Enables surgeons to accurately resurface only the diseased portion of the knee – improve acetabular cup positioning in total hip replacement
7	SPORT	Minimally invasive surgery	– single incision port – 3D vision system and two snake-hand instrumentations
8	SPIDER® Surgical System	Minimally invasive surgery (laparoscopic)	– Triangulation instrument via single incision port (18mm) – Tiny laparoscopic camera – True left and true right, flexible, articulating instrumentation with 360° range of motion – A single-operator and open platform with multiple working channels

Appendix 5

Whole overview of Cooper scoring model results

Regression Coeff.	Success factor	Weight	Sub-weight	Da Vinci	ARTAS	Medrobotics	Sensei/Magellen	Cyberknife	MAKOplasty	SPORT	Spider	Preceyes
1.744	1. Product superiority	0.25										
	1.1 QALYs Gap		0.25	2.61	1.12	0.33	0.075	1.52	0.84	2.62	0.64	1.31
0.722	2. Economic advantage user	0.13										
	2.1 Max ΔCost		0.13	$216,143,875.14	$74,639,293.96	$30,046,129.50	$17,793,210.15	$46,516,013.83	$132,584,516.89	$221,492,869.57	$60,198,248.71	$277,218,782.61
	3. Healthcare technology fit	0.13										
	3.1 Surgeon skills		0.07	3	5	3	3	5	5	3	4	4
	3.2 Space available		0.07	4	5	5	5	4	5	4	5	5
1.138	4. Company-project fit	0.13										
	4.1 Managerial skills		0.03	3	3	3	3	3	3	3	3	3
	4.2 Marketing research skills		0.03	4	4	4	4	4	4	4	4	4
	4.3 Financial resources		0.03	4	4	4	4	4	4	4	4	4
	4.4 Production resources		0.03	3	3	3	3	3	3	3	3	3
0.342	5. Technological compatibility	0.06										
	5.1 Mechatronics		0.02	4	4	4	4	4	4	4	4	4
	5.2 Medical imaging		0.02	2	2	2	1	1	2	2	2	2
	5.3 ICT		0.02	2	2	2	2	2	2	2	2	2
0.354	6. Familiarity to the firm	0.06										
	6.1 Familiar product class for company		0.01	1	1	1	1	1	1	1	1	1
	6.2 Familiar salesforce distribution		0.01	1	1	1	1	1	1	1	1	1
	6.3Familiar types of users' needs served		0.01	1	1	1	1	1	1	1	1	1
	6.4 Familiar customers to company		0.01	1	1	1	1	1	1	1	1	1
	6.5 Familiar competitors to company		0.01	1	1	1	1	1	1	1	1	1
0.801	7. Market need/size/growth	0.14										
	7.1 Size of target group		0.05	24237391	129605294	29976027	4359073	1431064	4226564	24237391	24237391	325739
	7.2 Reimbursement rate		0.05	$744.00	$10,000.00	$34,000	$7,000.00	$21,530.00	$1,350.00	$744.00	$744.00	$995
	7.3 Growing market		0.05	3	5	4	2	4	5	3	3	3
0.301	8. Market competiveness	0.05	0.05	**2**	**2**	**2**	**2**	**1**	**2**	**2**	**2**	**4**
0.225	9. Product scope	0.04	0.04	4	4	3	4	4	4	4	4	4
5.627	**Total**	1.00										

Appendix 6

Maximum value of each (sub)factor

Success factor	Weight	Sub-weight	Max Value
1. Product superiority	0.25		
1.1 QALYs Gap		0.25	2.62
2. Economic advantage user	0.13		
2.1 Additional Costs		0.13	1.00
3. Healthcare technology fit	0.13		
3.1 Surgeon skills		0.07	5
3.2 Space available		0.07	5
4. Company-project fit	0.13		
4.1 Managerial skills		0.03	3
4.2 Marketing research skills		0.03	4
4.3 Financial resources		0.03	4
4.4 Production resources		0.03	3
5. Technological compatibility	0.06		
5.1 Mechatronics		0.02	4
5.2 Medical imaging		0.02	2
5.3 ICT		0.02	2
6. Familiarity to the firm	0.06		
6.1 Familiar product class for company		0.01	1
6.2 Familiar salesforce distribution		0.01	1
6.3Familiar types of users' needs served		0.01	1
6.4 Familiar customers to company		0.01	1
6.5 Familiar competitors to company		0.01	1
7. Market need/size/growth	0.14		
7.1 Size of target group		0.05	129605294
7.2 Reimbursement rate		0.05	34000
7.3 Growing market		0.05	5
8. Market competiveness	0.05	0.05	4
9. Product scope	0.04	0.04	4

Appendix 7

Ideal normalization of the matrix

	A	B	C	D	N	O	P	Q	R	S	T	U	V	W
1					priorities (ad a: normalize the matrix)									
2	**Regression Coeff.**	**Success factor**	**Weight**	**Sub-weight**	**max**	Da Vinci	ARTAS	Medrobotics	Sensei/ Magellen	Cyberknife	MAKOplasty	SPORT	Spider	Preceyes
3														
4	1.744	1. Product superiority	0.25											
5		1.1 QALYs Gap		0.25	**2.62**	1.00	0.43	0.13	0.03	0.58	0.32	1.00	0.24	0.50
6	0.722	2. Economic advantage user	0.13											
7		2.1 Max ΔCost		0.13	1.00	0.000	1.000	0.000	1.000	1.000	1.000	0.000	0.000	1.000
8		3. Healthcare technology fit	0.13											
9		3.1 Surgeon skills		0.07	5	0.6	1	0.6	0.6	1	1	0.6	0.8	0.8
10		3.2 Space available		0.07	5	0.8	1	1	1	0.8	1	0.8	1	1
11	1.138	4. Company-project fit	0.13											
12		4.1 Managerial skills		0.03	3	1	1	1	1	1	1	1	1	1
13		4.2 Marketing research skills		0.03	4	1	1	1	1	1	1	1	1	1
14		4.3 Financial resources		0.03	4	1	1	1	1	1	1	1	1	1
15		4.4 Production resources		0.03	3	1	1	1	1	1	1	1	1	1
16	0.342	5. Technological compatibility	0.06											
17		5.1 Mechatronics		0.02	4	1	1	1	1	1	1	1	1	1
18		5.2 Medical imaging		0.02	2	1	1	1	0.5	0.5	1	1	1	1
19		5.3 ICT		0.02	2	1	1	1	1	1	1	1	1	1
20	0.354	6. Familiarity to the firm	0.06											
21		6.1 Familiar product class for company		0.01	1	1	1	1	1	1	1	1	1	1
22		6.2 Familiar salesforce distribution		0.01	1	1	1	1	1	1	1	1	1	1
23		6.3Familiar types of users' needs served		0.01	1	1	1	1	1	1	1	1	1	1
24		6.4 Familiar customers to company		0.01	1	1	1	1	1	1	1	1	1	1
25		6.5 Familiar competitors to company		0.01	1	1	1	1	1	1	1	1	1	1
26	0.801	7. Market need/size/growth	0.14											
27		7.1 Size of target group		0.05	129605294	0.187009	1	0.2313	0.03363	0.011042	0.03261	0.18701	0.187	0.002513
28		7.2 Reimbursement rate		0.05	34000	0.021882	0.29412	1	0.20588	0.633235	0.03971	0.02188	0.0219	0.029265
29		7.3 Growing market		0.05	5	0.6	1	0.8	0.4	0.8	1	0.6	0.6	0.6
30	0.301	8. Market competiveness	0.05	0.05	4	0.5	0.5	0.5	0.5	0.25	0.5	0.5	0.5	1
31	0.225	9. Product scope	0.04	0.04	4	1	1	0.75	1	1	1	1	1	1
32	5.627	**Total**	1.00											

Appendix 8

Weighted normalized decision

	A	B	C	D	E	Z	AA	AB	AC	AD	AE	AF	AG	AH
1	priorities					priorities * weight sf								
2		Regression Coeff.	Success factor	Weight	Sub-weight	Da Vinci	ARTAS	Medrobotics	Sensei/Magellen	Cyberknife	MAKOplasty	SPORT	Spider	Microsurgery
3														
4		1.744	1. Product superiority	0.25										
5			1.1 QALYs Gap		0.25	0.249	0.107	0.031	0.007	0.145	0.080	0.250	0.061	0.000
6		0.722	2. Economic advantage user	0.13										
7			2.1 Max ΔCost		0.13	0.130	0.039	0.015	0.005	0.044	0.075	0.130	0.034	0.000
8			3. Healthcare technology fit	0.13		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9			3.1 Surgeon skills		0.07	0.039	0.065	0.039	0.039	0.065	0.065	0.039	0.052	0.052
10			3.2 Space available		0.07	0.052	0.065	0.065	0.065	0.052	0.065	0.052	0.065	0.065
11		1.138	4. Company-project fit	0.13										
12			4.1 Managerial skills		0.03	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
13			4.2 Marketing research skills		0.03	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
14			4.3 Financial resources		0.03	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
15			4.4 Production resources		0.03	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
16		0.342	5. Technological compatibility	0.06										
17			5.1 Mechatronics		0.02	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
18			5.2 Medical imaging		0.02	0.020	0.020	0.020	0.010	0.010	0.020	0.020	0.020	0.020
19			5.3 ICT		0.02	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
20		0.354	6. Familiarity to the firm	0.06										
21			6.1 Familiar product class for company		0.01	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
22			6.2 Familiar salesforce distribution		0.01	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
23			6.3Familiar types of users' needs served		0.01	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
24			6.4 Familiar customers to company		0.01	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
25			6.5 Familiar competitors to company		0.01	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
26		0.801	7. Market need/size/growth	0.14										
27			7.1 Size of target group		0.05	0.009	0.047	0.011	0.002	0.001	0.002	0.009	0.009	0.000
28			7.2 Reimbursement rate		0.05	0.001	0.014	0.047	0.010	0.030	0.002	0.001	0.001	0.001
29			7.3 Growing market		0.05	0.028	0.047	0.038	0.019	0.038	0.047	0.028	0.028	0.028
30		0.301	8. Market competiveness	0.05	0.05	0.025	0.025	0.025	0.025	0.013	0.025	0.025	0.025	0.050
31		0.225	9. Product scope	0.04	0.04	0.040	0.040	0.030	0.040	0.040	0.040	0.040	0.040	0.040
32		5.627	**Total**	1.00										

Appendix 9

Positive ideal solutions and negative ideal solutions

	A	B	C	D	AI	AJ
1						
2	**Regression Coeff.**	**Success factor**	**Weight**	**Sub-weight**	Positive Ideal Solution	Negative Ideal Solution
3						
4	1.744	1. Product superiority	0.25			
5		1.1 QALYs Gap		0.25	0.329	0.007
6	0.722	2. Economic advantage user	0.13			
7		2.1 Max ΔCost		0.13	0.130	0.008
8		3. Healthcare technology fit	0.13		0.000	0.000
9		3.1 Surgeon skills		0.07	0.065	0.039
10		3.2 Space available		0.07	0.065	0.052
11	1.138	4. Company-project fit	0.13			
12		4.1 Managerial skills		0.03	0.033	0.033
13		4.2 Marketing research skills		0.03	0.033	0.033
14		4.3 Financial resources		0.03	0.033	0.033
15		4.4 Production resources		0.03	0.033	0.033
16	0.342	5. Technological compatibility	0.06			
17		5.1 Mechatronics		0.02	0.020	0.020
18		5.2 Medical imaging		0.02	0.020	0.010
19		5.3 ICT		0.02	0.020	0.020
20	0.354	6. Familiarity to the firm	0.06			
21		6.1 Familiar product class for company		0.01	0.009	0.009
22		6.2 Familiar salesforce distribution		0.01	0.009	0.009
23		6.3Familiar types of users' needs served		0.01	0.009	0.009
24		6.4 Familiar customers to company		0.01	0.009	0.009
25		6.5 Familiar competitors to company		0.01	0.009	0.009
26	0.801	7. Market need/size/growth	0.14			
27		7.1 Size of target group		0.05	0.047	0.000
28		7.2 Reimbursement rate		0.05	0.047	0.001
29		7.3 Growing market		0.05	0.047	0.019
30	0.301	8. Market competiveness	0.05	0.05	0.050	0.013
31	0.225	9. Product scope	0.04	0.04	0.040	0.030
32	5.627	**Total**	1.00			

Appendix 10

Rough calculation of total gross income of four highest result robotic cases

Robotic cases	Market size	estimated price	treatment duration (min)	patient per year {(working hrs/duration)*working days}	estimated units demand per year	total revenue per year
Da Vinci	24237391	$2,000,000.00	120	1200	20197.82583	$40,395,651,666.67
Cyberknife	1431064	$5,000,000.00	480	300	4770.213333	$23,851,066,666.67
PRECEYES	325739	$500,000.00	90	1600	203.586875	$101,793,437.50

Appendix 11

ICD-9-CM code definition for the most frequent surgeries

(*source:* http://icd9.chrisendres.com/index.php?action=procslist)

No.	Procedure	ICD-9-CM code	Code Definition
1	Operation on the cardiovascular system	35-39, 00.49-00.51, 00.53-00.55, 00.57, 00.61-00.66, 17.51, 17.52	35-39: operation on septa/valve of heart, vessels of heart, heart and pericardium, vessels 00.49-00.51: supersaturated oxygen therapy, implantation of pacemaker (CRT-P), and implantation of defibrillator (CRT-D) 00.53-00.55: implantation or replacement of pacemaker and defibrillator, insertion of drug-eluting peripheral vessel stent 00.57: any associated implantation or replacement of monitor 00.61-00.66: procedures on blood vessels 17.51-17.52: implantation or replacement of CCM
2	Operation on the digestive system	42-54, 17.1-17.3, 17.63	42-54: operation on esophagus, stomach, intestine, appendix, rectum, anus, liver, gall bladder, biliary tract, pancreas, hernia, and other operations on abdominal region. 17.1-17.3: Laparoscopic on inguinal hernia and large intestine 17.63: Laser interstitial therapy of liver
3	Operation on the musculoskeletal system	76-84, 00.70-00.77, 00.80-00.84, 00.85-00.87	76-84: operation, incision, excision on facial bones and joints, reduction of fracture and dislocation, repair and plastic operations on joint structures, operation on muscle, tendon, bursa and fascia, other procedures on musculoskeletal system 00.70-00.77: operation on hip procedures 00.80-00.87: knee and hip procedures