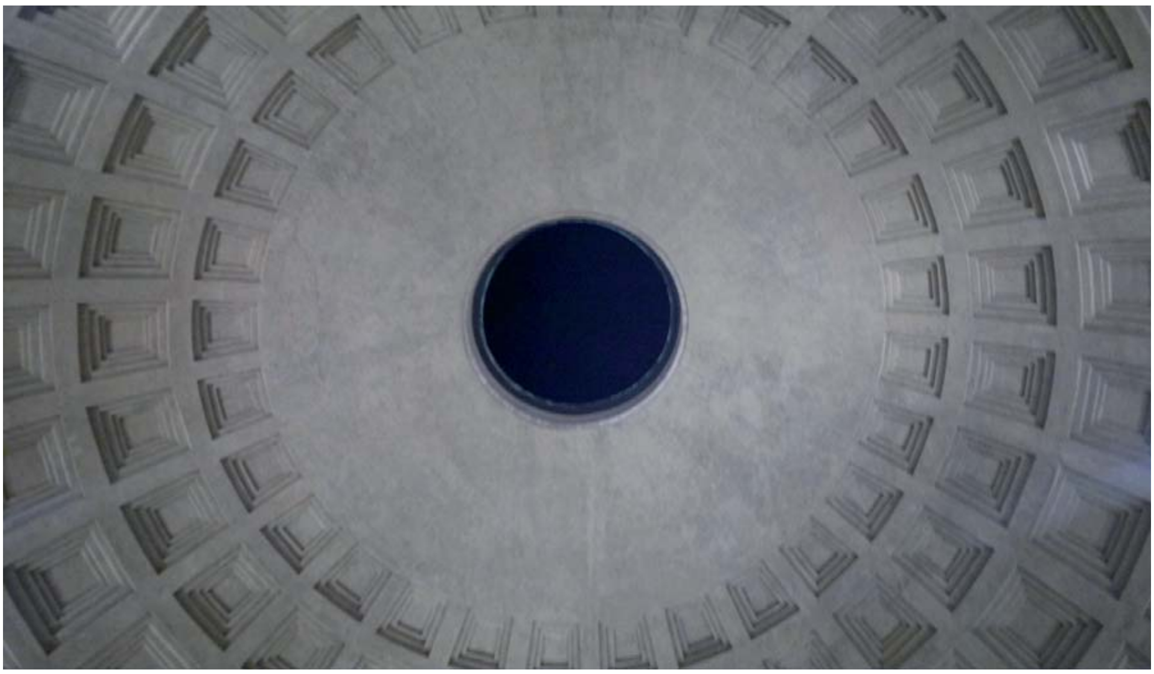
JYVÄSKYLÄ STUDIES IN BUSINESS AND ECONOMICS
110

Sakari Pieskä

Enhancing Innovation Capability and Business Opportunities

Cases of SME-Oriented Applied Research



JYVÄSKYLÄN YLIOPISTO

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2012

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ABSTRACT

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Enhancing the competitiveness of small and medium-sized enterprises (SMEs) is an important contemporary challenge for the future of Finland. This thesis investigates how competitiveness can be developed by enhancing innovation capability and business opportunities with collaborative applied research involving SMEs and applied research groups.

This thesis presents the main research results of collaboration projects involving an applied research team and SMEs. More than 50 companies participated in these projects, and the companies were mainly production-oriented SMEs. The applied research projects were conducted in the areas of robotics, simulation and wireless automation. The main results of the projects are presented in nine articles published previously. The results are analyzed in this study from the perspectives of innovation capability and business potential. The aim of the study is to explore what business opportunities have risen from the collaborative research projects of SMEs and an applied research team, and how this collaboration has enhanced the innovation capability of the two parties.

The collaborative projects analyzed in this study produced 22 business opportunities for evaluation. Half of them were assessed to have good or excellent business potential, and nine of them have already been used in the production of SMEs. The patented solutions indicate the practical innovativeness of the collaboration. Innovation capability was assessed to have increased remarkably both in the SMEs and in the applied research team. According to the experiences of this study, the main factor to enhance innovation capability in the SMEs and small research groups is the development of collaboration culture, which is based on integration of co-creation, trust and helping relationship with technology expertise, technological capability and business knowledge, which should proactively embrace the needs of current and future customers. The study presents recommendations on how innovation capability and business opportunities should be enhanced.

Keywords: innovation capability, business opportunities, SMEs, applied research, collaboration, robotics, simulation, RFID technology, wireless sensor networks

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PREFACE

We people have a tendency to look at our world only from the familiar perspective. Every now and then it is, however, wise to try to take alternative perspectives to find the new interesting sides of life. I have worked all my working life in research, development and teaching duties of technology. This study is an attempt to expand the view: it is a combination of technical, economical and entrepreneurial research. The study is based on nine publications in the area of technology development. The research results presented in these publications are now evaluated from the perspective of how they enhanced business opportunities and innovation capabilities in SMEs and in the applied research team involved. This study can be seen as an attempt to rise above the everyday project field like a skylark (*Alauda Arvensis*), the national bird of Central Ostrobothnia, which in springtime rises directly up in the heights above the fields and cheerfully sings when it looks down at the world from a different perspective. This study has been an interesting and rewarding journey, which has opened new views of life.

I want to thank my supervisor, Professor Matti Koiranen, for his valuable advice and instruction throughout the duration of this thesis project. He has encouraged me to adopt the chosen multidisciplinary approach of this study. I am grateful to the reviewers of my thesis, Professor Aarne Halme and Professor Yrjö Neuvo, for their constructive and encouraging comments and recommendations for finalizing my thesis. It was an honor to have these highly regarded experts to review my thesis. I thank them for the ability and energy to examine the outcome of my study. I would like to express my sincere thanks to Professor Aarne Halme for promising to be the opponent of my dissertation.

There are numerous people and organizations that deserve my gratitude for their support and contribution during this study. I have been fortunate to work in an innovative research team in CENTRIA with its collaborative network. I want to express sincere thanks to my co-workers at CENTRIA, especially to Mika Luimula, Jari Mäkelä, Jari Kaarela, Timo Rahja, Jani Rättyä, Joni Jämsä, Ossi Saukko, Janne Känsäkoski, Jorma Hintikka, Esko Sääskilahti, Seppo Jokelainen and Jouko Kärkkäinen. You have kept up good humor and innovation spirit high during the projects so that carrying out applied research has been fun with you. I also would like to give my best thanks to all the co-authors of the articles related to this study. For the opportunity to carry out this research I wish to thank the current and former directors of Central Ostrobothnia University of Applied Sciences and CENTRIA Research and Development: President Marja-Liisa Tenhunen, Vice-President Keijo Nivala, Research and Development Managers Antti Lauhikari (currently employed in industry), Lasse Jansson and Hannu Leppälä.

I want to acknowledge all the collaborating research and development organizations and people who have been in cooperation with the projects of this study either in steering groups or informal discussions. My own research organization CENTRIA has had a fruitful long-term cooperation with VTT and the University of Oulu in several projects. Especially I want to thank Dr. Mikko Sallinen and Dr. Tapio Heikkilä and their teams at VTT as well as Professor Jussi Karjalainen, Dr. Jouni Tervonen and Mr. Kari Mäntyjärvi and their teams at the University of Oulu for the cooperation during the study. I would also like to give my warmest thanks to my former co-worker Mr. Eero Korhonen, currently at the Oulu University of Applied Sciences, for collaboration and inspiring discussions during many projects of this study. Collectively, I wish to thank the numerous people in collaborating companies for participating in the projects of this study because the list of the names would be extremely long. Similarly, I also wish to thank our several international partners for successful cooperation during this study.

I want to give my sincere thanks to Dr. Esko Johnson, not only for competent advice on linguistic issues of this thesis but also for interesting discussions, especially concerning the various aspects of English language and scientific writing in different disciplines.

For the financial support given to this thesis, I would like to thank the Foundation of Private Entrepreneurs and the Finnish Cultural Foundation, Central Ostrobothnia Regional fund. I also wish to thank the following funding organizations for financing the projects during this study: the Finnish Funding Agency for Technology and Innovation (Tekes), European Regional Development Fund (ERDF), Council of Oulu Region, State Provincial Office of Oulu, Ylivieska Subregion, Nivala-Haapajärvi and Siikalatva Subregions, ERDF Interreg IVA Nord and Interreg IIIC programs, and private companies. Especially I want to thank Mr. Aki Lappalainen of the Council of Oulu Region, Mr. Veijo Korkiakoski of Tekes Oulu and Mr. Timo Kiema of the Ylivieska Subregion for fruitful collaboration and sharing the concern how to enhance the competitiveness of SMEs.

Last but not least, my warmest gratitude belongs to the most important people in my life: my dear wife Anna-Liisa and our children Maiju, Osku and Suvi with their companions. You have reminded me that there is always life beyond research. I wish to thank you Anna-Liisa for your encouraging motivation and support with the infinite patience you showed me throughout this project.

Ylivieska, January 2012

Sakari Pieskä

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ABBREVIATIONS

CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CENTRIA	Research and Development Unit of Central Ostrobothnia University of Applied Sciences
COP	Central Ostrobothnia Polytechnic (used until 2005)
COU	Central Ostrobothnia University of Applied Sciences (used from 2005)
DIGIMANUQ	CENTRIA's ERDF-Financed Project for Digital Manufacturing and Quality Assurance
DIM	Digital Manufacturing or Interreg IVA-Financed Project for Digital Integrated Manufacturing
EC	The European Community
EKIE	Interreg IIIC-Financed Project for Enhancing Knowledge Intensive Enterprises in Small Cities, Surrounded by Rural and Sparsely Populated Areas
ERDF	European Regional Development Fund
EU	The European Union
FDI	Foreign Direct Investment
GCI	Global Competitiveness Index
GPS	Global Positioning System
HF	High Frequency
ICT	Information and Communication Technology
IEEE	The Institute of Electrical and Electronics Engineering
Interreg	EC Initiative that Aims to Stimulate Interregional Cooperation in the European Union
IUS	Innovation Union Scoreboard
LUOVI	CENTRIA's TEKES-Financed Project for Natural Interaction and Interactive Control Methods for Robotics and Production Work Cells
OLP	Offline Programming
Oulu South	Southern part of Northern Ostrobothnia, includes Ylivieska, Nivala-Haapajärvi and Siikalatva regions
P2P	Peer-To-Peer
PC	Personal Computer
R&D	Research and Development
RASAUSE	CENTRIA's TEKES-Financed Project for Rapid and Safe Use of Robot Systems
RFID	Radio Frequency Identification
RIS	Regional Innovation System
ROBOTOOL	CENTRIA's ERDF-Financed Project for Robotics and Tool Manufacturing

SensoTag	CENTRIA's TEKES-Financed Project for Ubiquitous Computing in Maintenance Using Sensors
SME	Small and Medium-sized Enterprise
SWAM	CENTRIA's TEKES-Financed Project for Short Distance Wireless Applications for Machines and Systems
TEKES	The Finnish Funding Agency for Technology and Innovation
TURWA	CENTRIA's ERDF-Financed Project for Safe and Interactive Automation (SAFIA)
UHF	Ultra High Frequency
VoIP	Voice over Internet Protocol
VTT	Technical Research Centre of Finland
WAMS	Wireless Applications for Machines and Systems; the international seminar and exhibition held three times in Ylivieska
WLAN	Wireless Local Area Network (IEEE 802.11)
WSAN	Wireless Sensor and Actuator Network
WSN	Wireless Sensor Network

LIST OF ORIGINAL ARTICLES

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VIII Jämsä, J., Luimula, M., Pieskä, S., Brax, V., Saukko, O. & Verronen, P. 2010 Indoor Positioning with Laser Scanned Models in Metal Industry. In Proceedings of the IEEE International Conference on Ubiquitous Positioning, Indoor Navigation and Location-Based Service (UPINLBS), Kirkkonummi, Finland, 9.

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CONTENTS

1 INTRODUCTION

1.1 Background and motives

”There is a fundamental transformation of business underway”, argued the respected American professor C.K. Prahalad in his last book *The New Age of Innovation* which he wrote together with professor M.S. Krishnan just two years before he died in spring 2010. Prahalad and Krishnan stated that this transformation will alter the nature of the firm and how it creates value, and it is forged by digitization, ubiquitous connectivity, convergence of technologies and industries, and globalization. No industry is immune to these trends that cannot be reversed. Even if most examples in their book were concerning innovation management of large global companies, they also emphasized the importance of individuals and small companies in creating new innovations. (Prahalad & Krishnan 2008, 11)

Digitization, ubiquitous connectivity, convergence of technologies and globalization have become true challenges also for small Finnish companies, which are in many ways different from large and global companies. Prahalad and Krishnan also told that the change is critical for survival and growth. The Fraunhofer research group in Germany (Bullinger, Bannert & Brunswicker 2007) has found the same thing concerning also small companies: SMEs need to innovate in order to survive and create competitive advantage. According to the authors that need originates from four factors: globalization which gives rise to new competitors, the fact that large enterprises with more flexible production processes are also entering to niche markets, rapid technological progress that has changed the nature of competition, and the fact that more demanding customers require high quality with enhanced performance and user experience.

The ongoing transformation of business is based in two pillars presented in FIGURE 1 (Prahalad & Krishnan 2008). The focus of the first pillar is on the centrality of the individual: N = 1 designates one consumer experience at a time. The focus of the second pillar is not on ownership but access to resources:

R = G designates resources from multiple vendors which can be operating anywhere around the globe. The consequences of the transformation trend can be seen even in the business area of production-oriented SMEs in Finland. The uniqueness requirements have decreased the sizes of production series to approach one, and globalization has changed the situation in competition and supply chains. Digitization, ubiquitous connectivity, convergence of technologies and globalization are serious challenges for SMEs in the Central and Northern Ostrobothnia areas, which are in the focus of this study together with a small research team in the university of applied sciences situated in the same sparsely populated area. This study presents an approach to help SMEs and small research teams survive and grow in the new age of innovation.

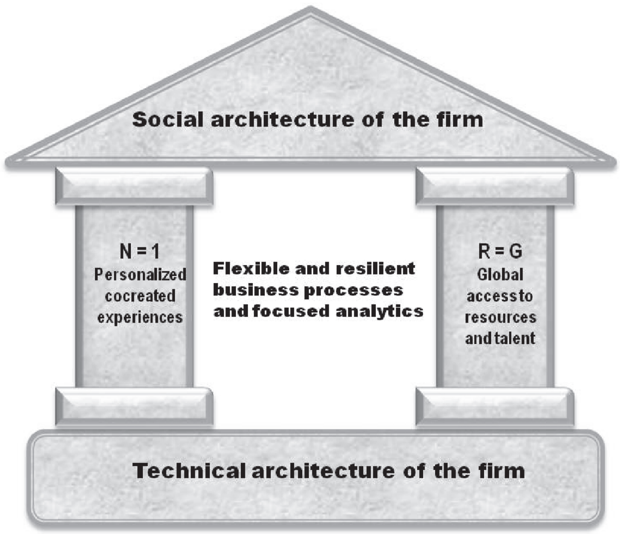

FIGURE 1 The New House of Innovation (adapted from Prahalad & Krishnan 2008, 237)

Small and medium size enterprises (SMEs) are currently recognized as a key driver for economic growth, innovation, employment and social integration in Finland and in the rest of the EU area. At the end of 2009 there were more than 300,000 SMEs in Finland which represent 99.8% of all enterprises. These employed 63.9% of all personnel in enterprises (Statistics Finland. 2010). In the EU area there are about 23 million SMEs, which represent 99% of businesses. The European Commission aims to promote successful entrepreneurship and to improve the business environment for SMEs, to allow them to realize their full potential in today's global economy (SMEs 2011). Therefore, support for SMEs is one of the European Commission’s priorities for economic growth, job creation, and economic and social cohesion. In Finland there is also a wide consensus that SMEs should be supported and encouraged to seek innovations and new business opportunities and business models. The Finnish Funding Agency for Technology and Innovation Technology (Tekes) has prioritized SMEs and it continuously monitors the success of SMEs in several ways. Even if Finland has had success in many rankings concerning innovation or competitiveness in the last decade (Europe's Digital Competitiveness Report 2010; Innovation Union Scoreboard 2011; OECD Finland 2010; OECD Science, Technology and Industry Outlook 2010; Porter & Stern 2001), there still remain a lot of challenges especially of developing SMEs which are situated in sparsely populated areas in Finland and do not operate in high-tech business.

The framework of this work lies in the results which were achieved in collaboration projects during 2002–2011 involving companies, CENTRIA Ylivieska and the cooperation network. More than 50 companies participated in these projects; the companies were mainly production-oriented SMEs. Production-oriented SME denotes in this study a company which is either operating within manufacturing, assembling, finishing, and packaging or otherwise in production or in designing and implementing production equipment. The topics and contents of the collaboration projects are presented later in Chapter 1.6.

CENTRIA is a research, development and further education unit of the Central Ostrobothnia University of Applied Sciences (COU). The main function of its research and development is to create possibilities for the development of the region's enterprises and communities. CENTRIA Ylivieska is one of CENTRIA's four regional units. The name CENTRIA was taken into use in 2001, and the name Central Ostrobothnia University of Applied Sciences (COU) was adopted in 2006 to replace Central Ostrobothnia Polytechnic (COP), which had become the official name in 1996. CENTRIA Ylivieska is a research and developing unit which can be placed on the same level with SMEs with its currently about 50 persons working in research, development, education and training. Even if the work of this study has taken place in the research unit of a university of applied sciences, this work is not focusing on organizational or specific issues of universities of applied sciences. The challenging collaboration theme of this study is based on the author's personal experience often shared by other applied research groups which can be situated in research centers or institutes, scientific universities and sometimes even in large companies.

In the beginning of 2002 the Ylivieska Unit of COP started competence development in three research and development projects of selected areas. New legislation had provided opportunities for polytechnics to engage in applied research to support regional development. The author started to work in full-time research in the framework of fairly large projects which were co-financed by the European Regional Development Fund, the Finnish Funding Agency for Technology and Innovation (Tekes), the Ylivieska region, and companies. The main target was to develop expertise and capability which could be used in the SMEs of the region to help these SMEs survive and grow in global competition.

The initial situation was in many ways challenging for applied research. When starting this study the Ylivieska Unit of Central Ostrobothnia Polytechnic had very little experience about academic applied R&D work; in fact the author was the only one in the research group who had experience about academic applied research from his previous positions in VTT (Technical Research Centre of Finland) and University of Oulu. The same situation was also with SMEs in our region: companies had little or no experience of participating in R&D projects. They had learned how to commission final-year thesis projects and how to take part in ICT training offered by CENTRIA or its predecessor YTOL-Instituutti, but they had not participated in research projects. SMEs typically have no research and development personnel of their own, which means that all development work has to be carried out alongside with ongoing production. The author's challenging task was to set up a research team and to promote its capability so that it would reach a nationally and internationally recognized level in applied R&D and active cooperation with local companies. The main activities in the first projects were carried out with a production engineering team of 5-10 persons. Later, the applied research team has been flexible in size and structure depending on the projects. It has used project members from other CENTRIA expertise areas, such as mobile programming, location aware technology, mobile user interfaces and GPS, WSN and RFID technologies. The mixing of expertise inside an organization has been found to be one of the key drivers for successful results. The applied research team of this study had almost regularly also included foreign students or exchange researchers working in the projects. The research cooperation network has also included universities and research institutes from Finland and abroad.

The personal interest for this study emerges from the author's working life experiences in the applied research work in VTT and University of Oulu in the 1980s and in the beginning of 1990s and after that teaching duties and SME-oriented applied research in Central Ostrobothnia University of Applied Sciences (COU). In the Oulu times, the areas of interest included interactive and autonomous control of robots and mobile working machines (for example Pieskä, Elsilä & Vähä 1988; Pieskä, Mäkynen, Kostamovaara, Elsilä, & Myllylä 1989; Pieskä, Heikkilä, Riekki, Taipale, Känsälä & Röning 1991). These topics also continued to be interesting in the applied research projects of this study. The teaching duties in COU included product development courses where the author introduced in early 1990s innovation topics which were quite new in the Finnish engineering education of that time. Therefore, applied research, seeking practically applicable innovative solutions and thus enhancing competitiveness of SMEs have been in the author's personal interest for more than a quarter of a century, and those topics still remain challenging and interesting.

In the innovation related literature many well-known authors not only emphasize the importance of practical implementation but also the hard work and trouble it may cause. According to Porter, the adoption of new knowledge in practice is as important as its creation (Porter & Kramer 2002). Already in 1985, Drucker called attention to the hard work the innovation process involves and stated that innovation is rather work than genius; it requires talent, ingenuity and knowledge, but especially hard focused and purposeful work (Drucker 1985, 133–140; Drucker 1998, 7-8). Tidd and Bessant describe the innovation management process that converts ideas into reality as a huge challenge. Innovation management differs from conventional project management because the challenge is about developing something which may never have been done before and there is uncertainty about the success (Tidd & Bessant 2009, 19).

Govindarajan and Trimble (2010) have presented in their recent book *The other side of innovation: solving the execution challenge* an impressive metaphor about how important and difficult it is to progress to the other side of the innovation – to its execution. The authors compare the innovation process to climbing to the summit of the challenging mountain of Mount Rainier, which is situated in the north-west of the United States. It has a heavily glaciated summit and is recognized as one of the world's most difficult to access mountain for novices, even if accompanied by expert guides. The climbing project needs months of preparation and still nearly half of those who are trying to reach the summit turn back unfulfilled. Those who manage describe that it feels like you are on the top of the world when you finally come to the summit of that mountain. Their big dream has been fulfilled. Mount Rainier is different from many other mountains because the return trip has turned out to be the most demanding and the most dangerous part of the climbing process. The return trip is no longer glamorous; it is only hard work to survive. It is just like the execution side of innovation. One of the most successful inventors of all time, Thomas Alva Edison, said in his famous proverb over a century ago that genius is 1 percent inspiration and 99 percent perspiration. That 99 percent is often the way back from the peak of the mountain. This study does not cover the whole way back, that is, solving the execution challenge. This study offers some examples about how the first part on the way back can be carried out in cooperation with your partners. Even if this part sometimes makes perhaps only 10 percent of the innovation execution challenge, it may be the most important 10 percent because the direction, strategy, tools and companions are chosen in that part of the trip. This study has been an interesting learning experience in climbing to the innovation mountain with the research team and SMEs, and about finding the way back. This study does not cover the whole way back. Creating new business models based on the business opportunities found in this research will be left to future studies.

One motivation for this study also comes from the realization that there is very little applied research that would combine practical technological R&D (technology push) and business opportunity (market pull) considerations in the related literature. There is also a lack of reports about collaborative applied research involving SMEs and applied research teams. Frankelius (2009) recently claimed based on his literature review that in R&D-based innovation literature there exist two myths which should be questioned. The first assumption is that the meaning of 'R' in R&D is most often technological, not for example research in economics, marketing or commercialization of research. Secondly, it is assumed that high-level knowledge required for innovation is almost always produced inside universities. This study attempts to question those myths. In the related literature most of the studies concerning SME participation in applied research have been carried out purely by using questionnaires, in some cases interviews supplemented the questionnaires. However, sometimes the lack of knowledge about technology or entrepreneurship can cause misleading deductions and speculations. The situation of an SME is also very difficult for the researcher to understand from outside if he/she only uses questionnaires or even short structured interviews. Deeper understanding requires a long and confidential cooperation relationship. The chosen approach of this study has potential drawbacks and strengths. The main weakness is the perspiration side: it takes lot of work and time to carry out this kind of study. The main benefit of this study is that during the research process the author has had the privilege to gain deep insights about SMEs' entrepreneurial and business aspirations as well as the technology behind them in collaboration projects. On the other hand, the SMEs have had a possibility to be introduced to state-of-the-art knowledge and news of automation technology and methods in an easy and practical form during the cooperation projects. This study also wants to encourage SMEs to get involved with innovative and successful cooperation with external research organizations.

1.2 Research task, research questions and contributions

Research can be defined as a critical process for asking and attempting to answer questions about the world (Dane 2011, 3). This study deals with the important contemporary question of enhancing the competitiveness and innovation capability of SMEs. The SMEs of this study are situated in a sparsely populated area in Central and Northern Ostrobothnia. This study combines technical, economical and entrepreneurial research. The framework and the empirical data of this study are the results generated in the collaboration projects involving SMEs, CENTRIA Ylivieska and the cooperation network. The main results of these projects are presented in the nine originals articles of this study. Additional information can be found also from other author's articles from the years 2003-2011, which are listed in the References section. These include 15 articles, where the author has been five times a main author and ten times a co-author. In this study, the technologically oriented perspective presented in the publications is expanded to provide insights of how these results have enhanced the business opportunities and innovation capability both of the SMEs and the research team. From this starting point, two main research questions are presented:

Q1: *What business opportunities have risen from the collaborative research projects involving an applied research team and SMEs in the selected areas?*

Q2: *How has collaborative applied research increased innovation capability and what are the main factors that enhance the innovation capability of SMEs and small research groups?*

The first question is divided into two sub-questions drawn from the main question:

Q1: *What business opportunities have risen from the collaborative research projects involving the applied research team and SMEs in the selected areas?*

What business opportunities have risen from the robotics and simulation research cases and to which extent have they already been utilized?

What business opportunities have risen from the Radio Frequency Identification (RFID) - and Wireless Sensor Network (WSN) -based wireless technology cases and to which extent have they already been utilized?

Answers to these questions will be presented in Chapters 3, 4 and 5. In addition, detailed information can be found in the articles presented in the List of Original Articles and in other author's articles presented in the References section.

The second question is divided into three sub-questions drawn from the main question:

Q2: *How has collaborative applied research increased innovation capability and what are the main factors to enhance innovation capability in SMEs and small research groups?*

How has collaborative applied research increased the innovation capability of the SMEs of this study?

How has collaborative applied research increased the innovation capability of the applied research team of this study?

What are the main factors to enhance the innovation capability of SMEs and small research groups based on the findings and experiences of this study and compared with related literature?

Answers to these questions will be presented again in Chapters 3, 4 and 5. Additional information can be found in the articles presented in the List of Original Articles and in other author's articles presented in the References section.

Related to the research questions, this study is seeking theoretical, practical and educational contributions. New scientific insights are sought by introducing the concept of proactive combination innovation, which could help to resolve the challenges of the fundamental transformation of business, which seem to be inevitable as discussed in Chapter 1.1. Digitization, ubiquitous connectivity, the convergence of technologies, and globalization will need proactive solutions where product and process innovations as well as open and closed innovations should be combined in a new way. Proactive combination innovation is defined and discussed further in Chapter 1.4. The evaluation of business opportunities and innovation capabilities requires the development of monitoring tools for this purpose. The monitoring tools are presented in Chapters 3 and 4. They are developed to evaluate the needs of technology development, innovation capabilities and business opportunities; they are also expected to bring a new scientific contribution in this study. Practical insights are sought to find business-related implications, and their contribution is based on a large number of cases presented in Chapters 3 and 4. Educational insights are sought for the development of learning processes in educational organizations and in companies. The educational contribution is also based on a large number of experimentations carried out during the cases of the study, and they are discussed in Chapter 5.

1.3 Research scope, context and delimitations

There have been discussions about research resources and funding being too much concentrated on technology and neglecting the development of economic issues, such as business opportunity considerations, and renewal and development of business models (Frankelius 2009; Hautamäki 2008; Ruckenstein, Suikkanen & Tamminen 2011; Sjöholm 2010; Ylén, Ventä, Tommila, Lappalainen, Hirvonen, Karhela, Paljakka, Lehtinen, Heilala, Peltonen, Malm, Valkonen, Voho 2010). Even if this study has both technical and economic aspects, it is still delimited to examination of only the first phases in the innovation management process towards business success. The original articles of this thesis were presented in technically oriented conferences, and therefore in those articles there is very little consideration of economics issues or business potential. The purpose of this study is to extend the scope to include business potential, entrepreneurial and innovation capability aspects. Successful innovation often demands development of innovative business models, e.g. open innovation based new business models which are becoming more and more important in the future (Brown 2006; Chesbrough 2006; Kaplan & Palmer 2010; Prahalad & Krishnan 2008; Ruckenstein et al. 2011; Sjöholm 2010). That is a very interesting subject but not in the core focus of this research due to its extent. However, some results of this study can be hopefully utilized later when developing new open innovation based business models. The renewal of business models, innovation management and innovative organization management (Burns 2011; Kaplan & Palmer 2010; Ramstadt 2008; Sjöholm 2010; Tidd & Bessant 2009) are as such so wide-ranging and challenging questions that they are mainly out of the scope of this research. Innovation policy and public inventions for promoting SMEs and their innovation based business are large and essential questions for the future in Finland and in the EU. These questions are considered in this study only from the perspectives of the innovativeness and competitiveness with reference to SMEs and applied research groups, using the experiences from the collaboration of local SMEs and the applied research team.

This research is delimited to cover collaborative applied research cases in the field of automation area where the author participated in collaborative applied research projects involving SMEs and the applied research team of CENTRIA, The research and development unit CENTRIA Ylivieska is situated in rural and sparsely populated area, where the closest science universities are situated quite far away (the nearest more than 100 km). Regionally, the collaborating companies come mostly from the region of Central Ostrobothnia or the southern part of the region of Northern Ostrobothnia, also called as Oulu South. It is typical for the Oulu South region to have a high number of companies in relation with population and a lack of process industries or large-scale engineering industries. The companies are mostly small, the core branches being metal and engineering, wood industry and ICT. As mentioned earlier, the SMEs involved in this research can mainly be described as production-oriented. Even if the collaborative projects mainly involved SMEs in one limited area and one applied research team, the author's former experiences from applied research in the University of Oulu and VTT strengthen the observation that most of the challenges and tasks are common with other applied research groups working with production-oriented SMEs.

This study deals with cooperation projects where social capability is crucial (Fagerberg 2010, 4-5). However, social capability itself as a phenomenon is not discussed in this study. Yet, it is still included as an integrated part of the innovation capability interpretations. The methodological approach to examine innovation capability is mainly qualitative. In the related literature there are some examples of how quantitative innovation capability can be examined (Branzei & Vertinsky 2006; Bullinger et al. 2007; Hadjimannolis 1999; Keskin 2006; Kobe, Harland & Meier 2004; Lin 2007; Romjin & Albaladejo 2002; Wang, Hong & Liu 2010) but there are also strong views that innovativeness and innovation capability are objects which cannot be examined reliably with numeric measurements. In this study, the extensive assessment of quantitative innovation capability is not carried out. Instead, the evaluation of innovation capability progress is based on taking a look at both SMEs and the applied research organization, where the author participated in the research as a project manager and senior research scientist. The chosen approach may raise questions about the objectivity and validity of observations; these arguments may to some extent be grounded. However, the range of research cases and SMEs involved in these cases gives a possibility to objectively compare cases and business opportunities in them. The author has also no direct business-related commitments to any companies involved in the cases.

A look at the literature on SME innovation research reveals that these studies were mostly carried out only with the help of questionnaires. Usually the response rate in questionnaires for production-oriented SMEs was low and therefore their validity is often questionable. In addition, based on the author's long experience of working with SMEs, the answers of questionnaires for production-oriented SMEs should be considered with care. Entrepreneurs often tell honestly that they have too little time to read each question thoroughly, and therefore their answers can be unreliable or even misleading. Especially if they do not know the person sending the questionnaire, they spend less time with the enquiry or leave it unanswered. If entrepreneurs know that the questionnaire is followed with interviews, they feel that they have to use more time on it. Thus, based on the author's experiences, data from questionnaires can be used only for giving initial impressions of SMEs, not as sole data for serious scientific research. That is the case especially in the area where this study was carried out. Most of the entrepreneurs in the area have no academic degrees, they are confused with the increasing flow of questionnaires, and they say that have no time for questionnaires and interviews unless these are related to their development efforts. Schein's (2009) concept about the humble inquiry supports the chosen limitation; this is discussed more in later chapters.

This study has strong practical elements, but still it is not aimed to include any instructions of the type 'how to do things right'. It aims to introduce and explore a number of applied research cases which were carried out in innovative cooperation involving SMEs and the research team of one university of applied sciences. The technological area of this study is delimited to certain areas of automation technology. The case projects are concerning robotics, simulation and wireless automation based on RFID and WSN technologies. For reasons of confidentiality, the names of the participating companies are not revealed, only the related business areas.

1.4 Definitions of key concepts and their interconnections in this study

Innovation is a concept which has achieved wide publicity especially during the last two decades, but still it has been found hard to define. It is important to make a distinction between creativity, idea, invention and innovation because for a while there has been confusion of these concepts in the public media and discussions. Creativity is the ability to produce novel ideas. An idea can lead to invention or innovation. Invention means discovering things that have never been discovered before. Innovation makes the ideas or innovations practicable when they are implemented and put into the market. In the innovation literature there is a wide range of definitions for innovation. Some of them are very general and thus denote almost all fresh and valuable thinking while more specific definitions limit innovation only to creating something new and implementing it successfully in the market (Brown 2006, ix-xii; Burns 2011, 65-69; Chesbrough 2006, xvii-xxxi; Christensen 2003, xi-xxxii; Down 2010, 157-165; Drucker 1985, 19, 33; Garcia & Calantone 2002; Govindarajan & Trimble 2010, 5; Hitt, Ireland & Hoskinsson 2005, 412; Porter 2008; Prahalad & Krishnan 2008, 47–48; Rafinejad 2007, 88-89; Sjöholm 2010, 26-32; Solatie & Mäkeläinen 2009, 28–57; Tyagi 2008, 1-3; Uljin & Brown, 2004, 2).

In his definitions of innovation, Drucker has made a point about the close relation between innovation and entrepreneurship: "Innovation is a specific tool of entrepreneurs, the means by which they exploit change as an opportunity for a different business or different service. It is capable of being presented as a discipline, capable of being learned, capable of being practiced" (Drucker 1985, 19). Furthermore, “Innovation is a specific function of entrepreneurship, whether in an existing business, a public service institution, or a new venture started by a lone individual” (Drucker 1998, 3). Discussing the relation between innovation and competitive advantage, Porter states as follows: “Companies achieve competitive advantage through acts of innovation. They approach innovation in its broadest sense, including both new technologies and new ways of doing things” (Porter 1990, 179). Uljin and Brown emphasize the implementation of innovation: “Innovation is creating something new and implementing it successfully in the market. Innovation deals with processes, products, services and technology” (Uljin & Brown 2004, 2). The same view is shared by J.S. Brown, the former director of the Xerox Palo Alto Reseach Center, who defines innovation as invention implemented and taken to market (Brown 2006, ix). Govindarajan and Trimble have in their latest book the broadest possible definition for innovation. For them an innovation initiative is any project that is new to you and has an uncertain outcome (Govindarajan & Trimble 2010, 5). Frankelius examines the concept from an etymological point of view. The word innovation has partly its roots in Latin ‘res novae’. The phrase was frequently used in the Roman Empire during the first century before Christ. Later, one of the first to use the more modern term *innovation* was King Edward VI in 1548. Part of the meaning of the term was ’something newly introduced’. Frankelius makes a conclusion from the etymological study that innovation really means something 1) new with high-level of originality, 2) in whatever area 3) that also breaks in to (or obtains a foothold in) society, often via the market, and 4) means something revolutionary for people (Frankelius 2009, 49). The last part differs remarkably from the definition by Govidarajan and Trimble.

This study uses the following definition for innovation, which is quite similar to the one presented by Uljin and Brown:

DEFINITION 1: Innovation

Innovation is creating something new and implementing it successfully in the market, which includes the organization's own use. Innovation deals with processes, products, services and technology.

As there are many definitions for innovation, there are also many types of innovations and many ways to categorize innovations. In the innovation literature, Schumpeter’s categorization originating from the 1930s can be considered a classic one while Tidd and Bessant, Govindarajan and Trimble, Chesbrough and Christensen have presented more recent categorizations of innovations. Schumpeter's classic concept of innovation goes far beyond technological change in the narrow sense. He is concerned with carrying out of new combinations in his concept, which includes five types of innovations (Burns 2011, 66; Langlois 2003, 3; Schumpeter 1934, 66):

1. The introduction of a new or improved good or service: that is one with which consumers are not yet familiar - or of a new quality of a good.
2. The introduction of a new process: method of production that is one not yet tested by experience in the branch of manufacture concerned.
3. The opening of a new market: that is a market into which the particular branch of manufacture of the country in question has not previously entered, whether or not this market has existed before.
4. The identification of new sources of supply or raw materials: irrespective of whether this source already exists or whether it has first to be created.
5. The creation of new types of industrial organizations: carrying out of the new organization of any industry, like the creation of a monopoly or the breaking up of a monopoly position.

These innovation types are basically still valid today even if the structure of the economy has changed considerably since Schumpeter's days when innovations took place mostly in large industrial enterprises (Down 2010, 158; Langlois 2003, 3).

Tidd and Bessant argue that there are four P-types of innovation (4Ps): product, process, position and paradigm innovations, which all can be further divided into incremental or radical innovations. ***Product innovation*** represents changes in the things (products/services) that an organization offers. Toyota Prius hybrid engines or LED-based lighting technology are good examples of radical product innovation. The Windows 7 or Windows Vista operating systems are examples of incremental product innovations. ***Process innovation*** represents changes in the ways in which they are created and delivered. Skype and other VoIP systems or lean approach for production are examples of radical process innovation. In contrast, improved fixed line telephone services and improved factory operation efficiency through upgraded equipment provide examples of incremental process innovation. ***Position innovation*** represents changes in the context in which products or services are introduced. The Lucozade case in the UK is often presented as a typical example of a radical position innovation: it used to be a medicinal drink but it was repositioned as a health drink aimed at the growing fitness markets. One laptop per child at a price of 100 $ or microfinance type credits to the poor are other examples of radical position innovations. On the other hand, segmenting and customizing computer configurations for individual users or targeting banking services at key segments (students, retired people, etc.) are examples of incremental position innovation. ***Paradigm innovation*** represents change in the underlying mental models which frame what the organization does. Tidd and Bessant present Bill Gates' aim to provide a home computer for everyone, the iTunes platform and Cirque de Soleil entertainment shows as examples of radical paradigm innovation. In contrast, the move by IBM from being a machine maker to becoming a service and solution company is an example of incremental paradigm innovation. Even if Tidd and Bressant give many examples of innovations belonging to some of these 4Ps categories, they admit that in many cases the lines between the categories are somewhat blurred, and one innovation can be a product or process innovation at the same time. (Tidd & Bessant 2009, 21-27)

The four fundamental categories of innovation proposed by Govindarajan and Trimble are continuous process improvement, process revolutions, product and service innovations, and strategic innovations. ***Continuous process improvement*** involves countless small investments in incremental process innovations. General Electrics' well publicized six-sigma program is an example of an innovation type where the focus is on incremental process innovation. ***Process revolutions*** improve existing business processes through the implementation of major new technologies. Govindarajan and Trimble argue that an example of process revolution, the introduction of RFID technology, can improve supply chain management productivity as dramatically as by 30 percent. RFID technology will be discussed in detail later in this study (see Chapter 4). ***Product or service innovations*** are creative new ideas which do not change existing business models. Govindarajan and Trimble state that consumer products by toy or game manufacturers are typical for this type of innovations; Cabbage Patch dolls and Razor kick scooters are presented as examples. ***Strategic innovations*** may include process or product innovation, but they always involve uncertain, new business models. General Motors' OnStar, a new business unit to commercialize an integrated information, safety and communication systems for certain GM vehicles, is presented as an example of strategic innovation. Canon's strategic innovation was to redefine potential customers from the previous focus of large companies to the new focus of home offices. Also the previously mentioned IBM shift from selling hardware and software to selling complete solutions can be regarded as a strategic innovation. Govindarajan and Trimble propose that the cost, timeframe, and risk of each type of innovation increases when shifting from continuous process improvements to process revolutions, product and service innovations and finally to strategic innovations. They also suggest that each innovation type requires a profoundly different management approach. They encourage companies to try all four of these, but to focus on strategic innovation because it is the key to breakthrough growth. (Govindarajan and Trimble 2005, xvii– xxvii)

According to Chesbrough (2006) innovations can be categorized in two main types: open and close innovations. ***Closed innovation*** is the traditional paradigm where companies must generate their own ideas and then develop, build, market, distribute, service, finance and support them on their own. On the other hand, ***open innovation*** is a term promoted by Henry Chesbrough, professor and executive director at the Center for Open Innovation at the University of California, Berkeley. Recently there has been a general trend towards open and distributed innovation processes driven by more advanced and inexpensive computing and communications. Chesbrough defines open innovation as a paradigm that combines internal and external ideas into architectures and systems whose requirements are defined by a business model.

The business model utilizes both external and internal ideas to create value while defining internal mechanisms to claim some portion of that value (Chesbrough 2006, xxiv). In his book *Democratizing innovation* (2005), von Hippel discusses how the user-centered innovation process can transform manufacturer-centered innovation development systems into open innovation processes in a revolutionary way. To some extent this study overlaps open innovation and user-centered innovation processes but does not attempt to examine in depth the creation of new open innovation based business models. However, Chesbrough's statement "A world of opportunities awaits the company that can harness ideas from its surrounding environment to advance its own business and that can leverage its own ideas outside its current business" (Chesbrough 2006, 195) is something that perfectly matches this study.

Christensen (2003) divides innovations in two classes depending on whether they are based on sustaining or disruptive technology. ***Sustaining innovation*** improves the performance of established products, typically aimed for mainstream customers in major markets. Technological advances are usually sustaining in character. Conversely, ***disruptive innovation*** brings to market a very different value proposition that was available previously; this type of innovation may improve a product or service in ways that the market does not expect. It can lead to major change in social practices – the way we live, work and learn. Digital photography, mobile telephony and electronic greeting cards downloadable over the Internet are typical examples of disruptive innovation. Products based on disruptive innovations usually bring some new features for the customer. They are typically cheaper, simpler, smaller and more convenient to use. Disruptive innovations allow a whole new population of consumers to access a product or service that was previously unavailable for them due to the high price or skill requirements. (Christensen 2003)

Tidd and Bessant (2009, 535) have presented Skype as an example of successful disruptive innovation, which combined two emerging technologies to create a new service and business model for telecommunications. Voice over Internet Protocol (VoIP) and peer-to-peer (P2P) file sharing gave the possibility to launch an innovative business model with provision of free software and free calls between computers. In the business model, revenues were generated in several ways, including premium services, software licensing and web advertising. Skype was created in 2003 by the Swedish entrepreneur Niklas Zennström and within five years it had 310 million registered users in 2008. Innovation management of disruptive technologies is not easy. Brown (2006) states that successful disruptive innovation demands an innovative business model, which is not easy to create because it is almost impossible to predict the way that disruptive innovations will shape social practices. Chistensen also argues that segmentation of markets by product attributes or type of customer will fail to identify potentially disruptive innovations; Tidd and Bessant share his view (Chistensen 2003, 257-261; Tidd & Bessant 2009, 422-423).

Kim and Mauborgne (1997) divide innovations based on strategic logic into ***conventional innovations*** and ***value innovations***. Their value innovation concept has emphasis on both value and innovation. In value innovation, competition and benchmarking competitors are not on the focus, but the idea is to provide superior value to the customer. A value innovation can be a quantum leap in an organization. Wang and Ahmed (2002) consider value innovation comparable to creative destruction (Schumpeter 1934), disruptive innovation (Christensen 2003) and breakthrough innovation (Garcia & Calantone 2002; Wang & Ahmed 2002). These can all be seen to create fundamentally new and superior value, or to do things in a totally new way. Wang and Ahmed also introduced their 5-S model of creative quality and value innovation (Arhio 2007, 106-107; Wang & Ahmed 2002, 419-420). The five S-characteristics in their concept are: satisfying, surprising, superposing, surpassing and stimulating. Their cross-disciplinary approach is targeted for sustaining competitive advantage in the hyper-competitive world as they describe it (Wang & Ahmed 2002, 417).

In its recent Innovation Union Scoreboard 2010 (2011), the European Commission categorizes innovations into four categories: product, process, marketing and organizational innovations.

There is also a wide range of other categorizations. On the one hand, incremental and radical/breakthrough innovations and on the other hand, continuous and discontinuous innovations are typically distinguished in several categorizations. However, there has also been criticism of categorizations and the way they were made. Garcia and Calantone (2002) found that the terms radical, really-new, incremental and discontinuous are used ubiquitously to identify innovations. They questioned the difference between the various classifications, arguing that it is important to take into account both the marketing and technological perspectives as well as a macrolevel and microlevel perspectives when identifying innovations. There exist also opinions that many innovations are impossible to put into existing categories. Recently Prahalad and Krishnan (2008) presented their criticism of pigeonhole innovations and claimed that hardware and software innovations, manufacturing and service innovations, product and service innovations, and process and product innovations are all categories of the past. Bridgestone's smart tyres, the iPod, iPhone and Google are presented as examples of the new age of innovations which are not possible to put into a single traditional innovation category, for example that of product, process, packaging, pricing, distribution or billing innovation (Prahalad & Krishnan 2008, 37).

Most of innovations which are dealt with in this study do not belong to only one single category; this conclusion is in line with the findings of Prahalad and Krishnan. In this study, the range of innovations under interest are combinations of product and process innovations, which can also have some relation to marketing or organizational innovations as shown in FIGURE 2 and labeled as *Proactive Combination Innovations*. These are in the core interest of this study. In fact, from the historical perspective, this approach follows

Schumpeter's (1934) entrepreneurial spirit. Schumpeter envisioned that entrepreneurs proactively created opportunity utilizing innovative combinations (Burns 2011, 14).

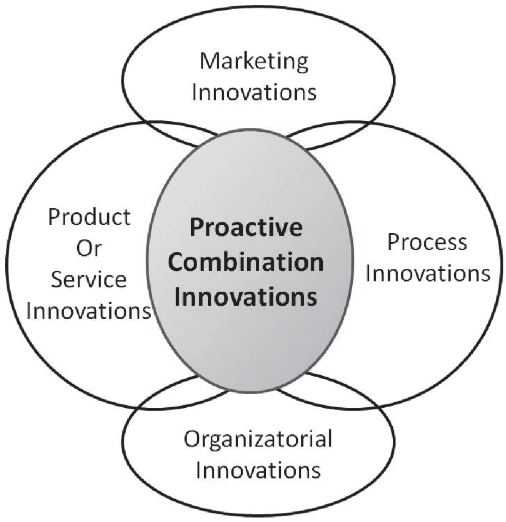

FIGURE 2 Proactive combination innovation and its relations to other innovations

This study uses the following definition for proactive combination innovation:

DEFINITION 2: Proactive Combination Innovation

Proactive Combination Innovation is a novel integration, which proactively combines elements from at least two of the product, service, process, marketing and organizational innovation categories. It may also include components from both open and closed innovation categories.

Proactive refers to preparing expected and unexpected changes in the future; e.g. product innovations take into account the future process changes such as RFID-based identifying of products also in smaller shops or factories or the increasing spread of mobile phone based payments, or utilization of social networks for marketing products or services. However, proactive combination innovations have to fulfill the requirement Drucker stated a quarter century ago: "Don't innovate for the future. Innovate for the present!" (Drucker 1985, 137). This means that these innovations should be ready to be taken into use, but following the open innovation principles they are designed so that they can confront the future change of social practices introduced by disruptive innovations. This may also require continuous reinventing of strategy in some high technology areas which are developing fast. Proactive Combination Innovations can also cover the future needs of SMEs' customers; these needs may be currently unclear for customers. Collaboration projects involving research groups and SMEs can also bring about proactive combination innovations to fulfill the future technological needs for SMEs, which they have not yet encountered or are not prepared to face. Proactive combination innovations will in the future be more and more cross-disciplinary in nature.

An important part of innovation processes is the capability to fully utilize the latest technology and capability to innovate. There are several types of technological capability in the literature; the most important type for this study is ***innovation capability.*** Romijn and Albaladejo define innovation capability as one type of technological capability which refers to the ability to make major improvements and modifications of existing technologies, and to create new technologies (Romijn & Albaladejo 1999). Innovation capability is also defined as the skills and knowledge needed to effectively absorb, master, and improve existing technologies, and to create new ones (Lall 1992; Romijn & Albaladejo 2002). Kobe, Harland and Meier (2004) define that the task of innovation capability is to develop new products and to adapt the whole enterprise to the changing environment. The Fraunhofer research group (Bullinger et al. 2007) developed a three-stage approach to improve innovation capability. In their concept, innovation capability is defined as the holistic, corporate-wide potential of a company to generate new and unique values. Innovation capability relates to a variety of areas and is influenced by different factors inside and outside the organization.

This study uses the following definition for innovation capability:

DEFINITION 3: Innovation capability

Innovation capability denotes the ability to make major improvements and modifications of existing technologies and to create new technologies, skills and knowledge to adapt them to the changing environment.

The notion of opportunity has become one of central issues in the field of entrepreneurship (Berglund 2007, 243; Down 2010, 53). In the literature, two or three perspectives on opportunities are discussed widely; the existing opportunities are recognized, discovered or created in social processes. In the recent literature, the discovery and exploitation view is often linked with the writings of Shane (2000, 2001, 2003) while the creation view in social processes with articles of Sarasvathy (2001, 2003).

The discovery perspective can be traced to the Austrian economic tradition, especially Kirzner (1999, 2008), who in the 1970s introduced the notion of alert discovery of arbitrage opportunities. Drucker's innovation definition also includes the relation between innovation and business opportunity (Drucker 1985, 19). He has described that innovation is the specific tool for entrepreneurs to exploit change as an opportunity for a different business or a different service. Drucker (1985, 35) states that systematic innovation means monitoring seven sources for innovative opportunities: the unexpected occurrence; the incongruity; innovation based on process need;

changes in industry structure or market structure; demographics; changes in perception, mood and meaning, and new knowledge, both scientific and nonscientific. The first four come from within the enterprise and three last outside the enterprise or industry. The connections between these seven areas are often unclear and overlapping. Venkataraman (1997) defines that an entrepreneurial opportunity consists of a set of ideas, beliefs and actions that enable the creation of future goods and services in the absence of current markets for them. Shane and Venkataraman (2000) created a framework for entrepreneurial opportunity seeking based on exploration and exploitation of profitable opportunities. Shane and Eckhardt (2003) extended and elaborated this individual-opportunity framework on entrepreneurship and updated their previous work with more recent contributions.

Lately there have been further interests and discussions about the creative view of entrepreneurial opportunities. Sarasvathy, Dew, Velamuri and Venkataraman (2003) presented their concept of three views for entrepreneurial opportunity: the market as an allocative process, a discovery process, and a creative process. The ***allocative view*** is based on ***opportunity recognition***: if both sources of supply and demand exist, the opportunity for bringing them together has to be recognized, and then the match-up between supply and demand has to be implemented either through an existing or a new firm. Franchising is a typical example of the allocative process. The ***discovery view*** is based on discovery of opportunity: if only one of the two exists, then the nonexistent side has to be discovered before the match-up can be implemented. Applications of new high technology solutions are often examples of the discovery view; the supply exists, so the demand has to be discovered. If neither supply nor demand exists in an obvious manner, one or both have to be created. Here a ***creative view*** is needed for ***opportunity creation***. The creative view often includes several economic inventions in marketing and financing; sometimes it requires the creation of new markets. Down (2010, 54) argues that contemporary economics sees opportunities as existing 'out there' waiting to be found, but people should create opportunities together based on creative innovation process paradigm. This does not mean that the outside world does not exist. The point is that in this view, economic and social life and opportunities are produced via the relations between people, institutions, material objects and language.

More business opportunity views and their suitability for SME-oriented applied research are discussed later in Chapter 2.5. This study relies on the creative view of business opportunity seeking but is, however, not ignoring the discovery view or opportunity recognition. This study uses the following definition for business opportunity:

DEFINITION 4: Business opportunity

A business opportunity is defined as a marketable result from a systematic innovation process. The opportunities can be in some cases recognized, but more typically they are developed by hard innovative work where people create opportunities together.

Applied research is defined as work undertaken to acquire new knowledge directed primarily towards a specific practical application (Official Statistics of Finland 2011). In this definition applied research includes seeding applications for the findings of basic research or determining new methods or ways of solving a particular problem.

Applied research is often underestimated, especially in theoretical academic research. However, as discussed in Chapter 1.1, the most challenging part of innovating is the execution, and applied research is an essential part of it. Applied research is neither pure development work nor an extension of basic research; it is research which is focused on some application. Applied research usually needs strong theoretical background, for example in mathematics and physics. According to Tidd and Bessant (2009, 253) applied research refers to scientific study and research that seeks to solve practical problems. Applied R&D involves both knowledge push and need pull components. Applied R&D is directing research in areas of particular needs. Regulation both pushes in key directions and pulls innovations through in response to changed conditions. User-led innovation may be triggered by user needs, but it often involves creating new solutions to old problems – essentially pushing the frontier of possibility in new directions. Tidd and Bessant (2009, 253) warn about the risk of focusing on either of the pure forms of push or pull components. The collaborative approach with SMEs and the research team used in this study minimizes the danger for biasing the research too much either to the push or pull side.

The applied research of this study is focused on production-oriented SMEs. The European community has an official definition for SMEs: *The category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding 50 million euro, and/or an annual balance sheet total not exceeding 43 million euro* (SMEs 2011). In this study the SME-sized local units of larger companies are also considered as SMEs because their resources and working culture are the same as in the firms that fit into the official SME definition. This study uses the following definition for the production-oriented SME:

DEFINITION 5: Production-oriented SME

The production-oriented SME is a business entity which mainly fits to EU definition of SME and is production-oriented in the sense that it manufactures, assembles, finishes, packages products or produces or designs and/or implements production equipment. The SME definition is expanded here also to larger companies' local units, which operate as actual SMEs in their business.

1.5 Research methodology, methods and data of this study

This study is multidisciplinary by its nature. It combines elements of technological, business and entrepreneurship research to find answers to the challenging questions presented in Chapter 1.2. It is also a synthesis of different research methodologies, approaches and methods. This study can also be described as a mixed multi-case, multiphase research study. In this chapter, issues of alternative research methodologies, methods, approaches and data collection are discussed to examine the methodological background of this study.

Research studies are often divided into two categories, quantitative or qualitative, based on data collection and analysis techniques used in the research. Saunders, Lewis and Thornhill (2009, 482) summarize the differences between quantitative and qualitative data collection and analysis: quantitative data is based on meanings derived from numbers while qualitative data is based on meanings expressed through words. Quantitative data collection results in numerical and standardized data while qualitative collection results in non-standardized data requiring classification into categories. Quantitative data analysis differs from qualitative as it is conducted through the use of statistics and diagrams while qualitative data analysis is conducted through the use of conceptualizations. Qualitative research has experienced extensive growth during last decades. It has also advanced from being seen as a way of revealing interesting anecdotes to being as a significant method for generating new knowledge about human experience (Conklin & Hayhoe 2011, vii-ix). Recent literature shows that both quantitative and qualitative research of today employ a wide variety of different methods and approaches under these two groups (Conklin & Hayhoe 2011; Dane 2011; Koskinen, Alasuutari & Peltonen 2005).

In many research studies there is a need to use both quantitative and qualitative methods. Combining different research methods is not a new phenomenon (Järvinen & Järvinen 2000; Koskinen et al. 2005; Niiniluoto 2002; Tamminen 1993), but in the more recent literature, mixing different research methods, methodologies and approaches is getting more and more interest and importance (Creswell & Plano Clark 2011; Saunders et al. 2009; Walliman 2011). Multi-method and mixed method studies have reached popularity especially in the last decade. Mixed methods research was formerly defined as methodology which only combined qualitative and quantitative research, but lately it has been extended to incorporate many diverse viewpoints. It combines methods, a philosophy, and a research design orientation. Creswell and Plano Clark (2011, 13) propose that mixed methods research is practical in the sense that the researcher is free to use all methods possible to address the research problem. Mixed methods research is often a natural choice because individuals tend to solve problems using both words and numbers; they combine inductive and deductive thinking, and employ skills for both observing people and recording their behavior.

Research can be considered from many scientific and methodological viewpoints, which are much wider than just choosing the data collection and analysis method. Philosophy of science can be defined as application of a philosophical method to science: research work and its results (Niiniluoto 2002, 21). Philosophy, research paradigm, approach, strategy, design choices, techniques and procedures are examples of different views how research work can be examined. The difference between the explanations of research methods, on the one hand, and methodology, on the other hand, is often unclear also in many scientific articles.

In this study, the term research methodology refers to the theory of how the research study should be undertaken while the term method refers to techniques and procedures used to obtain and analyze data (Saunders et al. 2009, 3). The background of many research methodologies and methods come from the social sciences. Therefore, many issues cannot be applied directly in this kind of study which is a combination of technological, business and entrepreneurship research. An important issue confronting the study of the social sciences, but not so pertinent in natural or economical sciences, is the question of the position of the researcher and the human subject, and the status of social phenomena. The two extreme approaches are termed positivism and constructivism, the latter being also known as interpretivism or relativism. The positivist approach is based on accepting that the world around us is real, and that we can find out observable events about these realities with scientific methods. Relativism, on the other hand, maintains that what we see around us is the creation of our minds. We can only experience this fact personally through our preconceptions, beliefs and values. That means that we are not neutral observers but part of society. TABLE 1 compares the alternative bases of how positivism and relativism are interpreting the world. (Saunders et al. 2009; Walliman 2011)

This study can be considered as a combination of both approaches but its emphasis is mainly on the relativist side (see TABLE 1). This is because the researcher is part of the process, and different interpretations affect the research process with complex interactions.

TABLE 1 Comparison between positivist and relativist approaches (adapted from Walliman 2011, 22-23)

Issue	Positivist	Relativist
Philosophical basis	Realism: the world exists and is knowable as it really is.	Idealism: the world exists but different people construe it in very different ways.
Role of research	To discover universal laws and generalizations.	To reveal different interpretations of the world as made by people.
Role of researcher	Neutral observer.	Part of the research process.
Theoretical approach	Rational, using inductive and scientific methods and value free data.	Subjective, using inductive methods and value laden data.
Methods	Experiments or mathematical models and quantitative analysis to validate, reject or refine hypotheses.	Surveys and observations with qualitative analysis to seek meaningful relationships and the consequences of their interactions. Analysis of language and meaning.
Analysis of society	Search for order. Society is governed by a uniform set of values and made possible only by acceptance of these values.	Search for dynamics. Multitude of values leading to complex interactions. Society made possible by negotiation.

Research philosophy is an overarching term relating to the development of knowledge and the nature of that knowledge in relation to research (Saunders et al. 2009, 600). In the literature there are two major ways of thinking about research philosophy: ontology and epistemology. ***Ontology*** is concerned with the nature of reality and it is divided into objectivism or subjectivism. ***Objectivism*** assumes that social entities exist in a reality external to social actors concerned with their existence. ***Subjectivism*** holds that social phenomena are created from the perceptions and consequent actions of those social actors responsible for their creation. ***Epistemology***, on the other hand, studies the nature of knowledge and especially its validation and the methods used. As to the methods of acquiring knowledge, there are two basic approaches: empiricism and rationalism. ***Empiricism*** deals with knowledge gained by sensory experience and it uses inductive reasoning. ***Rationalism*** uses a deductive approach: knowledge is gained by reasoning. In this study, objectivism is the basic stance, but some subjectivism is also used for example in the analysis of questionnaires, interviews, innovation capabilities and business potentials.

Research philosophies can be categorized into four classes: positivism, realism, interpretivism and pragmatism. ***Positivism*** based philosophy maintains that all phenomena, including social, can be analyzed using a scientific method. Positivism is usually closely associated with quantitative methods of data gathering and analysis. ***Realism*** states that objects exist independently of our knowledge of their existence**.** Direct realism says that what you see is what you get while critical realism argues that what we experience are sensations, not the things directly**.** ***Interpretivism (contructivism*** or ***relativism)*** recognizes the embedded nature of the researcher: there is an interactive link between the researcher and participants, and it involves humans in their roles as social actors situated in their historical and cultural milieus. **Pragmatism** integrates different perspectives to help collect and interpret data in practical ways. (Saunders et al. 2009, 119)

Paradigm is a term frequently used in social sciences and often linked to research philosophies. It can sometimes lead to confusion because it tends to have multiple meanings. In research philosophy, a paradigm can be defined as the way of examining social phenomena from which particular understandings of these phenomena can be gained and explanations attempted (Saunders et al. 2009, 118). A recent definition states that a paradigm is the overall effect of the acceptance of a particular general theoretic approach, and the influence it has on the scientist's view of the world (Walliman 2011, 175). In the original definition by Thomas Kuhn, it means a set of generalizations, beliefs and values of community specialists (Creswell & Plano Clark 2011, 39). Creswell and Plano Clark (2011, 39-47) introduced term ***worldview*** for mixed methods research. According to their definition, a worldview in mixed methods research is composed of beliefs and assumptions about knowledge that informs the study. They also categorize the worldviews of research philosophies into four classes (postpositivism, constructivism, participatory and pragmatism) and the worldview elements into the five classes of ontology, epistemology, axiology, methodology and rhetoric. Postpositivism is often associated with quantitative approaches while constructivism and participatory research are usually associated with qualitative approaches. Pragmatism is typically associated with mixed methods research. TABLE 2 presents Creswell's and Plano Clark's view how the four worldviews have practical implications on relation to the five worldview elements (ontology, epistemology, axiology, methodology and rhetoric) and questions associated to these elements.

From the philosophical view or worldview (see TABLE 2), this study can be associated with pragmatism because it integrates different perspectives in the way pragmatism describes; constructivism, however, is often the basis for integrations and it is supplemented with participatory, sometimes even postpositivist, worldviews. Also, when looking at the categorization of research philosophies (Saunders et al. 2009) which was presented earlier in this chapter - positivism, realism, interpretivism and pragmatism - this study belongs mainly to pragmatism which, however, also combines other philosophical views. Critical realism was also mentioned as a potential contribution for mixed methods research, but Creswell and Plano Clark (2011, 45) state that it is often associated to theoretical research and so it is not in the focus of this research. However, Paloniemi (2010) has in his recent study proposed that critical realism can be used as a philosophical base of studies on business opportunity creation. Altogether, authors of recent literature give support for the chosen approach of this study: they encourage flexibility in adopting and mixing research philosophies, approaches and methods (Creswell & Plano Clark 2011; Saunders et al. 2009; Walliman 2011).

TABLE 2 Four worldviews, five worldview elements and their implications for practice (adapted from Creswell & Plano Clark 2011, 42)

Worldview ' Worldview Element "	Postpositivism	Constructivism	Participatory	Pragmatism
Ontology What is the nature of reality?	Singular reality -e.g. researchers reject or fail to reject hypotheses	Multiple realities -e.g. researchers provide quotes to illustrate different perspectives	Political reality -e.g. findings are negotiated with participants	Singular and multiple realities -e.g. researchers test hypotheses and provide multiple perspectives
Epistemology What is the relationship between the researcher and that being researched?	Distance and impartiality -e.g. researchers objectively collect data on instruments	Closeness -e.g. researchers visit participants at their sites to collect data	Collaboration -e.g. researchers actively involve participants as collaborators	Practicality -e.g. researchers collect data by 'what works' to address research question
Axiology What is the role of values?	Unbiased -e.g. researchers use checks to eliminate bias	Biased -e.g. researchers actively talk about their biases and interpretations	Negotiated -e.g. researchers negotiate their biases with participants	Multiple stances -e.g. researchers include both biased and unbiased perspectives
Methodology What is the process of research?	Deductive -e.g. researchers test an a priori theory	Inductive -e.g. researchers start with participants' views and build up to patterns, theories, and generalizations	Participatory -e.g. researchers involve participants in all stages of the research and engage in cyclical reviews of results	Combining -e.g. researchers collect both quantitative and qualitative data and mix them
Rhetoric What is the language of research?	Formal style -e.g. researchers use agreed-on definition of variables	Informal style -e.g. researchers write in a literary, informal style	Advocacy and change -e.g. researchers use language that will help bring about change and advocate for participants	Formal or informal -e.g. researchers may employ both formal and informal styles of writing

Saunders, Lewis and Thornhill (2009, 108) presented an illustrative presentation about relations between some research philosophies, approaches, strategies, choices, time horizons, techniques and procedures (see FIGURE 3). The outer level of this research onion, the philosophies, can be divided into positivism, realism, interpretivism and pragmatism. They raise a justifiable question about the practical use of understanding the philosophical position (Saunders et al. 2009, 109). Is it as useful as the outer layer of the real onion, which is cast aside when only the inner layers are used? However, Saunders, Lewis and Thornhill try to convince that knowing the philosophical position is important to enhance understanding of the way in which the study is approached. Walliman (2011, 15) reminds that also unphilosophical persons have unconscious philosophies, which they apply in their practice.

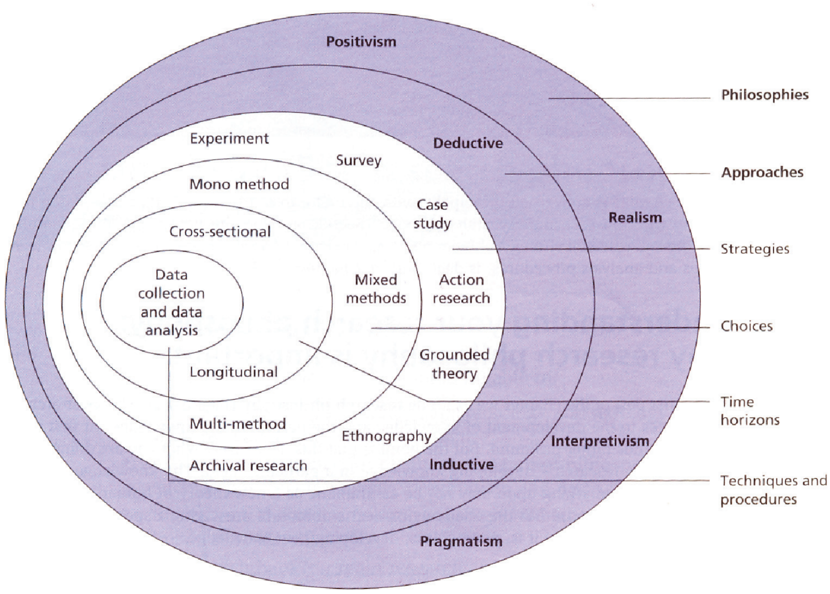

FIGURE 3 The research onion (Saunders et al. 2009, 108)

In the second outmost layer are inductive and deductive approaches. An inductive approach involves the development of a theory as a result of the observation of empirical data while the deductive approach can be defined as 'first theory then research'. The two middle layers include strategies and choices. The strategy layer includes several different kinds of research strategies, or research designs as Walliman (2011, 9-13) calls them. According to Saunders et al., experiment, survey, case study, action research, grounded theory, ethnography and archival research are examples of research strategies. The layer of available choices is divided into mono, mixed methods and multi methods. In the core of the onion are techniques and procedures for data collection and analysis, which are surrounded by time horizons. These can be either cross-sectional or longitudinal. Saunders et al. make an important notice that often questions concerning the choice of research methodology or research methods start from data collection and analysis, for example the choice between certain quantitative or qualitative methods. However, before moving on to these, there are many important layers of the research onion to be peeled away. (Saunders et al. 2009, 106-127)

When considering the research onion for this study, it can be stated that mixed methods are used in every layer. In the philosophy level, pragmatism is the main choice which also combines other philosophies. The approaches level mainly uses the inductive approach, but in some cases also deductive elements are taken into consideration. In the strategy level, case study and action research are the most important strategies for this study, and therefore they need a closer look later in this chapter. Multi-method and mixed methods are the most important in the choices layer; these were discussed earlier in this chapter. The time horizons of this kind of academic studies are often cross-sectional: the study of particular phenomena at a particular time. This study, however, can be defined as a longitudinal study: the study of particular phenomena over an extended period of time. Saunders et al. (2009, 155) warn that longitudinal studies will take plenty of time which is definitely true also in this study: the first SME-oriented applied research projects started as early as in 2002. In the core of the onion are the data collection techniques and analysis procedures where combinations of different qualitative and quantitative methods are used.

The case study strategy can be defined as an approach that involves an empirical investigation of a particular contemporary phenomenon within its real life context, using multiple sources of evidence (Koskinen et al. 2005; Noor 2008; Saunders et al. 2009, 588; Yin 2009). Case studies make it possible to understand the complex real-life activities in which multiple sources of evidence can be used. Case studies concern with how and why things happen, allowing the investigation of contextual realities and the differences between what was planned and what actually occurred. *How* and *why* are thus typical research questions of case studies. According to Yin (2009), case studies can be explanatory, exploratory or descriptive.

The designs for case studies can be single- or multiple-case studies, and the methods used in case studies can be qualitative, quantitative, or both. Multiple-case studies can be designed to be either holistic or embedded. Holistic multiple-case designs have a single unit analysis in every case while embedded multiple-case designs have multiple units of analysis in every case (Yin 2009, 46-60). Case studies also allow generalizations as the result of findings using multiple cases can lead to some form of replication. Multiple-case studies follow the logic of two or more cases being included within the same study precisely because the investigator predicts that similar results will be found. Every case should be selected so that it either predicts similar results (a literal replication) or predicts contrasting results for anticipatable reasons (a theoretical replication). If such replications are found for several cases, the overall results have more confidence (Noor 2008, 1604; Yin 2009, 55). Many features of case studies suit well in this study, where different approaches are combined. This study can also be considered as an embedded multiple-case study because tens of SME-oriented applied research cases have been carried out and the results are analyzed to find business opportunities and generalizations how innovation capabilities can be enhanced in SMEs and small research groups

Action research is a research strategy for the management of a change, involving close collaboration between practitioners and researchers. The term action research was introduced as early as 1946 by the founder of American social psychology Kurt Lewin. It has close connections with experimental learning theories developed by John Dewey, Jean Piaget, Kurt Lewin and David

A. Kolb (Dane 2011, 10-12; Kolb 1984, 4-19; Saunders et al. 2009, 147-148). Lewin emphasized the practicality of action research with his statement: "Research that produces nothing but books will not suffice" (Lewin 1946, quotation in Heikkinen & Jyrkämä 1999, 25). The consistent theme in all Lewin's work was his concern for the integration of theory and practice. This was symbolized in his most famous remark: "There is nothing so practical as a good theory" (Kolb 1984, 9).

The idea of self reflection is central in action research, which thus provides the researcher a practical way of looking at his or her own work (Heikkinen & Jyrkämä 1999; McNiff 2002). Another key idea in action research is change intervention, which has double meaning. In action research, reality will be changed so that it is possible to examine it. On the other hand, reality will be examined so that it can be changed (Heikkinen & Jyrkämä 1999, 44-45). Action research is iterative in nature, and it is often carried out in a spiral of cycles which include diagnosing, planning, taking action and evaluating (McNiff 2002; Saunders et al. 2009, 147-148).

Action research type of studies are known also by many other terms, such as participatory research, collaborative inquiry, emancipatory research, action learning, action science and contextual action research (Hiltunen 2010, 51-81; Järvinen & Järvinen 2000, 129-137; O'Brien 1998; Saunders et al. 2009, 147-148; Whyte 1989), but all of these are variations on a theme. Action research is simply a 'learning by doing' strategy: a group of people identify a problem, do something to resolve it, see how successful their efforts were, and if not satisfied, try again (O'Brien 1998, 1). This study can be considered to involve important elements of action research because practicality and learning by doing are essential strategies throughout the applied research cases in the study. The author also has responsibility for integrating education and research in the university of applied sciences; thus experimental learning cycles of action research fit perfectly also in education. The applied research cases of this study follow the change intervention principle of action research: both sides of change intervention are present in this research. The evaluation of technological innovation capability and business opportunities carried out in this study follows the self-reflective principle which is central in action research.

Developmental research (Richey, Klein & Nelson 2004; Tamminen 1993, 150-162) has close relations to action research: in that approach all information is acquired in connection with actions. In the beginning, there is usually a gap between the realities of researchers and practice. Tamminen (1993, 158-162) states that developmental research can bridge that gap via four tasks: familiarization of the research object, creative thinking, evaluation of ideas, and active commitment to implementation. There is sometimes confusion about the term of developmental research as it is used in the literature: in some connections it can mean studies related to developmental psychology of child. In the related literature, developmental research is sometimes also called development research (van den Akker 1999) but this can cause more confusion: development research is often associated with the development and training in developing countries. Richey et al. (2004) presented a profound literature review and presentation about the nature of developmental research. This study can be considered to follow the principles presented in the literature on development research: development work during this study surely decreases the gap between the reality of researchers and the practice. All of the four development tasks that Tamminen (1993, 158-162) described are also part of this study.

In their recent interesting essay, Sarasvathy and Venkataraman (2011) submitted a totally different view for methodological discussion, and they call it a provocative argument in the way of reasoning about the world. The two respected authors introduce ***the entrepreneurial method*** analogous to the scientific methods. They raise a question if the contemporary thinking of entrepreneurship as a sub-discipline of economics of management is the wrong way. Sarasvathy and Venkataraman claim that entrepreneurship can be regarded as a method both on the historical parallels and recent empirical findings. They admit that there are many open questions considering the entrepreneurial method, and some of those are discussed in their essay. The main differences of the entrepreneurial method and the scientific method are presented in TABLE 3.

TABLE 3 Comparison of the entrepreneurial method with the scientific method (adapted from Sarasvathy & Venkataraman 2011, 115)

Comparison	**Scientific method**	**Entrepreneurial method**
Similarities in historical development	**Early explanations:** - Some special people are able to (are even born to) "read the signs"—from the True Book (of God or Nature) - Real science is born when the experimental method of the craftsmen is adopted by the university-scholar and the humanistic literati **Scholars begin to argue that:** - There is no qualitative difference between the processes of revolutionary science and journeyman science—i.e., anyone can learn to do science and do it well	**Early explanations:** - Some people are able to (are even born to) see opportunities while others are not - University-scholars (whether they are theoretical social scientists or empirical policy researchers) begin to understand what actual entrepreneurs really DO **Scholars begin to argue that:** - Key elements of the entrepreneurial method can be the same for the extraordinarily successful entrepreneur as well as the ordinary entrepreneur—i.e., it can be taught and learned
Differences in content	Harnesses the potential of Nature **Purpose:** - To achieve human ends - Aims to discover general "laws"—the emphasis is on universality and inevitability - Focus is on the objective - Mechanisms involve data gathering, formal models, analytical techniques and testing for correspondence with reality - Dominant logic: Experimentation	Unleashes the potential of human nature **Purpose:** - To engender new ends as well as achieve old ones - Aims to generate and refine design principles—the emphasis is on locality and contingency - Focus is on the inter-subjective - Mechanisms involve action, interaction, reaction, transformation and explicit co-creation - Possible candidate for a dominant logic: Effectuation

When considering this thesis study, many aspects of the entrepreneurial method presented in TABLE 3 are also similar to the applied research carried out in cooperation with the research team and production-oriented SMEs. Sarasvathy and Venkataraman emphasize the active cooperation of entrepreneurs and their stakeholders. In the case of collaborative projects with production-oriented SMEs, everyone who can affect or be affected by the projects is considered stakeholder. Based on the author's experience, the active and continuous cooperation of the research team and SMEs is crucial for successful implementation of the entrepreneurial method. This is the only way for the research team to understand what entrepreneurs really do. The mechanisms involved are those proposed by Sarasvathy and Venkataraman (see TABLE 3): action, interaction, reaction, transformation and explicit co-creation. The relations between the innovations, entrepreneurial method and automation in SMEs are considered more in Chapter 2.

As a conclusion of methodological considerations, this study is a synthesis of several research approaches, and it integrates several research methods. From the philosophical view, this study can be considered to relate to pragmatism because it integrates several perspectives in the way pragmatism describes. However, constructivism is often the basis for integration, and it is supplemented with participatory, sometimes even postpositivist worldviews (Creswell & Plano Clark 2011; Saunders et al. 2009). When considering its research methods, this study can be described as a mixed multi-case, multiphase research study, where features of action research and developmental research are integrated (Creswell & Plano Clark 2011; Heikkinen & Jyrkämä 1999; McNiff 2002; Richey et al. 2004; Saunders et al. 2009; Tamminen 1993). Experiential learning and learning-by-doing principles inspired by the work of Dewey, Lewin, Piaget and as integrated by Kolb (1984) can also be considered the basic methodological foundation of this study. It uses principles of case-study research starting from research questions: the second research question with its subquestions (presented in Chapter 1.2) starts with *How?* – which is typical for case study research (Yin 2009, 8-14). As to the subcategories of case study research, this study can be recognized as an embedded multiple-case study because in every case it includes several embedded units of analysis (Yin 2009, 46-60). The pragmatic and learning-by-doing approach of this study can also be considered to use features of the entrepreneurial method proposed by Sarasvathy and Venkataraman (2011).

1.6 Research phases of this study

This research is a multiphase study carried out mainly in CENTRIA's SME-oriented applied research projects in 2002-2010. This chapter begins with a brief description of these research projects and after that the details of the six research phases of this study are presented (see FIGURE 4). The first five phases belong to every project while the analysis of business opportunities was carried out in 2010–2011 based on the results of five first phases of the different projects. The first two phases concentrate on analyzing the needs of SMEs and state-of-art in selected automation technology areas. In the terms of action research, the third, fourth and fifth phases can be described as change intervention while the last phase is concentrated on self-reflection.

The author started in 2002 as a project manager and main research scientist in a project called ROBOTOOL, which concentrated on developing know-how for the local industry on computer-aided tool design and manufacturing, robotics, robot simulation and off line programming. The project was financed by the European Regional Development Fund/Provincial State Office of Oulu, Ylivieska region, Central Ostrobothnia Polytechnic and companies which were mainly SMEs. As a result of the project CENTRIA created a development network which was able to promote business in the region via providing research, developing and training services on computer-aided tool design and manufacturing, 3D measuring and quality management, robotics, robot vision, robot simulation and off line programming.

The ROBOTOOL project was followed by two additional ERDF-funded projects. DIGIMANUQ (2005-2007) was concentrated on digital manufacturing and automation while the focus of the TURWA/SAFIA (2007-2010) project was on safe and interactive automation. The author acted as a project manager and a main research scientist in these three projects as well as in two Tekes projects RASAUSE (2003-2005) and LUOVI (2009- 2011), which were funded by Tekes (the Finnish Funding Agency for Technology and Innovation), companies and Central Ostrobothnia University of Applied Sciences. RASAUSE was focused on the rapid and safe use of robot systems, and LUOVI's main interest was to develop natural interaction and interactive control methods for robotics and production work cells. The author worked as a sub-project manager and a research scientist also in two other Tekes projects: SWAM (2005-2007) - Short Distance Wireless Applications for Machines and Systems, and SensoTag (2007-2009) - Ubiquitous Computing in Maintenance Using Sensors. Currently the author has been participating in ERDF project CENTRIA Platform (2010-2012) as a research scientist. The author has gained international cooperation experience with many international universities and research institutions during these projects and especially when participating in the two EU Interreg projects, EKIE (2005-2007) - Enhancing Knowledge Intensive Enterprises in Small Cities, Surrounded by Rural and Sparsely Populated Areas, and DIM (2009-2012) - Digital Integrated Manufacturing suitable for SMEs.

The number of companies involved in these projects varied in the ERDF-financed projects between 10-30 SMEs per project and in TEKES- and Interreg-financed projects 5-15 companies per project. More than 90 percent of the companies were local SMEs, which were typically production-oriented SMEs. In CENTRIA's ERDF and TEKES projects the partners were mainly from Finland. However, some cooperation was carried out with foreign research organizations, for example from Germany, Poland, Lithuania, Netherlands, France and Japan. In the Interreg IIIC project EKIE, the partners came from five countries: Italy, Germany, Ireland, Estonia and Finland. In the ongoing Interreg IVA project DIM, the partners come from Norway, Finland and Sweden.

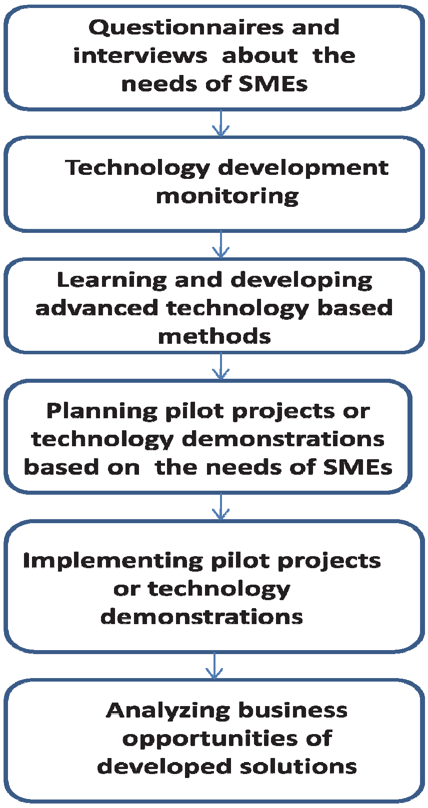

FIGURE 4 Research phases in this study

During the projects there have been several questionnaires and interviews, which constitute the first research phase. The purpose of the questionnaires was to gather information for focusing the applied research in the projects. According to Saunders et al. (2009, 362-363) questionnaires can be divided into the self-administered and interviewer-administered type. Furthermore, self-administered questionnaires can be categorized into three classes: Internet and intranet–mediated, postal, and delivery and collection questionnaires. Interviewer-administered questionnaires can be divided into telephone questionnaires and structured interviews. In this study, the more extensive questionnaires were self-administrative, either postal or Internet or intranet-mediated questionnaires. After that, some of the SMEs were selected for interviewer-administered questionnaires. The SMEs chosen for those interviews were either typical representatives of a certain SME group or they showed a special interest to develop subjects which were in the core focus areas of projects.

As discussed earlier in Chapter 1.3, the survey response rate by production-oriented SMEs is usually low – in the cases of this study typically 10–20%. Therefore, their scientific validity as such is often insufficient. However, the experiences of CENTRIA's research team confirm that SMEs which participate in surveys are usually development-oriented and give valuable information. These companies are representative examples of the whole range of production-oriented SMEs in the area. Typically, a great deal of additional valuable information was gathered later when the questionnaires had been completed with face-to-face interviews or sometimes with telephone questionnaires or interviews. The number of companies participating in the surveys varied between 50 and 500 companies in North Finland. The latest questionnaires of the DIM project were sent to 660 companies in northern parts of Finland, Sweden and Norway. In addition to questionnaires and interviews carried out in the projects of this study, external information was used based on other surveys or investigations. In 2003 Antinoja and Hakuli published the results of their competence forecast study on in the *Oulu South* area. The results of their study were also used to focus the projects of this study. In the similar way, the results of studies conducted by Chydenius Institute (Aradóttir 2005; Virkkala & Niemi 2006) were used, and so were the results of certain Tekes projects, for example the recent SERVE project (Ylén et al. 2010).

In the second phase of this study, technology development and status of automation were monitored from several sources including continuous follow-up of conferences and publications, analysis of statistics, future trends and roadmaps, and visits to conferences, exhibitions, universities and companies. A typical conference visit was made to a conference on robotics, automation, mechatronics, wireless and ubiquitous technology while exhibitions include general technical exhibitions such as the Hannover Fair and special exhibitions, for instance the Automatica Fair, which is concentrated on automation, robotics, computer vision and wireless technologies. A remarkable way for international networking were the WAMS seminars organized three times in Ylivieska by CENTRIA and University of Oulu; the most recent was held in October 2010 (Hänninen 2010; WAMS 2010). The number of participants was every time between 150 and 200 representing more than 10 countries. WAMS also included a small exhibition area with demonstrations of new products or methods developed by research units or suppliers. Benchmarking visits were also one of the tools to gather information about successful ways of carrying out SME-oriented research. In the EKIE project, the implementation included benchmarking of research and development in SMEs and research units of selected areas around Europe. This included areas in the Marche region in Italy, the Sophia Antipolis Technology Park in France, the Ginsheim-Gustavsburg area near Frankfurt in Germany, the Galway area in Ireland, the Tamsalu-Tarto areas in Estonia and the *Oulu South* and Raahe areas in Finland. Those benchmarking visits gave an impressive insight of similarities and differences of SME-oriented applied research in different parts of Europe. The second phase also included analyses of opportunities to use the gathered information of technological development for local SME-oriented applied research in order to develop new technological solutions for SMEs.

In the third phase, CENTRIA's research team first learned how to use the most advanced technology found in phase 2. After that the research team started to adapt and develop methods suitable for local SMEs, which was necessary because many advanced technology solutions found in the world have been designed for large companies and could not be directly implemented for SMEs. The third phase also included developing some novel methods targeted for SMEs. The fourth phase in the projects was planning the pilot projects or technology demonstrations based on needs of SMEs. In this phase, the goals and the objects for implementations were planned in detail. In the fifth phase, the plans were implemented either in the SME production facilities or in CENTRIA's laboratories. The difference between pilot projects and technology demonstrations was in the extent and direct applicability of the research work. The pilot projects were more extensive and concentrated to finding a feasible basic solution for some problem where suppliers were not able to provide an answer. A typical pilot project was carried out in 3-6 months. Technology demonstrations were carried out typically in 1 week to 3 months, and their purpose was to show to the SMEs what kind of opportunities the advanced technology could bring. Often these demonstrations led to further development work, either directly by SMEs or together with the research unit and suppliers. The third, fourth and fifth phases have included hundreds of visits to SMEs or vice versa SME representatives' visits to CENTRIA. Phases 3-5 will be discussed in more detail in Chapters 3 and 4.

The last phase, i.e. the analysis of business opportunities, was carried out in 2010–2011 based on the results of five first phases which were carried out in the projects introduced earlier in this chapter. In this phase, the results presented in the list of original articles were analyzed and 22 business opportunities were taken into comparison. The analysis compares the business potentials for SMEs, the stages of practical implementation, technology development needed by suppliers or research, and the increase of competence needed in SMEs. The comparisons will be presented in Chapters 3 and 4. The sixth phase also included an evaluation of how technological innovation capability progressed both in the SMEs and in the research team during the projects. The results of this evaluation will also be presented in Chapters 3 and 4.

1.7 Structure of the thesis

The structure of this thesis is exceptional. Traditionally, dissertation theses are written as either purely monographic or article based thesis reports where the summary part of the report highlights the results of the study and summarizes the answers to the research questions. This thesis report has quite an extensive monographic investigation about how business opportunities and innovation capabilities are enhanced during the course of the collaborative applied research of this study in the light of related literature. However, this report is not a traditional monograph because the articles are an essential part to understand the unity of the study and the thesis report. This thesis report contains nine articles (I-IX) which have been selected from the author's 24 articles from 2003-2011 related to the area of this study; the additional 15 articles (5 main author, 10 co-author) are listed in the References section. The author participated in planning the contents, introduction and conclusions of the articles and was a major or co-writer of these articles, especially in the parts concerning robotics, simulation and industrial applications of RFID and WSN technologies. In the collaborative projects related to these articles, the author has contributed to choosing the focus of research challenges, planning the research work, and coordinating and managing the research activities as a project manager or principal research scientist.

Chapters 1 to 5 are not a conventional summary of these articles. Instead, they view the articles from a business oriented perspective. Chapters 3.1, 3.2, 4.1 and 4.2 summarize the research progress, technological advances and research findings of the articles. However, the articles do not directly consider the research questions of this thesis study. Chapters 3.3, 3.4, 4.3, 4.4 and Chapter 5 seek answers to the research questions, and present results and answers found to them. The idea of this special structure in the thesis is to increase mutual understanding and dialogue between disciplines. As discussed earlier in Chapter 1.5, this thesis is multidisciplinary combining the elements of technological, business and entrepreneurship research. The structure selection can be considered to follow the spirit of many classical innovation principles which encourage researchers to challenge the conventional procedures and structures; these approaches are discussed further in Chapter 2.

Chapter 1 introduces the background and motives for this study and presents the research task and scope of the research. Definitions of key concepts and research methodology and methods are also discussed in this chapter as well as the research phases of this study.

In Chapter 2, the most essential issues and current trends of innovations, competitiveness and business opportunities for SMEs are discussed. Chapter 2 is not restricted to the state-of-the-art presentation of the previous and current research but it also evaluates these issues and trends in regard to how relevant and useful they are and how they relate to the SME-oriented applied research. Chapter 2 begins with general considerations of innovation, entrepreneurship and competitiveness and their significance to SMEs. Competitiveness, innovativeness, innovation capabilities and regional aspects are then examined from the viewpoint of SMEs. Chapter 2 also includes literature reviews of the most essential business opportunity and innovation capability research related to SMEs. Chapter 2 ends in discussion of innovation challenges for production-oriented SMEs.

Chapter 3 presents the research results and findings from the author's original articles concerning robotics and simulation. The evaluations concerning the business opportunities of research results and innovation capability development in robotics and simulation technologies are also presented in Chapter 3.

Chapter 4 is analogical to Chapter 3, but now RFID and WSN technologies are examined. Chapter 4 introduces the research results and findings, and the evaluations of business opportunities and innovation capabilities.

Chapter 5 features conclusions and a discussion of the study. The chapter starts with main research findings, and the research questions stated in Chapter 1 will be answered. The contributions of the study and limitations are also presented in Chapter 5. The chapter ends with the discussion and recommendations together with the look at future research needs.

After Chapter 5 the remaining part of this report includes a Finnish summary and the nine original articles.

2 INNOVATIONS, COMPETITIVENESS AND BUSINESS OPPORTUNITIES OF SMES

2.1 Relations between innovation, entrepreneurship and production automation

"Innovation! Innovation! Innovation! More than 'globalisation' and 'clusters' it is a word that really sets policy-makers juices flowing. Almost every developed and developing nation is seeking to increase its rate of innovation and aims to foster technologically driven economic growth." This is how Down in his recent book (Down 2010, 157-158) describes the status of innovation in current media and its impact on technology policies. On the other hand, it is important to remember that innovation is a two-edged sword as Chesbrough (2006, xvii) describes it: "Most innovations fail. And companies that don´t innovate die." The Fraunhofer researchers also state the importance of innovation (Bullinger et al. 2007, 17): "SMEs need to innovate in order to survive and create competitive advantages. Competitive success is dependent upon an organization's management of its innovation competencies." The European Union also prioritizes innovation so much in the Europe 2020 strategy that it wants the whole union to be called the Innovation Union (Europe 2020). The homepage of Innovation Union tells that innovation has been placed at the heart of the Europe 2020 strategy for growth and jobs (Innovation Union 2010).

Innovation is hard to define as was discussed in Chapter 1.4, but entrepreneurship is, if possible, even harder to define in order to reach common acceptance. Landström (2005, 10) reported that about twenty years ago there were almost one hundred different definitions for entrepreneurship, and many more were introduced in two last decades. Until this day there are no universally accepted definitions of the terms entrepreneur and entrepreneurship. Venkataraman (1997, 120) has doubted if any consensus for defining entrepreneurship would be at all possible. Therefore, he prefers to define entrepreneurship as a scholarly field. However, the Oxford Dictionary defines an entrepreneur as a person who attempts to profit by risk and initiative

(Burns 2011, 11; Oxford Dictionaries 2011). This definition claims that entrepreneurs are willing to take risks. The origin of the word can be traced back to the 18th century; it comes from the French word *entreprendre,* which means something like 'to undertake' or 'the ability to take charge'. It has been told that it was used in the early 19th century for denoting the director of a musical institution. In the literature the 18th century economist Richard Cantillon and the 19th century French economist Jean-Baptist Say are often presented to be the first ones to introduce and define the term entrepreneur. Richard Cantillon (1680-1734) is widely credited as being the first person to use the word 'entrepreneur' when it appeared in his famous *Essay on the Nature of Commerce in General* which was published in French in 1755. Half a century later Say mentioned that "the entrepreneurs shift economic resources from an area of lower productivity to higher productivity and greater yield" (Burns 2011, 14; Drucker 1985, 21). Drucker claimed that since this time there have been two hundred years of total confusion over definitions of entrepreneur and entrepreneurship. Say had been an admirer of 18th century economist Adam Smith, who thus also influenced attempts to define entrepreneurship. Of all the major modern economists, Joseph Schumpeter was the first to concern himself with the idea of the entrepreneur and his impact on the economy. (Burns 2011, 5-15; Drucker 1985, 21–36)

Innovation and entrepreneurship are tightly related. Schumpeter is often considered as the one who created the link between entrepreneurship, innovation and growth (Burns 2011, 71-74; Landström 2005, 13-14; Schumpeter 1934). According to Schumpeter (Burns 2011, 71-74; Carree & Thurik 2003, 442-443; Chiles et al. 2007, 468-472; de Jong & Marsili 2010, 5-10; Down 2010, Landström 2005, 13-14; Langlois 2003; 43-46; Schumpeter 1934; Velde 2004), the entrepreneur creates imperfections in the market by introducing new innovations. In his overall theory of economic development, Schumpeter described the process of *creative destruction* where the innovating entrepreneur challenges incumbent firms by introducing new inventions that make current technologies and products obsolete. Schumpeter was interested in the business cycles of capitalism and the role that innovation plays in this process. In the Schumpeterian view, the entrepreneur is considered to be an innovator who shocks and disturbs the economic equilibrium during times of uncertainty, change and technological upheaval. In the literature, the relation between entrepreneurship and innovation is often divided into two or three categories: the Schumpeterian view is often opposed with views by Kirzner or Knight (Carree & Thurik 2003; Chiles et al. 2007; de Jong & Marsili 2010; Down 2010, 43-46; Goss 2007; Kirzner 1999, 2008; Landström 2005, 13-14; Langlois & Cosgel 1993). Kirzner was interested in the convergence toward equilibrium. In his view, entrepreneurial profits are discovered on the basis of knowledge and information gaps that arise between people in the market. Innovation and new combinations are not necessary conditions in the Kirznerian view; the entrepreneur is an alert person, discovering opportunities by acting as an arbitrageur or a price adjuster. Knight, a contemporary of Schumpeter, highlighted the distinction between risk which can be known and uncertainty which is unknowable. In his view, the profit was a reward for the entrepreneurs, the bearers of uncertainty. Criticism has also been raised against these classic concepts including claims that these are less interested in entrepreneurial issues than universal laws of behavior of economic systems. Down argues that these concepts are products of economic theory and not serious investigation of entrepreneurial processes by empirical research. He suspects that economically constructed, this wood is soon falling in the enterprise studies. Sarasvathy and Venkataraman (2011) go even further in their recent essay: they propose a revolution where the entrepreneurial method should be considered as an alternative for scientific methods. They also argue that the entrepreneurial method should be taught, not only in entrepreneurial studies, but to everyone as a necessary and useful skill and an important way of reasoning about the world (Sarasvathy & Venkataraman 2011, 113).

Drucker can be considered the first one to present innovation and entrepreneurship as a purposeful and systematic discipline, based on his classic book *Innovation and Entrepreneurship* (Drucker 1985). He argued that innovation is a specific function of entrepreneurship, whether in an existing business, a public service institution, or a new venture started by a lone individual. (Drucker 1998, 3; Hitt et al. 2005, 411). He stated that innovation is the specific tool for entrepreneurs to exploit change as an opportunity for a different business or a different service. Entrepreneurs should need to purposefully search the sources of innovation, and they should also need to know how to apply the principles of successful innovation (Drucker 1985, 19).

In the literature, entrepreneurial characteristics often include personal qualities such as opportunistic, innovative, self-confident, proactive and self-motivated; visionary with flair (Burns 2011, 38-42). These are the same qualities which are needed to work successfully in the development of robotics, simulation or wireless technologies. To this list of entrepreneurial characteristics, Delmar (2006, 161-166) adds risk-taking propensity, need for achievement, over-optimism and desire for autonomy to. These characteristics also often appear in the development projects of robotics, simulation and wireless technologies both in SMEs and applied research groups.

Casson (2005) stressed the importance of optimism for the entrepreneur: optimism creates an opportunity because the pessimism of other people creates a psychological barrier to entry. Casson also extended his early theories of the entrepreneur stating that one of the most important entrepreneurial roles is to be an information manager, which is certainly true considering the increasingly global digital world of the production-oriented SMEs of this study. Down (2010, 69-71) stresses the central role of self-identity in the creative process and in finding the entrepreneurial identity. Self-identity, a term defined by famous British sociologist Anthony Giddens, describes the self as reflexively understood by the person in terms of his biography. According to Down, the interactions with others are crucial for the construction of self-identity; the same thing was also found essential in collaborative applied research with SMEs and research team of this study.

Jones-Evans (2006, 281-282) listed the entrepreneurial skills required by the intrapreneur: vision and flexibility; action-oriented dedication; persistence in overcoming failure, and setting self-determined goals. They are again common in development of robotics, simulation and wireless technologies both in SMEs and applied research groups, which in fact often work like intrapreneurs.

Importance of creativity is also essential when considering innovation and entrepreneurship (Burns 2011, 74-75; Down 2010, 69-72; Uljin & Brown 2004, 1-9). According to Csikszentmihalyi (1997, 197-198), creative persons differ from one another in many ways, but in one respect they are unanimous: they all love what they do and the opportunity to do it in a certain way which they enjoy. If conditions are right, this can lead to a flow of creativity which can be described in some cases as a state of mind where one may forget oneself, time and surroundings (Csikszentmihalyi 1997, 113-126). This flow of creativity is often only ascribed to people working with arts, but it can also be the driving force of an innovative R&D team. Applied research work usually needs all the five phases of the creative process: preparation, incubation, insight, evaluation and elaboration (Csikszentmihalyi 1997, 79-80). The creative process can lead to truly innovative solutions which may be a radical, disruptive or proactive combination of innovations. Production automation is a field where the practice of creativity, innovation and entrepreneurship are tightly connected. On the other hand, Govindarajan and Trimble (2005, 5) remind that creativity can often be the opposite of efficiency in many ways. They lay emphasis on the execution side of innovations, which they regard much more important than creativity needed for successful innovations (Govindarajan & Trimble 2005, 2010). The case implementations of this study also assure that the execution side of innovations is truly challenging.

SMEs face many barriers in trying to be innovative. Acs (2003, 2006) stated that according to conventional wisdom, small firms inherently have a deficit of knowledge assets which brings them disadvantage in generating innovative output. Acs (2006) also found that the economic and social environment has changed in such a way, shifting the innovative advantage more towards smaller enterprises. Fagerberg, Srholec and Verspagen (2010) stated that innovation is often assumed to be carried out only by the highly educated labor in R&D intensive companies which have strong ties to leading centers of excellence in the scientific world. The Fraunhofer researchers (Bullinger et al. 2007, 24) found that within SMEs, innovation processes are often neither efficient nor systematic and therefore hinder a successful and rapid transformation of innovative ideas into products and services that prove their value on the market. O'Gorman (2006, 417-418) listed a range of common problems which small businesses have in their innovation processes. Most SMEs lack the financial, technical and human resources needed to innovate. The lack of time by the owner-manager for long-term thinking prevents the development of both technical and market-led innovations. The absence of marketing experience restricts the customer-driven innovations. Even technologically competent small engineering or software firms face problems in the management of technology because of rapid development and convergence of technology. To solve these problems O'Gorman proposed cooperation with universities or technical institutes and with other businesses. The problems of SME innovation processes listed above are likely the same as production-oriented SMEs of this study face. The solution model, cooperation with CENTRIA's research team and suppliers, also fits O'Gorman's proposal.

Production automation is a technology field where innovations are essential for a company that wants to survive in competition (Anderson 2010; Ylén et al. 2010). That is the case both for production equipment suppliers or software vendors and for companies which are using those innovations in their production. Production-oriented SMEs also learn to look for new innovations from exhibitions or from their equipment or software suppliers. It is typical that new products in production automation have no *plug-and-play* type of solutions to be used in production operations. Integrating new sensors or actuators in the production process often involves innovative work by the SMEs. The integration and development work is often entrepreneurial in nature. However, SMEs are often at the mercy of the knowledge of their current dealers because they have no resource to continuously monitor the progress of automation. If SMEs and research groups cooperate on a continuous basis, the monitoring and implementations of the most recent solutions can be carried out effectively in co-operation, or in some cases new innovations can be created based on co-operation. If this cooperation network also includes continuous cooperation with automation equipment dealers and software vendors, the results of development can be implemented without delays of the delivery process, which is extremely important when considering the competitiveness of SMEs. This co-operation network has an essential role when together creating proactive combination innovations, which were defined and discussed in Chapter 1.4. SMEs know best the needs of their customers and their own resources in fulfilling those needs. Automation equipment and software dealers know best the currently available equipment, software and the related updates in the near future. The role of research groups is to extend the knowledge about current and especially future possibilities of automation technology and their applicability in SME production. Continuous cooperation of the development network facilitates the mechanisms which Sarasvathy and Venkataraman described in their entrepreneurial method: action, interaction, reaction, transformation and explicit co-creation (see TABLE 3 in Chapter 1.5). Cooperation also assures that research groups and equipment and software dealers reach better understanding of what actual SMEs really do.

2.2 Innovation-based competitiveness and SME-oriented applied research

Innovation and entrepreneurship have direct connections to competitiveness. Porter stated that companies achieve competitive advantage through acts of innovation, but he also noted that companies can sustain it only through relentless improvements (Porter 1990/2008, 179-180). He proposed that companies should select generic strategies for competitive advantage from cost leadership, differentiation or focus while Prahalad and Krishnan reminded that companies can also get competitive advantage through business processes, and therefore they should strive for clarity in their business logic and focus on core competencies and the essence of innovation (Prahalad & Krishnan 2008, 45-61, 235-250). Twenty years ago, Porter made propositions how a company can promote innovations and improvements, and these are relevant even today. First, a company should seek pressure and challenge, not avoid them. Second, it should find the most capable competitors as motivators, and respect and study them. Third, a company should also prepare a platform for international success by improving the national environment by forming clusters and welcoming domestic rivalry. Success in global competitiveness assumes that a company can selectively take advantages in other nations and use alliances selectively only when these bring true benefits. Even if globalization aspects are important, Porter pointed out that competitive advantage is created at home, where selections for strategy, product and process technology are made and where the actual production takes place. (Porter 1990/2008, 207-211)

An important concept related to ***competitiveness*** is Porter's well-known ***value chain***, where a company's activities are divided into technologically distinct activities which it performs to do business. A business is profitable if the value it creates exceeds the cost of performing these activities. To gain ***competitive advantage*** over its competitors, a company must either perform these activities at a lower cost or perform them in a way that leads to differentiation and more value. In the value chain concept, Porter divided a company's value activities into nine generic categories, which belong either to primary or secondary activities. Primary activities include inbound logistics, operations, outbound logistics, marketing and sales, and services. Support activities provide infrastructure and the inputs that allow the primary activities to take place: firm infrastructure, human resource management, technology development and procurement. According to Porter, competitive advantage in either cost or differentiation is a function of the company's value chain. Even if Porter introduced his value chain concept first time more than a quarter century ago, it is still valid also for production-oriented SMEs. (Burns 2011, 308-309; Grant 2010, 222-225 and 374-382; O'Gorman 2006, 406-422; Porter 1985/2008, 75-81)

Porter also examined the forces that shape industry competition and examined how information technology can alter them (Porter & Millar 1985/2008, 75-81). The five forces that shape ***industry competition*** according

Porter are: rivalry among existing competitors, bargaining power of buyers, bargaining power of suppliers, threat of new entrants, and threat of substitute products or services (see FIGURE 5). Information technology can alter each of the five competitive forces and attractiveness of industries. Information technology can in fact change the whole nature of competition in three ways: by changing industry structure, by creating new competitive advantages in either cost or differentiation and by spawning new businesses. Porter saw that information technology with computer-aided design and automation is in industry giving flexibility to customize and to serve small market niches. He argued that advanced technology or innovations are not by themselves enough to make an industry structurally attractive, and proposed that low-technology industries can be far more profitable than sexy high technology industries. Porter also reminds that new technology can raise fixed cost remarkably, and this in turn increases the threat of substitution because the process of making a substitute product is now quicker, easier and cheaper. Many of Porter's 1985 visions of the effects of information technology to competition have come true in everyday work in industries all over the world. Information technology has an increasingly important role also in the production-oriented SMEs of this study. (Burns 2011, 146-148; Porter & Millar 1985/2008, 75-81; Porter 2008, 3-21).

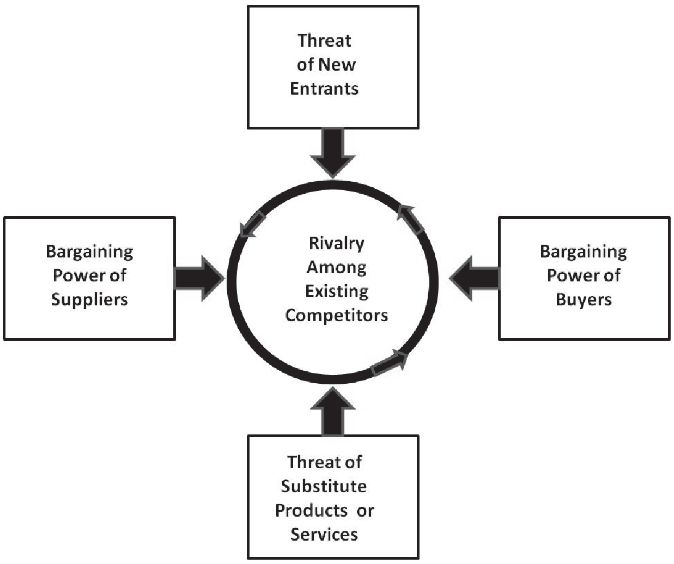

FIGURE 5 The five forces that shape competition in industry (adapted from Porter 2008, 4)

Porter (1990/2008, 171–178) carried out a thorough analysis of national competitiveness, which is increasingly getting harder due to globalization. He argued that a nation's competitiveness depends on the capacity of its industry to innovate and upgrade. According to Porter, there is no single accepted definition of the term ***national competitiveness***. He argued that the only meaningful concept of competitiveness at the national level is productivity.

In the 1980s and 1990s many national competitiveness studies examined the success of Japan. Nonaka and Takeuchi (1995) presented their view why Japanese companies have become successful (FIGURE 6). They consider Japanese companies to be unique in the way how they bring about continuous innovation based on internal and external links. Knowledge is first accumulated outside the company, then shared widely within the organization, stored as part of company's knowledge base, and finally utilized for developing new technologies and products. The conversion process from outside to inside and back again leads to new products, services and systems. This dual internal and external activity fuels the continuous innovation and is the key for the success of Japanese companies.

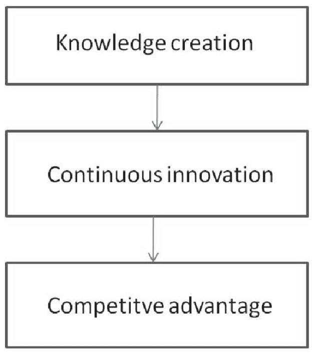

FIGURE 6 Japanese view about the relation between innovation and competitiveness (Nonaka & Takeuchi 1995, 6)

Finland's success in many rankings of innovation and competitiveness can be considered partly to have been based on effectively combining knowledge derived from outside and inside companies. The combination of internal and external activity of SMEs is essential also in the production-oriented SMEs in this study.

There are many research surveys and reports which compare national innovativeness or competitiveness. Five of them, issued in 1992, 2002, 2010 and 2011, were analyzed during this thesis study. Lall (1992) studied national technological capabilities and firm-level technological capabilities especially in developing countries. Porter and Stern (2001) and Furman, Porter and Stern (2002) examined competitive advantages of nations and developed a concept which integrates aspects of competitiveness and innovativeness. In this chapter, two recent Global Competitiveness Reports by World Economic Forum concerning the years 2010-2011 (Schwab 2010) and 2011-2012 (Schwab 2011) will also be discussed.

Lall (1992) studied national technological capabilities especially in developing countries and compared them with a number of industrialized countries. Lall developed a simple framework for explaining the growth of national capabilities, based on the interplay of incentives, capabilities and institutions. He showed that national technological capabilities are not simply the sum of thousands of individual firm-level capabilities developed in isolation. He concluded that carefully and selectively applied interventions are necessary for industrial success. In recent decades, Finland has successfully applied many interventions to promote innovativeness, and the positive results can be seen in surveys discussed later in this study.

Porter and Stern (2001) examined about ten years ago how the competitiveness of countries correlates to national innovative capacity. They first introduced a framework for analyzing national innovative capacity and constructed an innovative capacity index that allowed them to rank countries on overall innovative capacity as well as its important components. Finland clearly succeeded in this comparison: it was second after the United States while for example Japan was twelfth. In addition to the ranking tables, Porter and Stern tried to answer questions like 'Why does the intensity of innovation vary across countries?' and 'How does innovation depend on location?' When Porter and Stern compared the results of the innovative capacity index and their Current Competitiveness Index, they found that these were highly correlated. Improving innovative capacity is a way to increase productivity necessary for achieving and sustaining overall competitiveness. This fact has not changed in a decade: building innovative capacity has a strong relationship to a country's overall competitiveness and level of prosperity. Furman, Porter and Stern (2002) introduced the concept of national innovative capacity to integrate previous perspectives on the sources of differences in the intensity of innovation and R&D productivity across countries and to provide an empirical framework to distinguish among alternative causes of these differences. They emphasized the importance of the quality linkage between public private sectors, such as the Fraunhofer Society and Vocational Training System in Germany. In Finland research units in the universities of applied research, such as CENTRIA, could be in the key role as a linkage between the public and private sectors.

The World Economic Forum has published annual competitiveness reports for more than three decades. These reports have examined the various factors enabling national economies to achieve sustained economic growth and long-term prosperity. The latest report, The Global Competitiveness Report 2011-2012 (Schwab 2011) was published in September 2011. Since 2005, the report has based its competitiveness analysis on the Global Competitiveness Index (GCI). In the report, the GCI is defined as a highly comprehensive index for measuring national competitiveness, which captures the microeconomic and macroeconomic foundations of national competitiveness. In the report, competitiveness is defined as the set of institutions, policies, and factors that determine the level of productivity of a country. (Sala-i-Martin et al. 2011, 3-4)

The many determinants driving productivity and competitiveness are captured within the GCI by including a weighted average of several different components, each measuring a different aspect of competitiveness. These components are grouped into 12 pillars of economic competitiveness (FIGURE 7). The first four of them are ***Basic requirements***, which are the key for factor-driven economics. Pillars 5 to 10 belong to ***Efficiency enhancers*****,** which play a key role for factor-driven economics. Business sophistication and Innovation pillars (11 and 12) belong *to* ***Innovation and sophistication factors***, which are the key for innovation-driven economics. Finland belongs to the group of innovation-driven countries with 34 other advanced counties. The most interesting pillars for this study are the two last ones**,** ***Innovation*** and ***Business sophistication*** together with the ninth pillar ***Technological readiness*** from the Efficiency enhancers group.

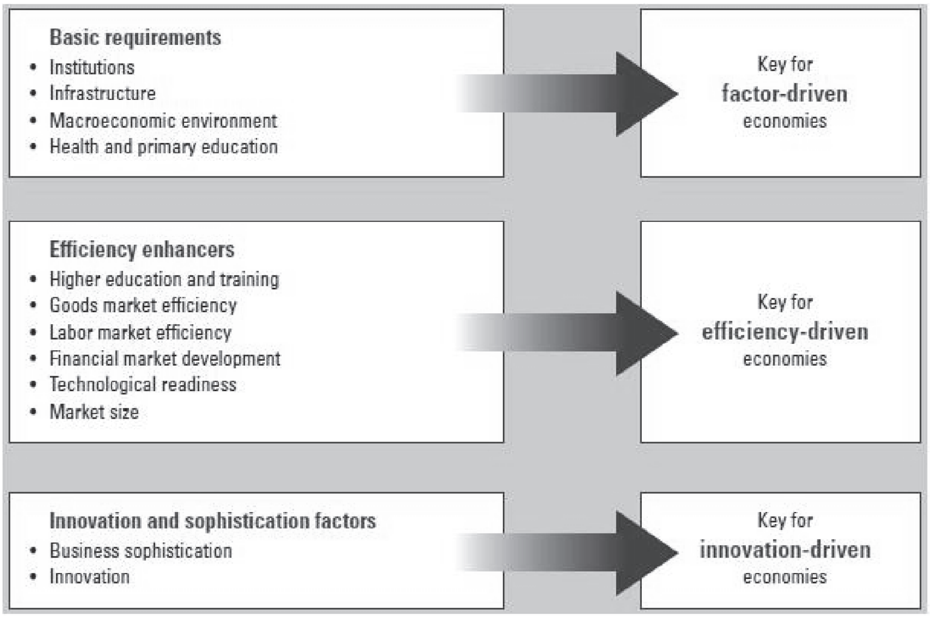

FIGURE 7 The twelve pillars of competitiveness in the GCI (adapted from Sala-i-Martin et al. 2010, 9)

Finland has succeeded well in the Global Competitiveness Index, which can be seen in TABLES 4 and 5 and in FIGURE 8. TABLE 4 shows the top ten countries in the GCI of the latest report. In the *Overall index*, Finland moved up three positions passing the United States, Germany and Japan, and reached the fourth position in 2011. Finland has been assessed to have well-functioning and highly transparent public institutions. Finland has reached the top positions in the *Health and primary education* and in the *Higher education and training* pillars, which the report argues to be the result of a strong focus on education over recent decades. According to the report, this has provided the workforce with the skills needed to adapt rapidly to a changing environment and has laid the ground for their high levels of technological adoption and innovation. Finland is also categorized as one of the innovation powerhouses in Europe, ranking third on the related pillar; Finland is behind only Switzerland and Singapore. Finland's success supports Porter's statement that a nation's competitiveness depends on the capacity of its industry to innovate and upgrade (Porter 1990/2008, 171).

TABLE 4 The top ten countries and their ranks in the Global Competitiveness Index 2011-2012 and 2010-2011 (adapted from Sala-i-Martin et al. 2011, 16 and Sala-i-Martin et al. 2010, 16)

2011-2012	Overall index		Basic requirements		Efficiency enhancers		Innovation and Sophistication Factors	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score
Switzerland	1	5.74	3	6.18	2	5.53	1	5.79
Singapore	2	5.63	1	6.33	1	5.58	11	5.23
Sweden	3	5.61	4	6.06	7	5.33	2	5.79
Finland	4	5.47	5	6.02	10	5.19	4	5.56
United States	5	5.43	36	5.21	3	5.49	6	5.46
Germany	6	5.41	11	5.83	13	5.18	5	5.53
Netherlands	7	5.41	7	5.88	8	5.29	9	5.30
Denmark	8	5.40	8	5.86	9	5.27	8	5.31
Japan	9	5.40	28	5.40	11	5.19	3	5.75
United Kingdom	10	5.39	21	5.60	5	5.43	12	5.17
2010-2011								
Switzerland	1	5.63	2	6.05	4	5.41	2	5.71
Sweden	2	5.56	4	5.98	5	5.32	3	5.67
Singapore	3	5.48	3	6.05	1	5.49	10	5.07
United States	4	5.43	32	5.21	3	5.46	4	5.53
Germany	5	5.39	6	5.89	13	5.11	5	5.51
Japan	6	5.37	26	5.35	11	5.17	1	5.72
Finland	7	5.37	5	5.97	14	5.09	6	5.43
Netherlands	8	5.33	9	5.82	8	5.24	8	5.16
Denmark	9	5.32	7	5.86	9	5.20	9	5.15
Canada	10	5.30	11	5.77	6	5.32	14	4.95

Finland has remained its position in the *Basic requirements* (5th) and in the *Innovation and sophistication factors* (4th) and moved up four positions in the *Efficiency enhancers*. Inside these three main components, Finland has been evaluated as a top country in the *Health and primary education* (pillar 4) and in the *Higher education and training* (pillar 5) while Finland gets the lowest positions in the *Market size* (54th), the *Goods market efficiency* (21th) and the *Macroeconomic environment* (20th). The report has found that the most problematic factors for doing business in Finland are tax rate and regulations, access to financing, and inefficient government bureaucracy. (Sala-i-Martin et al. 2011)

As shown in FIGURE 8, Finland is almost in every part of the GCI on the same level or above the average of the innovation driven countries. The only exception is the market size, where Finland is somewhat below the average.

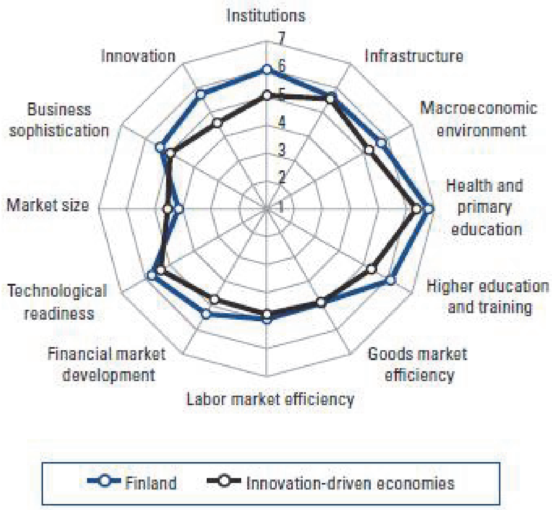

FIGURE 8 Finland's position in the Global Competitiveness Report 2011-2012 (Schwab 2011, 176)

Even if Finland has succeeded well in the GCI evaluation of competitiveness and innovativeness, there are certain areas which could be better in Finland to have a higher ranking. When considering the recent GCI (Sala-i-Martin et al. 2011) with this study and SME-oriented applied research, the most interesting pillars are *Innovation* (12), *Business sophistication* (11) and *Technological readiness* (9). In the most recent report, Finland was in the top ten for both *Innovation* (3rd) and *Business sophistication* (9th), but was in the 12th place in *Technological readiness*. The *Innovation* top ten countries from the 142 economies analyzed were Switzerland, Sweden, Finland, Japan, United States, Israel, Germany, Singapore, Taiwan and Denmark. In *Business sophistication* the order was Japan, Sweden, Switzerland, Germany, Netherlands, Denmark, Austria, United Kingdom, Finland, and United States. In the *Technological readiness* pillar Finland is out of the top ten having position 12. Switzerland was on the top followed by Sweden, Iceland, Denmark, Netherlands, Hong Kong, Norway, United Kingdom, Luxembourg, and Singapore. When considering the reasons why Finland is on 3rd place on *Innovation*, but only 12th in *Technological readiness*, the subgroups of the pillars have to be analyzed. This is presented in TABLE 5 where Finland's positions in the last two reports is compared including the subgroups of the pillars. From TABLE 5 it can be seen that the most problematic areas in Finland are foreign direct investments (FDI) and technology transfer, and local support quantity. SME-oriented applied research similar to this study has no tools to increase foreign direct investments, but it can help SMEs in technology transfer. Local R&D units such as CENTRIA can sometimes work as a high quality local supplier and developer for example in production related software.

TABLE 5 Finland's ranks in the Global Competitiveness Index pillars 9, 11 and 12 in two latest reports (adapted from Sala-i-Martin et al. 2010, 157 and Sala-i-Martin et al. 2011, 177)

	Rank 2010-2011	Rank 2011-2012
9th pillar: Technological readiness		
9.01 Availability of latest technologies	4	5
9.02 Firm-level technology absorption	12	11
9.03 FDI and technology transfer	93	97
9.04 Internet users	8	7
9.05 Broadband Internet subscriptions	14	15
9.06 Internet bandwidth	17	10
11th pillar: Business sophistication		
11.01 Local supplier quantity	80	88
11.02 Local supplier quality	19	14
11.03 State of cluster development	9	4
11.04 Nature of competitive advantage	4	6
11.05 Value chain breadth	9	7
11.06 Control of international distribution	25	16
11.07 Production process sophistication.	5	5
11.08 Extent of marketing	29	16
11.09 Willingness to delegate authority	6	7
12th pillar: Innovation		
12.01 Capacity for innovation	5	5
12.02 Quality of scientific research institutions	13	18
12.03 Company spending on R&D	5	4
12.04 University-industry collaboration in R&D	3	4
12.05 Gov't procurement of advanced tech products	6	8
12.06 Availability of scientists and engineers	1	1
12.07 Utility patents per million population	6	6

FDI = Foreign Direct Investment

One interesting aspect of competitiveness is *digital competitiveness* which has also an effect to SMEs. European Commission Information Society has annually published *Digital Competitiveness* reports which analyze recent developments in this important policy area of the European information society; the latest report was published in May 2010 (Europe's Digital Competitiveness Report 2010). This report has also an extension part for ICT country profiles, where Finland has succeeded quite well; the same situation was also in 2010 (Europe's Digital Competitiveness Report 2010 - ICT Country Profiles). Digital competitiveness has a crucial role in the Europe 2020 Strategy, which the European Commission launched in March 2010 (Europe 2020). Digital Society is one of the seven flagship initiatives of the Europe 2020 Strategy, set out to define the key enabling role that the use of Information and Communication Technologies (ICT) will have to play if Europe wants to succeed in its ambitions for 2020.

2.3 Innovativeness and innovation capabilities of SMEs

Innovation capability and innovativeness are important for SMEs to survive and create competitive advantages. Measuring, evaluating and enhancing innovation capabilities or innovativeness of SMEs has been found a hard task. The central problem in measuring innovativeness or innovative capability is that these are not directly observable or identifiable. Therefore, indirect measures have to be developed for innovative capability evaluation (Bullinger et al. 2007; Romijn & Albaladejo 1999; Tura, Harmaakorpi & Pekkola 2008).

Furman, Porter and Stern developed the term *national innovative capacity*, which is the ability of a country to produce and commercialize a flow of innovative technology over the long term (Furman et al. 2002; Porter & Stern 2001). Porter and Stern also concluded that innovation has become perhaps the most important source of competitive advantage in advanced economies, and building innovative capacity has a strong relationship to a country's overall competitiveness and level of prosperity (Porter & Stern 2001, 15).

Various kinds of innovation capability assessments have been used by consultants (Bullinger et al. 2007; Kobe et al. 2004), and there exist companies which offer help in innovation and innovation capability assessments, such as Ideo and Strategyn (Kelley & Littman 2004; Ulwick & Bettencourt 2008). Innovation literature also mentions several examples about different evaluations of innovation capability (Bao 2010; Branzei & Verinsky 2006; Bullinger et al. 2007; Hadjimanolis 1999; Keskin 2006; Kobe et al. 2004; Lin 2007; Romijn & Albaladejo 2002; Tura et al. 2008). Innovation capability evaluation tools are often quite specific in nature, and they are mainly based on quite straightforward statistical analyses of questionnaires or surveys. Some of these innovation capability evaluation tools use the number of patents as one indicator for the innovativeness of the firm. However, the expense and effort needed in the patent pending process is often beyond the SMEs capability, which is also the situation in most of the production-oriented SMEs in this study. This lack of activity does not mean that these SMEs are not innovative; they may have a lot of innovative solutions in their development projects. There are also strong views that innovativeness and innovation capability are matters which cannot be examined in any reliable way with quantitative measurements, especially when considering SMEs and taking into account the regional aspects (Bullinger et al. 2007; Tura et al. 2008). The proposed innovativeness or innovation capability measurements often also lack analysis of tools how to enhance SMEs' innovation capabilities.

In this chapter, three different reports of innovation capability evaluation tools are briefly examined. The first one deals with the innovation capability of small UK electronics and software firms (Romijn & Albaladejo 2002). The second concept is the Fraunhofer three-stage approach to evaluate and improve the innovation capability and innovation management of SMEs, which in their study originated mainly from the mechanical and electrical engineering sectors

(Bullinger et al. 2007). The third innovation evaluation tool that will be discussed is the Innovation Union Scoreboard 2010, which was prepared for the European Commission innovativeness evaluation tool. It provides a comparative assessment of the innovation performance of the EU27 Member States and the relative strengths and weaknesses of their research and innovation systems (Innovation Union Scoreboard 2010).

Romijn and Albaladejo examined the determinants of innovation capability in small UK electronics and software firms, which can be considered as high-tech small firms. Their conceptual framework is presented in FIGURE 9. The innovation capability is a result of the various internal and external inputs. Some of these are presented in FIGURE 9.

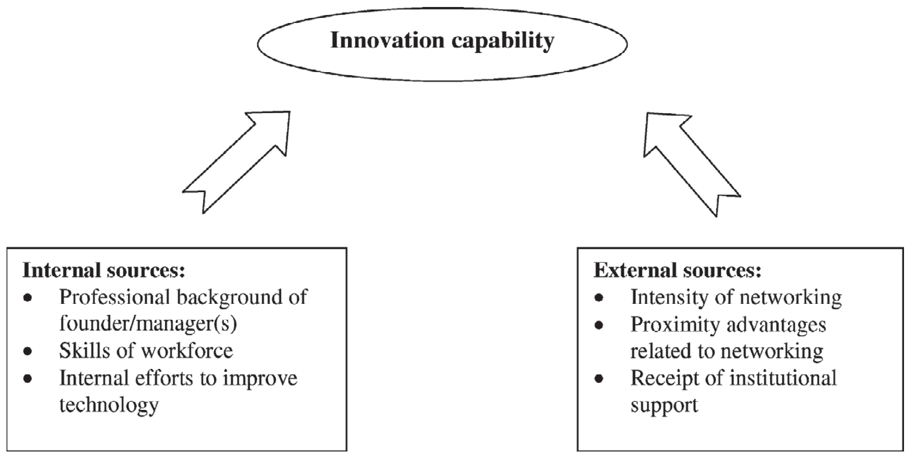

FIGURE 9 Conceptual Framework for Innovation Capability Evaluation (Romijn & Albaladejo 2002, 1056)

The Romijn and Albaladejo model emphasizes the interaction with the development network, where the interaction includes suppliers, customers, public assistance, agencies, industry associations, and foundations. One advantage of the network is that it can provide missing external inputs into the learning process which the firm itself cannot easily provide. The network can also increase the effectiveness of such 'learning-by-interacting' by regional clustering between the network actors. The advantages of the development network by Romijn and Albaladejo are similar to what the author has found in this study, where the main partners in the development networks are SMEs, suppliers, customers, research units and educational institutes. These two last ones belong to public assistance in the list presented by Romijn and Albaladejo.

In their measurement of innovation capability, Romijn and Albaladejo (2002) focused on product innovation because they found it to be a dominant form of innovation in the 33 small high-tech firms of southeast England in their study. They used three measures of product innovation. The first one was a simple binary variable that indicated whether or not a firm had accomplished at least one major product innovation in last three years. The second variable was the number of patents held. The third measure of innovation capability was the product innovation index, which is based on extensive qualitative information about the extent and significance of each firm's innovative outputs generated during the last three years. Romijn and Albaladejo admitted that the two first indices were quite crude for SMEs because the first variable did not include information about the degree of newness of the innovations and the second one was troublesome because many innovations of small firms were never patented due to the expenses and the firm's limited resources needed to patent protection. The third variable, the product innovation index, was meant to get around the drawbacks of the first two variables. The classification in the product innovation index had two dimensions, namely the degree of novelty embodied in the innovations and the extent to which the development of these innovations required specialized scientific or advanced technological expertise. As both of these dimensions used a scale from 5 (most innovative) to 1 (least innovative), Romijn and Albaladejo made a correlation analysis between the three variables in the evaluation of innovation capability.

The main research findings of the Romijn and Albaladejo study showed the importance of R&D investments and prior experience in a scientific environment for boosting innovativeness. The results pointed to the importance of specialized knowledge and experience in science more than practical technical skills or general managerial capabilities. This was probably caused by the type of the firms - high-tech SMEs - in the study and it differed from the production-oriented SMEs of this study. The Romijn and Albaladejo analysis did not provide much support for the importance of the overall intensity of external networking to innovativeness. However, the local interactions clearly did appear to matter, and notably those with R&D institutions and suppliers. The closeness of R&D interaction has been found even more important for Finnish SMEs (Aradóttir 2005; Lester & Sotarauta 2007; Tura et al. 2008; Virkkala & Niemi 2006) and it is emphasized in the production-oriented SMEs of this study.

The Fraunhofer researchers (Bullinger et al. 2007) created a three-stage approach to evaluate and improve the innovation capability and innovation management of SMEs. The background for their development endeavor is the observation that innovation processes in SMEs are often neither efficient nor systematic, which makes the innovation cycle from ideas to market slow. In the Fraunhofer approach, innovation capability is defined as the holistic, corporate-wide potential of a company to generate new and unique values. The three phases are the following: *Innovation audit*, *Design phase* and *Innovation card and implementation*. In the first phase, the *Innovation audit* is conducted by external experts, and it includes both process and performance audits. The process audit investigates the enablers of the innovation system while the performance audit focuses on results and outputs of individual innovation processes and the innovations system. The result of the Innovation audit phase is a detailed analysis of all levels of innovation management. This first phase also produces the identification of focus areas as one result. In the second phase, the *Design* *phase*, customized concepts to design measures for selected modules or focus areas are developed. This leads to detailed measures, action plans and roadmaps in a form of a customized innovation scorecard. In the third phase, the *Fraunhofer Innovation card* is implemented for enabling companies to continuously monitor their innovation system. The purpose in the implementation of the designed modules and the innovation card is to monitor the continuous improvement, which makes their approach positively different from many other concepts presented in innovation capability literature. (Bullinger et al. 2007)

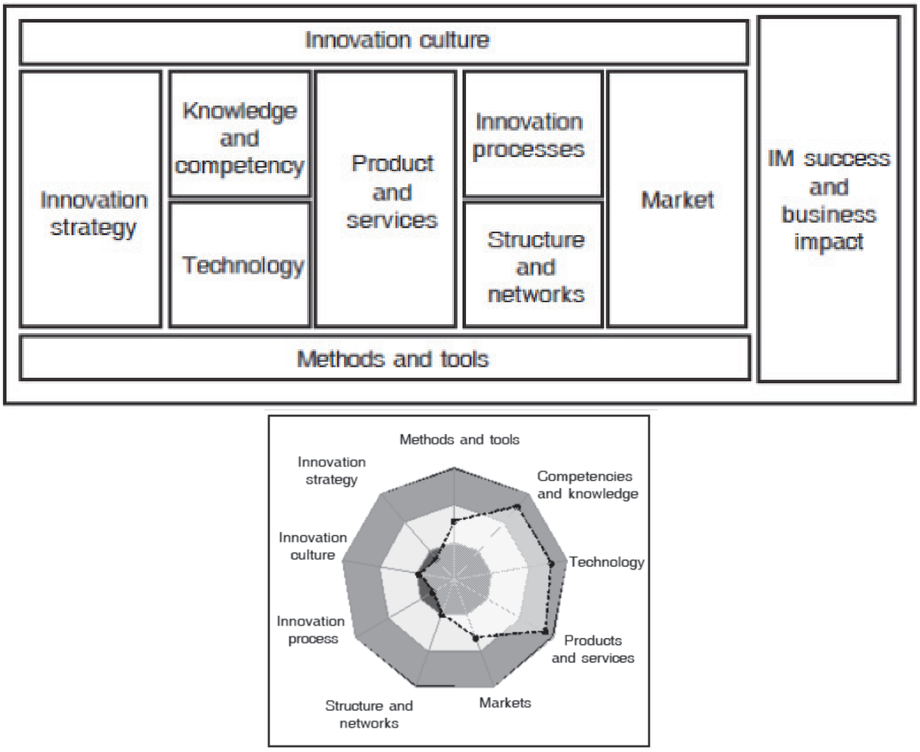

FIGURE 10 Fraunhofer innovation management model and an example of result presentations (Bullinger et al. 2007, 20, 27)

The conceptual framework behind the proposed three-stage approach is the Fraunhofer innovation management model (presented in FIGURE 10). The model is divided into ten key areas, which were identified during their development project, and they form the base of for evaluation and control of innovation management activities of SMEs. TABLE 6 presents the typical innovation management areas and the key success factors to assess innovation capability in the Fraunhofer model.

TABLE 6 Areas and key success factors to assess innovation capability in the Fraunhofer model (adapted from Bullinger et al. 2007, 21)

INNOVATION MANAGEMENT AREA	KEY FACTORS
1. Innovation strategy	Vision for innovation, Roadmap in place, Innovation goals clearly defined and communicated
2. Technology	Definition of technology strategy, Continuous technology forecasting, Evaluation and sourcing of technology
3. Competence and knowledge	Understanding own strengths and weaknesses, Capability to enhance the knowledge base, Systematic knowledge management
4. Products and services	Superiority of products/services, Continuous improvement of existing products/services, Strong customer-orientation
5. Structure and networks	Successful external cooperation, Budget flexibility, Internally networked organization
6. Processes	Systematic idea management, Successful product/process and service development, Integrated life-cycle management
7. Market	Market intelligence and industry trends, Strong cooperation with suppliers and customers
8. Methods and tools	Project management, Performance measurement, Benchmarking
9. Innovation culture	Climate for innovation, Commitment of senior management, Efficient communication
10. Innovation management success and business impact	High profit from new products/services, Cost reduction through process innovation, Strong value growth

The Fraunhofer innovation management model is a comprehensive concept to evaluate innovation capability and innovation management of SMEs. It also provides tools for enhancing innovation capability and continuous innovation management, which are lacking from many other concepts. It is also developed to assess different kinds of innovation capability in various areas, which is the same goal that Kobe et al. (2004) stated for their tool. However, the Fraunhofer concept looks quite a complex and time-consuming method and it may be hard to find production-oriented SMEs which are eager to commit themselves to develop their innovation management based on this model.

The Maastricht Economic and social Research and training centre on Innovation and Technology (UNU-MERIT) prepared an innovativeness evaluation tool and a report (Innovation Union Scoreboard 2010) for the European Commission. The methodology behind the scoreboard tool is presented in a separate IUS 2010 Methodology report (Hollanders & Tarantola 2011). The *Innovation Union Scoreboard 2010* is the first edition of the new tool, which is, however, based on the previous European Innovation Scoreboard. The new tool is meant to help monitor the implementation of the Europe 2020 Innovation Union flagship (Innovation Union 2010) by providing a comparative assessment of the innovation performance of the EU27 Member States and the relative strengths and weaknesses of their research and innovation systems. The IUS 2010 largely follows the methodology of previous editions of European Innovation Scoreboards in distinguishing between three main types of indicators (Enablers, Firm activities and Outputs) and eight innovation dimensions (Human resources, Open, excellent and attractive research systems, Finance and support, Firm investments, Linkages & entrepreneurship, Intellectual assets, Innovators, and Economic effects). Each innovation dimension includes 2-5 indicators, capturing in total 25 different indicators. IUS uses the most recent statistics from Eurostat and other internationally recognized sources as available at the time of analysis. The methodology behind the scoreboard tool is presented in a separate IUS 2010 Methodology report (Hollanders & Tarantola 2011), which provides more detailed discussions of each of the indicators.

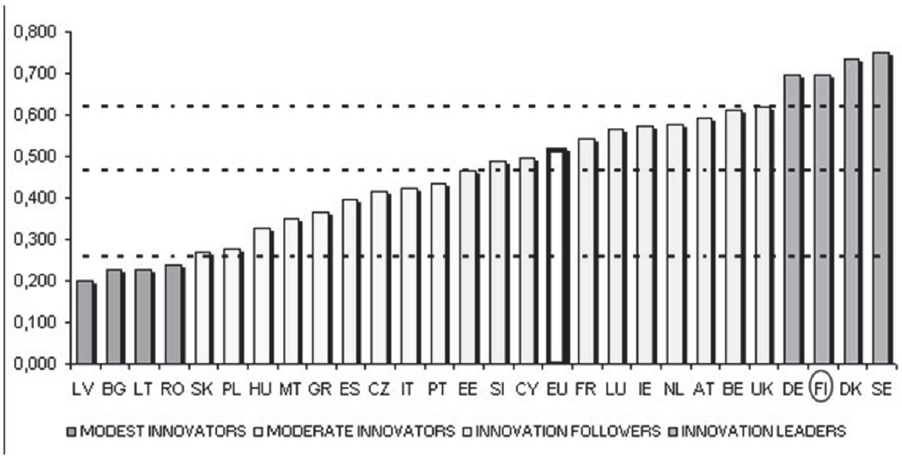

FIGURE 11 EU Member States' Innovation Performance (adapted from Innovation Union Scoreboard 2010, 9)

Based on the IUS 2010 report, Finland is one of the innovation leaders in Europe. According to the Summary Innovation Index, the member states fall into the following four country groups: Modest innovators, Moderate innovators, Innovation followers and Innovation leaders. Denmark, Finland, Germany and Sweden all show a performance well above that of the average of 27 EU countries (EU27). These countries form the group Innovation leaders (FIGURE 11).

The survey's eight main dimensions describing innovation performance are presented in FIGURE 12. When looking at details of FIGURE 12, it can be concluded that there is only one dimension in the innovation performance index (*Innovators*) where Finland does not belong to the top ten EU countries.

That *Innovators* dimension includes three indicators, which measure very important issues concerning the SME-oriented applied research of this study: SMEs introducing product or process innovations as percentage of SMEs, SMEs introducing marketing or organizational innovations as percentage of SMEs, and high-growth innovative firms. Based on the survey, it can be concluded that there is a real need for enhancing innovation capability of SMEs in Finland, especially for creating marketing and organizational innovations.

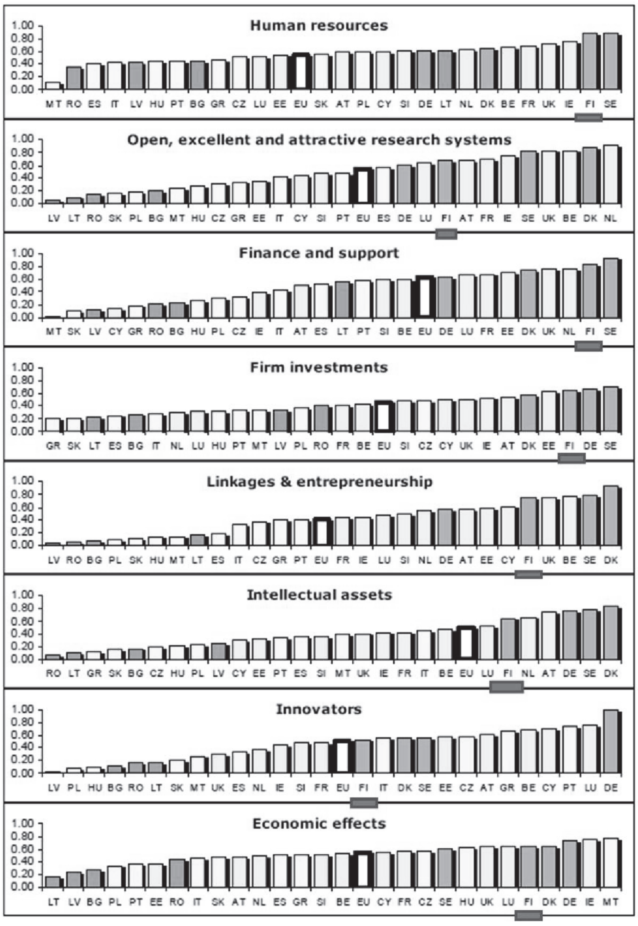

FIGURE 12 EU Member States' Innovation Performance per Dimension, Finland underlined (adapted from Innovation Union Scoreboard 2010, 14)

2.4 Regional aspects in enhancing the competitiveness of SMEs with applied research

The examination of competitiveness can be expanded from firm-level to regions, states or nations. Regional considerations often concentrate on successful innovation-led clusters, such as Silicon Valley in the USA, Cambridge in the UK, Emily-Romana Region in Italy or Baden-Württemberg in Germany (Down 2010, 153; Tidd & Bessant 2009, 62-63). These areas often have many highly innovative, growth-oriented SMEs which every region wants to be established in their area to form an efficient cluster. Down (2010, 154) remarks that the reality of the local economic context is much more complex: small entrepreneurial firms do not have inherent propensities or resources to operate in local networks. Therefore, many research projects and reports have examined regional aspects on competitiveness or innovativeness (Aradóttir 2005; Asheim & Coenen 2005; Asheim, Coenen & Svensson-Henning 2003; Asheim & Isaksen 2002; Davidsson 2006; Jones-Evans 1998; Lester& Sotarauta 2007, Teräs 2008; Tura et al. 2008; Virkkala & Niemi 2006). In this chapter, competitiveness and innovativeness are limited mainly to reports concerning regions in the EU, Nordic countries or Finland because they have many similarities when comparing the SMEs in the region of this study. For example American or Asian regions often have such a wide range of cultural or legislative differences so that studies concerning these areas are not wholly relevant for this study.

Jones-Evans (1998) coordinated an EU project *Universities, Technology Transfer And Spin-Off Activities – Academic Entrepreneurship In Different European Regions*, which examined the process of technology transfer from universities to industry and the development of academic entrepreneurship in seven small countries of the periphery regions of the EU, i.e. Ireland, Northern Ireland, Sweden, Finland, Wales, Spain and Portugal. The study involved 3-6 universities in each country including six universities in Finland: one from Oulu, two from Tampere and three from Turku. The final report presents the results of the examination of technology transfer process from universities to industry in these seven different countries of Europe. The main findings showed that there is a strong potential for developing increased university-industry collaboration in Europe if the right institutional policies can be put into place; the European Commission should be a facilitator for this. The study came to the conclusion that for any initiative to succeed, it must take into account the local circumstances - for both universities and firms. The study also showed that academic entrepreneurship exists in a range of different institutional and regional settings, and it often has to overcome the same barriers for success in all countries.

The regional aspects are even more essential in this study than in the regions of Turku, Tampere and Oulu, which were part of the focus in the study coordinated by Jones-Evans (1998). The firms which took part in university industry collaboration in the three regions were often high-tech oriented and their personnel had academic degrees and experience of collaboration with universities. Conversely, the production-oriented SMEs of this study usually have minor or no experience from R&D collaboration with universities or research institutes. However, the innovativeness of entrepreneurs brings a strong potential for developing increased R&D collaboration; the present study has the same conclusion as the EU project coordinated by Jones-Evans (1998).

The research group can help SMEs in technology transfer, and collaboration can also fill gaps of knowledge or skills. As Fontes (1997) noted, collaboration can create a bridge between two different environments enabling the development of common language, which facilitates further contacts.

Asheim et al. (2002, 2003, 2005) examined regional innovations systems of Nordic SMEs and the use of knowledge in these innovation processes. Asheim et al. (2005) used the terms of analytical and synthetic knowledge bases. In the ***analytical knowledge base***, innovations are based on the creation of new knowledge, which can lead to radical innovations. Knowledge is typically codified scientific knowledge often based on deductive processes and formal models. Knowledge processes are usually formally organized, for example in R&D departments. University-industry links and respective networks are important and more frequent with analytic knowledge than with synthetic knowledge. In the ***synthetic knowledge base***, innovation takes place by application or novel combination of existing knowledge, and it usually leads to incremental innovations. Synthetic knowledge is typically problem related engineering knowledge, which often also includes tacit knowledge of concrete know-how and practical skills. University-industry links are relevant, however, mainly in the field of applied research. Learning with synthetic knowledge is interactive and usually the learning-by-doing type. Asheim claims that it takes place mainly with clients and suppliers, sometimes with professional and polytechnic schools. Asheim has a traditional science-based university attitude, which sees that applied research is just a simple implementation of existing knowledge and training of people's skills to use it. However, many science-based universities carry out more and more applied research and have found the many aspects and challenges of applied research. As Govindarajan and Trimble have noted (see Chapter 1.1), the execution side of innovation is often much more difficult and much more important than the ideation part of innovation. In Finland, applied research involving enterprises is defined as one the key tasks for universities of applied sciences. Therefore, the synthetic knowledge base can be seen as a natural choice for regional collaboration with clients, suppliers, production-oriented SMEs and the research team of CENTRIA.

Asheim and Isaksen (2002) categorized three types of regional innovation systems (RIS) which are presented in TABLE 7. In the first type, the ***territorially embedded regional innovation network***, firms base their innovation activity mainly on localized learning processes, which are stimulated by geographical, social and cultural proximity. The innovation networks may be further developed into the ***regional networked innovation systems***, where the firms and R&D organizations are still embedded in a specific region and characterized by localized, interactive learning. However, the systems have a more planned character through the strengthening of the regional, institutional infrastructure. This means that R&D institutes, vocational training organizations and other local organizations are more involved in the innovation processes of enterprises. In course of time, this networking can develop to a regional cluster of firms surrounded by a local supporting institutional infrastructure. In the third type, the ***regionalized national innovation system***, parts of industry and the institutional infrastructure are more functionally integrated into national or international innovation systems. This means that innovation collaboration to a lager extent takes place with actors outside the region. This collaboration is based on a linear model as the cooperation mainly involves specific innovation projects to develop more radical innovations, mainly with the use of scientific, formal knowledge. Therefore, cooperation requires people with the same kind of education, sharing the same formal knowledge, rather than belonging to the same local community.

TABLE 7 Some characteristics of three main types of regional innovation systems (adapted from Asheim & Isaksen 2002)

Main type of RIS	The location of knowledge organisations	Knowledge flow	Important stimulus of cooperation
Territorially embedded regional innovation network	Locally, however, few relevant knowledge organisations	Interactive	Geographical, social and cultural proximity
Regional networked innovation systems	Locally, a strengthening of (the cooperation with) knowledge organisations	Interactive	Planned, systemic networking
Regionalised national innovation systems	Mainly outside the region	More linear	Individuals with the same education and common experiences

When comparing these RIS models and this study, it can be stated that the situation in 2002 was purely the first type, the *territorially embedded regional innovation network*. In the course of time, it moved to the *regional networked innovation system* with some features of the *regionalized national innovation systems*. However, because the research group has no permanent funding, and it has to work on uncertain project-based funding, the systemic networking typical to the *regional networking innovation systems* is difficult or even impossible.

Asheim et al. (2003) reported about the results of a Nordic Industrial Fund project where 13 cases from heterogeneous sectors (from low to high technology) in Finland, Sweden, Norway and Denmark were analyzed. The findings show that SMEs that innovate through science-driven R&D tend to collaborate with partners across the world in search for new and unique knowledge. SMEs that innovate through engineering based user-producer learning tend to collaborate with a nearby partner. In these cases, innovation often involves the application of existing knowledge or new combinations of knowledge. For this regional collaboration in innovation issues, social capital and trust are the cornerstones. One finding of the project is that formal collaborative research between regional R&D institutes and universities, on the one hand, and SMEs, on the other hand, is still a relatively new phenomenon.

According to Asheim et al., the barriers to a more efficient knowledge transfer are in many cases ascribed to cultural differences between organizations and people working in universities and SMEs. The same observation is emphasized in this study with production-oriented SMEs, where few people have academic degrees and people are not used to discussing by using scientific definitions or to working in abstract, conceptual, formal and theorizing manner. In the latest collaboration projects involving SMEs, CENTRIA and universities or VTT, CENTRIA's research team has also been an interpreter of cultural differences of the academic world and rushed everyday life of SMEs. During the projects, CENTRIA's research team has continuously learned how to actually cooperate with SMEs. To succeed, this learning process must be based on trust and social capital, which as Asheim et al. (2003, 8) state, is still quite poorly understood, and thus more research in this field is certainly needed. The successful cooperation with SMEs is often based on helping principles which the guru of corporate culture and organizational development Edgar H. Schein presented in his recent book (Schein 2009). These helping aspects of collaboration are discussed more in later chapters.

Virkkala and Niemi participated in and reported for the Finnish part in two Nordic region projects. ***Innovation Systems and the Periphery*** (ISP) was targeted to explore how innovation capabilities of firms, in selected industries in periphery regions, can be enhanced through the means of innovation and regional policy, and the strengthening of innovation systems (Aradóttir 2005). The ISP project used a case study approach with fourteen cases in Finland, Sweden, Norway, Denmark and Iceland. Each of these cases explored the contemporary phenomenon of innovation within a single industry sector in a single Nordic area. One of the cases concerned the production of electronics and wireless technology in the *Oulu South Region* (Northern Ostrobothnia) of Finland. The primary data was gathered by thirteen interviews, nine with representatives of SMEs and four with representatives of supporting agents. Virkkala and Niemi reported that the most important public sector partner of the firms interviewed was CENTRIA, with which each of the firms interviewed had some cooperation. The firms emphasized the positive attitude of the local authorities and other local actors, and considered them not only as the local and sector-specific pool of skilled workers but also as sources of encouragement. The firms saw collaborative development projects as important ways of upgrading their skills. These projects were mostly initiated by local developers, particularly CENTRIA. Virkkala and Niemi reported that according to one interviewee, CENTRIA is capable of combining the skills of different firms. In the most successful cases, the knowledge can be combined and sold to clients outside the region. (Aradóttir 2005)

The goal for the project ***Peripheral Localities and Innovation Policies*** (PLIP) was to learn from good practices between the Nordic Countries (Virkkala & Niemi 2006). The main findings were that in order to create functioning good practice networks, some kind of institutionalized facilitating mechanism is needed to provide the conditions for long term processes of learning within wide-ranging networks. The same thing was discussed earlier when considering the facilitation of systematic long-term development, which could transform regional systems into *regional networked innovation systems* of Asheim's RIS types (TABLE 7). Innovative cooperation involving CENTRIA Ylivieska and the SME's in the Oulu South area was chosen in the PLIP project as one of the good practices, which were looked for, analyzed, compared and finally transferred to other regions. The transferability analysis took place through workshops in the case study areas. CENTRIA's way of working with SMEs was benchmarked in the learning workshops held in Sweden and Denmark. According to the study, CENTRIA Ylivieska was a driving force in a favorable cycle of education, innovation projects and business development in the region. Virkkala and Niemi describe CENTRIA's role very positively in the report:

> *Centria Ylivieska plays a very essential role in regional development, especially concerning the industrial sectors corresponding to the fields of technology taught at the Ylivieska Unit of COU. There is no other actor of comparable size with regard to personnel or the versatility of the equipment available. The work done in Centria can in practice be seen in the activities of very many local firms, but it also has a central role in the innovation system of Oulu South as a whole… Centria Ylivieska has adopted a proactive way of acting. Centria and the Ylivieska Unit of COU develop technological knowledge and equipment for the needs of local enterprises, which is of benefit to the manufacturing sector in the region. Centria's research and development activities are also linked to the education unit, through the involvement of teachers and students in many projects.*
> (Virkkala & Niemi 2006, 39)

Lester and Sotarauta (2007) edited a report which summarizes the results of an international collaboration project *Local Innovation Systems*. This studied innovation-enabled industrial change and the competitiveness of regions in 23 locations in six countries (USA, Finland, UK, Taiwan, Japan and Norway). The main findings of the project show that universities can contribute to local innovation processes in a variety of ways and thus have a positive impact on the competitiveness of regions; universities can be and should be engines of innovation. This presupposes that universities understand what kind of industrial transformation is occurring in the local economy. The case study results show that universities can participate in local innovation processes typically via education and training, and by bringing new codified knowledge in the form of articles, technical reports, theses, patents, and hardware or software prototypes. In addition, universities should increase the local capacity for scientific and technological problem solving, and provide spaces for open-ended conversations about industry development pathways and new technological and market opportunities. The same tasks have been found to be important also in the collaboration of production-oriented SMEs and the research team of CENTRIA. Education and training are tasks which SMEs traditionally expect from universities (either scientific or applied sciences). Increasingly, they need open-ended conversations about rapid technological development and opportunities in global economy, and obviously collaboration in problem solving.

The *Local Innovation Systems* project also included case studies in economically less favored regions. Pori and Seinäjoki were chosen as examples for these case studies. Kosonen (2007, 141) reported that the less favored regions face four major challenges: a) how to link local actors to national and global knowledge networks, b) how to mobilize the scarce resources and competencies of the region to create a local innovation environment, c) how to compensate for a thin institutional environment by networks, and d) how to strengthen the local institutional base and knowledge structure by creating new organizational types to avoid lock-ins. These challenging tasks are also common in the Central and Northern Ostrobothnia regions. The answers found in the Pori and Seinäjoki areas are the creation of local consortia where universities, university filial centers and polytechnics (currently universities of applied sciences) work together to enhance the competitiveness of local companies. The same kind of solution was also developed during the time of this study in Ylivieska in the form of the RFM Laboratory, where Oulu Southern Institute (a filial of University of Oulu) and CENTRIA (R&D unit of Central Ostrobothnia University of Applied Sciences) work together in applied research projects with local companies, mainly SMEs.

Teräs (2008) carried out a comparison study of three non-metropolitan science-based clusters. The cases were focused on high technology industries: information and communication technology (ICT) in Oulu, Finland and in Luleå, Sweden, and ICT and pharmaceutical industries in Pisa, Italy. The results of the study show that regional science-based clusters are not isolated entities but are increasingly more connected to the external environments and global markets than before. However, the local cluster activities and the social connections between the local cluster actors continue to be relevant. According to Teräs, the data in the study indicate that the critical mass plays an important role especially in the development of regional science-based clusters in non-metropolitan regions. On the other hand, the optimal size for the non-metropolitan cluster should not be too large to have more alternatives and to allow more flexibility and to avoid the problems related to metropolitan clusters. The results of the study cannot be directly applicable for the production-oriented SMEs in Central Ostrobothnia and the southern part of Northern Ostrobothnia because most of the firms are other than high-technology companies and are situated far from science-based clusters.

However, the results about the significance of social connections and flexibility are important also in this study. The critical mass both of the company and the R&D side is needed. This requires more active collaboration with SMEs and research and developing organizations.

Tura, Harmaakorpi and Pekkola (2008) examined the measurement approaches of regional innovativeness and found that it is a particularly challenging task. They tried to overcome some problems with their network-based innovative evaluation matrix for evaluating and developing regional innovation policies.

The author participated during 2005-2007 in the Interreg IIIC project EKIE (Enhancing Knowledge Intensive Enterprises in Small Cities, Surrounded by Rural and Sparsely Populated Areas) where the regional competitiveness of SMEs was developed in six EU areas. The author and CENTRIA's research team provided their main contribution for regional development in projects mainly financed by the European Regional Development Fund. The ERDF tool has proven a valuable way for promoting regional innovation systems in two ways: enabling new technology investments and increasing the expertise and capability within the applied research team. The accumulated expertise and knowledge of the new technology was also transferred to SMEs in these collaborative applied research projects. The author's projects were introduced earlier in Chapter 1.6, and the results will be analyzed in following chapters.

2.5 Business opportunity views and their suitability for SME-oriented applied research

Opportunity views were considered earlier in this study in Chapter 1.4 and together with innovation-entrepreneurship relationships in Chapter 2.1. A brief overview of different perspectives on opportunities will be presented in this chapter, and their suitability for SME-oriented applied research will be examined. In the entrepreneurship literature, as discussed in Chapter 1.4, opportunity types are categorized into two or three groups. The traditional division is between the Schumpeterian and Kirznerian views on entrepreneurship and opportunities (Burns 2011, 71-74; Carree & Thurik 2003, 442-443; Chiles et al. 2007, 468-472; de Jong & Marsili 2010, 6-10; Down 2010, 43-46; Kirzner 1999; Landström 2005, 13-15; Schumpeter 1934).

In the *Schumpeterian view*, opportunities emerge out of the entrepreneur's internal disposition to initiate changes in the economy. The entrepreneur is considered to be an innovator who shocks and disturbs the economic equilibrium during times of uncertainty, change, and technological upheaval. The entrepreneur is an individual who creates a new combination and pursues it in the market

The *Kirznerian view* implies that individuals secure entrepreneurial profits on the basis of knowledge and information gaps that arise between people in the market. In this view, the entrepreneur is an alert person, discovering opportunities by acting as an arbitrageur or a price adjuster in the marketplace, capitalizing on knowledge or information asymmetries. In the Kirznerian view, innovation and new combinations are not necessary conditions.

Kirzner (1999, 2008) stated in his later writings that both the Schumpeterian view and his own view can be simultaneously accepted. The same point applies to SME-oriented applied research: SMEs should be alert to discover opportunities, but also create new combinations in collaboration with research groups and suppliers and take them into market or into use in their production. (Chiles et al. 2007; de Jong & Marsili 2010; Down 2010; Kirzner 1999, 2008; Langlois 2003; Schumpeter 1934)

In the recent literature, two perspectives on opportunities have begun to emerge (Berglund 2007, 243; Down 2010, 53): the existing opportunities are either discovered or created in social processes. The discovery view is often linked with the writings of Shane (2000, 2001, 2003) while the creation view with the articles by Sarasvathy (2001, 2003). Berglund (2007) has presented a comparison between discovery and creation perspective (TABLE 8).

In neoclassical and Austrian economics frameworks, true knowledge of the future is seen to exist, even if in dispersed, personal and tacit forms. To the radical subjectivists, such knowledge cannot exist because the future is yet to be created. Radical subjectivists extend the Austrian notion of subjectivism from alertness and personal values, to explicitly include imagination and creative expectations about the future. Entrepreneurial action is thus making history instead of merely responding to it. As shown in TABLE 8, the major difference between the two perspectives is that according to the discovery view, existing opportunities are discovered and exploited but in the creation view they are created in social processes. The creation view emphasizes cooperation in creative social processes while in the discovery view the individual has the key role.

As mentioned in TABLE 8, the discovery perspective can be traced to Austrian economic tradition; especially to Kirzner (1999, 2008), who in 1970's introduced the notion of the alert discovery of arbitrage opportunities. Drucker's (1985, 1998) seven sources for firms to systematically search for creative innovations are often referred to as a base for opportunity seeking (Burns 2011, 121-125; Tidd & Bessant 2009, 462-465). These seven sources include four opportunity sources from within the enterprise or industry: unexpected occurrences, incongruities, process needs, and industry or market changes. The last three come from outside the enterprise or industry: demographics changes, changes in perception, mood and meaning, and new knowledge, both scientific and nonscientific. The boundaries between these seven areas are often unclear and overlapping. Drucker's opportunity monitoring ideas belong mainly to the discovery view, but his concept of knowledge-based innovations in the new knowledge opportunity source has some common features with the creative view.

TABLE 8 Differences between the discovery and creation perspectives (Berglund 2007, 251)

	Discovery	Creation
Basis in economics	Neoclassical and Austrian economics	Radical subjectivism
Ontological status of opportunities	Have real existence before being discovered	Are the emerging result of a creative social process
View of uncertainty	Hides existing opportunities	Made irrelevant by 'effectual' action
Role of the individual	Discoverer and exploiter of opportunities	Facilitator of creative social processes
Practical implications	Individuals should pursue promising industries and ideas, staying focused on areas where they are most likely to succeed	Individuals should, together with others, nurture exciting ideas found in their immediate environment

As Burns (2011) and Tidd and Bessant (2009) stated, Drucker's opportunity scanning process is useful also for contemporary firms. Furthermore, Burns suggests the use of brainstorming and other creativity encouraging techniques in opportunity scanning. Drucker's opportunity scanning framework can also be useful for the production-oriented SMEs of this study. When scanning for the opportunity sources outside the enterprise, the collaboration with local research groups and suppliers is extremely important. For example, the big demographic change - the phenomenon of population aging – will offer many opportunities for SMEs and those should be examined together.

The work of Shane and Venkataraman (Shane & Venkataraman 2000; Shane 2001; Venkataraman 1997) which represents the ***discovery view***, is highly regarded in the literature (Berglund 2007; Cooper 2003, 24-25; Down 2010, 53-54; Eckhardt & Shane 2003; Kontinen 2011, 25-26; Landström 2005, 19-20). Shane and Venkataraman (2000) support the view of Kirzner and argue that opportunities are discovered by individuals. They state that discovery is, however, not sufficient for entrepreneurship which also requires exploitation of the opportunity. Inspired by Austrian economics, Venkataraman argued that entrepreneurship as a scholarly field seeks to understand how opportunities to bring into existence future goods and services are discovered, created, and exploited, and further, by whom, and with what consequences (Venkataraman 1997, 120; Landström 2005, 19). Shane and Venkataraman (2000) created a framework for entrepreneurial opportunity seeking based on the exploration and exploitation of profitable opportunities. Shane and Eckhardt (2003) extended and elaborated that individual-opportunity framework on entrepreneurship and updated earlier works with more recent contributions. Shane (2001) also carried out an interesting empirical analysis about what attributes of technological inventions are the most important to increase the opportunities for new firm creation. In his study, he proved that the importance, radicalness and patent scope of the invention are the most significant attributes for new firm creation. According to Shane (2001), the more important the invention, or the more radical the invention, or the broader the scope of the patent, the higher the probability that it will be commercialized through the establishment of a new firm.

Recently there has been more and more interest and discussions about the ***creative view*** of entrepreneurial opportunities (Berglund 2007; Down 2010; Paloniemi 2010). The creative view of opportunities suggests that opportunities should be thought of in the context of entrepreneurs seeking to create their ventures in a world which fundamentally depends on entrepreneurial imagination and action for its development (Berglund 2007). In this view, opportunities are not discovered before exploitation but rather enacted in creative and social processes. The creative view can be traced to authors in the radical subjectivist tradition such as Lachmann (Berglund 2007; Chiles et al. 2007). Ardichvili, Cardozo and Ray (2003) argue that opportunity development also involves entrepreneurs' creative work. In their theory, entrepreneurs play proactive roles in opportunity identification, recognition and development as a multistage process. They propose that opportunity development should be in the focus rather than opportunity recognition. The development process is cyclical and iterative: an entrepreneur is likely to conduct evaluations several times at different stages of development. Therefore, evaluation could also lead to recognition of additional opportunities or adjustments to the initial vision.

The creation perspective is most clearly promoted by Sarasvathy (2000, 2001, 2003) who views entrepreneurial opportunities as creatively developed in the everyday activities of individuals and groups. As discussed in Chapter 1.4, Sarasvathy et al. (2003) categorized entrepreneurial opportunities into three views: opportunity recognition, opportunity discovery, and opportunity creation. ***Opportunity recognition*** is based on existing markets: if both sources of supply and demand exist, the opportunity for matching them together has to be recognized. After recognition, the supply and demand has to be matched either through an existing firm or a new firm. In ***opportunity discovery*** either demand exists, but supply does not, or vice versa. Then the nonexistent side has to be discovered before the matching can be implemented. If neither supply nor demand exists, one or both have to be created through the ***opportunity creation*** process. Sarasvathy et al. (2003, 157) argue that the creative view might be more general than the recognition and discover views because creative processes contain recognition and discovery as necessary inputs. Before someone can recognize or discover entrepreneurial opportunities, they must have been created. However, Sarasvathy et al. (2003) argue that to deepen the understanding of entrepreneurial opportunity, these three approaches have to be integrated.

Sarasvathy (2001) introduced the term ***effectuation*** into business opportunity seeking and combined it to causation logic. The logic of effectuation is based on the role of imagination instead of prediction, and it relies on controllable aspects of an unpredictable future. The creative view is based on this effectuation principle which inverts the key principles of predictive rationality (causation). The logic for using causation processes is: *To the extent we can predict the future, we can control it* (Sarasvathy 2001, 251). Causal rationality begins with a pre-determined goal and a given set of means, and seeks to identify the optimal – for instance the fastest, cheapest, most efficient – alternative to achieve the given goal. A variation of causal reasoning involves the creation of additional alternatives to achieve the given goal. This form of creative causal reasoning is often used in strategic thinking. Effectual reasoning, however, does not begin with a specific goal. Instead, it begins with a given set of means and allows goals to emerge contingently over time from the varied imagination and diverse aspirations of the founders and the people they interact with. While causal reasoning may or may not involve creative thinking, effectual reasoning is inherently creative. The logic for using effectuation processes inverts the logic of causation processes: *To the extent we can control the future, we do not need to predict it* (Sarasvathy 2001, 251). Sarasvathy (2000, 2) described causal thinkers to be like great generals, such as Genghis Khan, seeking to conquer fertile lands while effectual thinkers are like explorers, such as Columbus, setting out on voyages into uncharted waters.

A recent study also showed that entrepreneurial experts frame their decisions using an effectual logic while novices tend to use a predictive logic (Dew, Read, Sarasvathy & Wiltbank 2009). Experiences of this thesis study reinforce the belief that experienced entrepreneurs tend to use effectual logic in their decisions. This study is strongly relying on the creative view of business opportunity seeking: SMEs, research units and suppliers should create opportunities together using the chances that applied research projects provide. The recognition or discovery views are still not ignored but rather integrated to the creative view. The experiences of this study agree with Sarasvathy's view that creative processes involve recognition and discovery as necessary inputs.

2.6 Innovation challenges for production-oriented SMEs

Production-oriented SMEs will be facing many challenges in the next few years. Some of the most remarkable challenges are presented in FIGURE 13 and will be further examined in this chapter. As discussed in Chapter 1.1, Prahalad and Krishnan stated that the undergoing fundamental transformation of business is forged by digitization, ubiquitous connectivity, convergence of technologies and industries, and globalization. They also emphasized personalized, co-created experiences, which have close relations to user-driven innovations. Consideration of the importance of the user in the innovation process is not a new aspect; for example von Hippel (1988, 2005) examined it widely already in the late 1980s. User-driven innovations will continue to have more and more significance in the future. Kaplan and Palmer (2010) discuss the *servicizing world* when they are describing the future society where everything is considered as a service. Even if their argument is to some extent overrated, the servicizing world requires new thinking for production-oriented SMEs. Drucker (1985) argued already decades ago how demographic changes will provide possibilities for innovations in many areas of life. In the next few decades the radical changes in age pyramids and demographic dependency will also affect production-oriented SMEs in many ways. This progress will make it harder for these companies to get skilled staff but it will also bring new possibilities to develop new products, for example to assist elderly people.

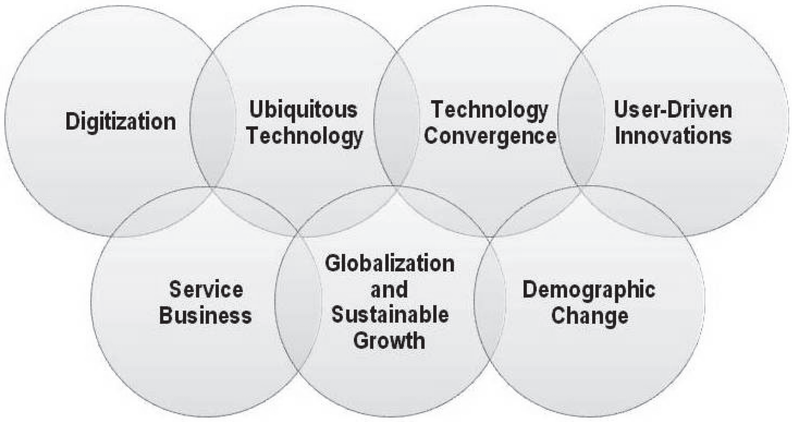

FIGURE 13 Some innovation challenges for production-oriented SMEs

Digitization or *digital technology* is transforming business in many sectors, including production-oriented SMEs and the service sector. There is a wide consensus that applying ICT and integrating it into products and services will be reflected in many sectors via improvements in productivity, products and services (Govindarajan & Trimble 2005, 2010; Hernesniemi 2010; Kaplan & Palmer 2010; Prahalad & Krishnan 2008; Rafinejad 2007). ICT has had a 40% impact on the productivity increase in Europe in the last ten years, and even higher in USA (Hernesniemi 2010, 39-40). Prahalad and Krihsnan claimed (2008, 240) that digitization is permeating every aspect of business, and every business is becoming e-business where the capability and quality of ICT architecture will play key role. They also remarked that the undergoing change, forged by digitization, ubiquitous connectivity and globalization, is critical for survival and growth (Prahalad & Krishnan 2008, 11). The development is particularly noticed also in recent reports which forecast the digital economy situation in 2020 in Europe and in Finland. *A Digital Agenda for Europe* (2010) presents a strategy for a digital economy in Europe, while the report *Europe 2020* (2010) presents a strategy for smart, sustainable and inclusive growth. The report called *Innovation Union* (2010) presents the strategy for the Europe 2020 Flagship Initiative Innovation Union. The European Commission Information Society publishes the annual the *Digital Competitiveness* report which analyze recent developments in this important policy area of the European information society. The latest issue was published in May 2010 (Europe's Digital Competitiveness Report 2010). The report called Digitaalinen Suomi 2020 (Hernesniemi 2010) presents a vision and scenarios for Finland to become a model ICT country by 2020. All these reports of the national and European level emphasize the importance of digitalization and ICT in every level of society but especially for the survival and growth in industry where SMEs are playing a more and more important role.

In the report *A Digital Agenda for Europe* this great potential of ICT can be mobilized through a well-functioning virtuous cycle of activity (see FIGURE 14).

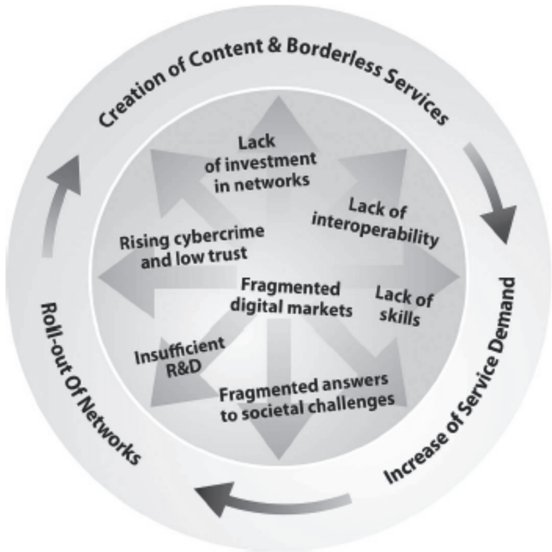

FIGURE 14 Virtuous cycle of the digital economy with the seven most significant obstacles (A Digital Agenda for Europe 2010, 4)

In the cycle, attractive content and services need to be made available in an interoperable and borderless internet environment. This stimulates more demand for higher speeds and capacity, which in turn will create business cases for investments in faster networks. The process can facilitate new innovative services exploiting higher speeds. This flow of activity can be largely self-reinforcing. It requires a business environment that fosters investments and entrepreneurship. However, although a digital way of life is emerging for many European citizens, many parts of technology utilization continue to be seriously incomplete. The statistics show that currently Europe is lagging behind its industrial partners mainly due to the obstacles presented in the inner ring of FIGURE 14. For example 30% of Europeans have not yet used the internet; Europe has only 1% penetration of fibre-based high-speed networks whereas Japan is at 12% and South Korea is at 15%; and EU spending on ICT research and development stands at only 40% of US levels (*A Digital Agenda for Europe* 2010, 5). The seven most significant obstacles for the progress are presented in the inner ring. On their own or in combination, these obstacles seriously undermine efforts to exploit ICT. The situation stresses the need for a comprehensive and united policy response at the European level. This policy will in turn affect the future of all SMEs and research groups in the EU area. (*A Digital Agenda for Europe* 2010)

The report *Digitaalinen Suomi 2020* (Hernesniemi 2010) introduces a vision and scenarios for Finland how it will become a model ICT country in 2020. In this vision, Finland will be a leading country in mobile integrated information and communications technology and the development of related products, systems and services. The e-services of the digital economy have evolved into a significant world-wide business sector also involving a great number of fast-growing SMEs. The report predicts that in 2020 ICT will be our most critical competitive advantage in Finnish strongholds which include industrial automation and systems, intelligent machines and systems and lifespan information systems (Hernesniemi 2010, 20).

The author sketched in CENTRIA's projects (ERDF project DIGIMANUQ and Interreg project DIM) a figure called the DIM wheel (see FIGURE 15) to describe the many dimensions which digitization can bring to product processes of production-oriented SMEs. The figure includes examples of technology used in applied research cases in CENTRIA's projects. Typically, SMEs involved in applied research projects started this DIM wheel step-by-step manner and often they will not need to cover all the aspects of the DIM wheel for a long time.

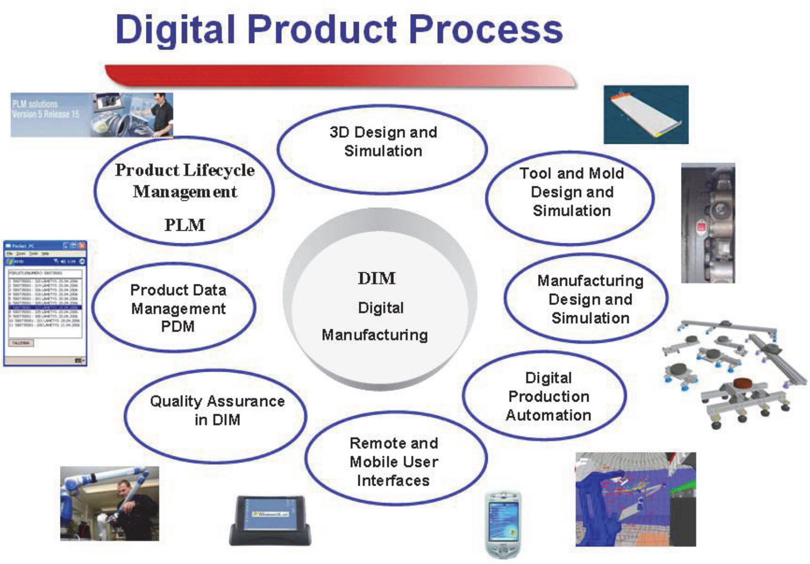

FIGURE 15 The DIM wheel

Ubiquitous technology is based on the radical improvements in microprocessor cost-performance and software. This progress has transformed the early large computing machines into compact devices that enable, mediate, support, and organize our daily activities (Lyytinen & Yoo 2002). This technology is also called many other names, including pervasive computing, ambient intelligence and ubicomp (ubiquitous computing). Ubiquitous technology may be the next step from distributed systems and mobile computing (Satyanarayanan 2001). The main idea behind pervasive or ubiquitous systems is to integrate the technological solutions so well that the user does not notice them; it is a technology which disappears. In his seminal article *The Computer for the 21st Century,* Mark Weiser (1991), often referred to as the father of ubiquitous computing, described ubiquitous technology as follows: "Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence." He clearly saw the advantages of ubiquitous technology: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser 1991, 19). It is one of the paradoxes of life that he did not have a chance to see the computer of the 21st century because he died in 1999 at early age of 47 years.

Ubiquitous technology includes the use of RFID and WSN technologies used in case projects and is considered more in Chapter 4. Ubiquitous solutions now cover many areas, including ubiquitous robotics, context aware systems for health care, fire and rescue services, tourism, traffic, and shopping (Abowd & Mynatt 2000; Aziz, Lo, Pansiot, Atallah, Yang & Darzi 2008; Bruns 2004; Kim, Kim & Lee 2004; Luimula, Pieskä, Sallinen, Alaspää & Saukko 2007). During the last decade, many new conference journals concerning ubiquitous technology have started with the aim to release the research results of both theory and practice. Applying location-awareness and ubiquitous computing in the industry is currently under intensive research and development activities especially because of signs of promising new business opportunities (Luimula 2010). Ubiquitous technology has an important role in the user interaction of future wireless solutions because ubiquitous technology can provide a natural interaction between the user and functions and services embedded in the environment or available through mobile devices (Ailisto, Pohjanheimo, Välkkynen, Strömmer, Tuomisto & Korhonen 2006).

Technology convergence is a wide concept which can be applied in many ways for science and technology, and in some cases it may be related to ubiquitous technology. Nordmann (2004) lists biochemistry, molecular biology, evolutionary medicine, computational linguistics, cognitive psychology and mechatronics as areas that are the result of the convergence of previously separate disciplines and domains. In ICT technology, convergence can be used to designate the multi-functionality of certain devices, such as smart phones. In production automation, multi-functionality is increasingly required from production equipment, and this will create new challenges to production-oriented SMEs. Mechatronics is a discipline which has examined more than 25 years the convergence of mechanics, electronics and information technology. Therefore, technology convergence is not a new issue for applied research groups or SMEs working in the area of production automation. The rapid progress in ICT and nanotechnology will make technology convergence in the future even more challenging for production-oriented SMEs. They will definitely need help from research organizations to follow the development. On the other hand, technological convergence offers new chances for companies that are able to identify business opportunities because converging technologies can lead to disruptive changes in the market (Larsen et al. 2009). It can also be a threat to companies that do not exploit innovation opportunities. Technology convergence is increasingly changing the market conditions for companies in many sectors of industry. (Larsen et al. 2009; Prahalad & Krishnan 2008)

In recent years, the term *converging technologies* has received a new, specific meaning. It designates the **NBIC** convergence - a synergistic combination of four major areas of science and technology**.** **N** refers to nanoscience and nanotechnology, **B** to biotechnology and biomedicine, including genetic engineering, **I** to information technology, including advanced computing and communications, and **C** to cognitive science, including cognitive neuroscience (Larsen et al. 2009; Nordmann 2004; Roco & Bainbridge 2003). Even if the NBIC convergence is still mainly in R&D laboratories, the first applications are coming into use for example with combinations of nano- and information technologies used in smart materials for packaging, equipment or surface treatment.

User-driven innovations have got much attention in last few years. One contemporary topic in user-driven innovations is called *crowdsourcing*, where innovating is distributed to a large number of people with the help of ICT solutions (Howe 2006; Sjöholm 2010). However, user-driven innovation is not a new issue. More than 20 years ago, von Hippel (1988) presented both theoretical considerations and practical examples of user-driven innovations. Later he introduced the concept of *democratizing innovation*, by which he meant that firms or individual users of products and services are increasingly able to innovate themselves (von Hippel 2005, 1). Empirical results have shown the benefits when many users innovate and when using so called lead users, who are ahead on important market trends (von Hippel 2005, 22). Lead users sometimes develop and modify products for themselves and then often freely reveal them. The disadvantage of user innovations is the intellectual properties which often are based on the fact that they have low ability to profit from patenting. In fact, von Hippel argues that the trend toward democrazing innovations leads to the situation where user-centered innovation systems can in some conditions entirely supplant manufacturer-based innovation systems.

The author's experience from collaboration with production-oriented SMEs does not fully support this trend. Even lead users may know so little about complicated manufacturing and materials technology that they cannot innovate or develop successful products themselves but together with production experts. However, in the future, user participation in innovation processes will be increasingly important also for production-oriented SMEs of this study. The usability experts of research groups can provide help to assure the user interaction will be taken into account in right manner in innovation processes.

Prahalad and Krishnan (2008, 11) also stated that in the future the focus of innovations will be on the centrality of the individual. Firms have to learn about one consumer and his/her experience at a time, even if they serve thousands or millions consumers. Value is based on unique, personalized co-created experiences (see FIGURE 1). This will have an impact on production-oriented SMEs in the way that the batch sizes of production series are decreasing and approaching to one. It brings a big challenge for modular product design and for production automation and SMEs need every possible help in that transformation process. The cooperation involving applied research groups and suppliers is one possible way to provide aid for SMEs.

Ruckenstein, Suikkanen and Tamminen (2011) consider in their recent report how user-driven innovations can be created. In the Finnish name of their report they propose to forget innovating and to concentrate on value creation. They suggest that research should focus on new user-driven value creation instead of examining innovation structures or processes. User-driven innovation practices are presented in seven cases of Finnish organizations. One of these cases came from Kone Corporation, which in 2004 started a development project for new kind of user interfaces for elevators. The background came from every-day problems of the users, such as an everyday situation where someone enters to the elevator with shopping bags in both hands. The development project led from pushing an elevator button to a wider consideration of total moving assistance in a constructed environment. This new view was called *people flow*, which is now in a central role of corporate strategy, and it can be found even in the corporate slogan and in the name of the corporation's customer magazine.

User interaction will play an extremely important role in service innovations. The traditional division to product-oriented and service-oriented business is changing as products are currently often equipped with service elements which bring additional value to customers. A recent VTT report (Kaasinen, Ainasoja, Vulli, Paavola, Hautala, Lehtonen & Reunanen 2010) presents a literature review about the current state of the art in user involvement in service innovations. The report also claims that the attitude towards users has been changing from a passive research object to an active design partner who can be a potential resource and co-producer. As the authors state, user involvement is especially beneficial in service innovation processes. Users that have faced problems using the service are motivated to give tips and to participate in development. Customer interaction may also shorten the development cycle and improve the quality of innovations.

User-driven innovating is common for both production-oriented SMEs and the applied research team of this study. However, involvement of user interaction has not always been systematic in either SMEs or in the research team during this study. SMEs often use direct feedback from customers or suppliers in their innovation process. This may lead to a bouncing development cycle. In last few years the applied research team has started to use usability examinations in its collaboration projects, which have brought some valid methods for user interaction considerations. The systematic involvement of user interaction will need more careful consideration in the future, especially in multi-discipline applications such as the development of health-care equipment and services.

Service business is considered one of the current global megatrends (Kaplan & Palmer 2010; Prahalad & Krishnan 2008; Ylén et al. 2010). Many manufacturing companies have turned to total solution providers (Antioco, Moenaert, Lindgreen & Wetzels 2008; Oliva & Kallenberg 2003; Ovaskainen 2010; Prahalad & Krishnan 2008; Ylén et al. 2010) and this development will also have an impact for production-oriented SMEs of this study. Chesbrough and Spohrer (2006) as well as Spohrer and Maglio (2008) described the progress of how employers shift from agricultural work and goods production to services. The authors described the situation that today we have shifted from post-agricultural world to the post-manufacturing world, where we now live in a services-based economy. Chesbrough and Spohrer (2006) proposed a few years ago that *services science* should be considered as a discipline for an academic field, even if they admitted its multidisciplinary nature. Lately, a number of researchers at universities and companies have begun to talk about an broader approach *Service Sciences, Management, and Engineering* (SSME), which is defined as the application of scientific, management, and engineering disciplines to tasks that one person, organization, or system beneficially performs for and with another person, organization, or system (Spohrer & Maglio 2008, 21-22). SSME has got a growing interest during the last decade (Spohrer & Maglio 2008; Ylén et al. 2010). Spohrer and Maglio (2008, 8-9) presented statistics which show that Japan and USA in 2003 had 70% of the labor force employed in the service sector and less than 5% in agriculture while China only had 35% in the service sector and 60% in agriculture. The situation will change in the future because the service sector has grown 191% in last 25 years in China while it has grown 21% in USA and 40% in Japan. The development in Finland also indicates shift from manufacturing to services (FinnSight 2015 2006; Hernesniemi 2010; Ovaskainen 2010; Rajala 2009; Sjöholm 2010; Ylén et al. 2010).

Prahalad and Krishnan (2008, 15) gave an example of transformation from manufacturing to service process: a tire manufacturer does not sell only tires anymore but charges for services. This manufacturer can make contracts with fleet owners based on general factors, which can consist of usage miles, type of loads, typical route structures and individual characteristics such as training of drivers and the quality of driving. The tire is still the core of the business but charging is based on tire usage, not on a one-time tire sale. This kind of business transformation requires new attitudes from both the former manufacturer and customers. The reason for transformation can come from customers, who do not any more want a product but service. Transformations may happen both in business-to-business and business-to-consumer type relationships. A former manufacturing company may also find that shifting to service business is a window to better understand customers' needs (Govindarajan & Trimble 2010, 73).

Kaplan and Palmer (2010, 11-16) state that a number of global megatrends are currently shaping the future business landscape. They raise ten of them as the most important enablers of new business models: pervasive cloud computing infrastructure, web-based value delivery, mobile value delivery, servicizing world (everything as a service), experience design, sensing and monitoring, collaborative contributions, social networking and communication, climate change and sustainability, and globalization with local reference. In the future, most of these megatrends will also have an effect to the production-oriented SMEs of this study. This study has already shown SMEs demonstrations in some of these areas, such as collaborative contributions, mobile and web-based value delivery, sensing and monitoring, and globalization with local reference. These ten megatrends will have a dramatic impact on creating new possibilities for future service business innovations.

Future trends will change the business models, but according to Kaplan and Palmer (2010, 17), an understanding of future trends will not be enough. SMEs as well as large companies must use and develop their creative imagination to find the elements for successive business models based on service logic. Research organizations should help this process in a spirit which Wong (2006) defines as a collaborative culture. As Schein (2009, 144-157) argues, this helping process is dynamic, and it includes building of trust, cooperation, collaboration, teamwork, leadership, and change management. These issues will be further discussed in next chapters.

Kaplan and Palmer (2010, 17-70) argued that if companies wish to hold forerunner characteristics when shifting to service business, they have four choices for the business model innovation strategy. *Attribution Based Innovations* focus on the most important attributes of existing products in ways that shift the business model from goods to services. *Knowledge Based Innovations* focus on data, information and knowledge gathered automatically or through customer interactions. This knowledge is used to reinforce existing products or services or to create wholly new services. *Mobile Web Based Innovations* focus on transforming existing products or traditional services into a mobile or web-based service platform and experience. These innovations should satisfy the users' wishes in a world which Kaplan and Palmer (2010, 39) describe as 'anytime-anywhere access of just about anything'. *Solution Based Innovations* focus on the value of existing products or services by adding services that meet more customers by introducing complementary service models. These innovations shift the concept of customer value to the next level by trying to understand customers from a solutions perspective. This requires looking at the broader context of the customer and also to proactively see unaddressed problems and opportunities. This view can be seen having connections to the author's *proactive combination innovation* concept described in Chapter 1.4. When considering production-oriented SMEs, attribute and knowledge-based innovation models are currently the common ways for them, but with long-lasting partnerships they could shift to solution-based innovations. That would need collaboration not only with customers but with suppliers and applied R&D organizations. With the help of collaborating organizations and companies also mobile web based innovations can provide business opportunities in the future.

VTT has recently carried out a study about how automation can support business processes (Ylén et al. 2010). The study looked at how SMEs in the field of automation should face the challenges that the shift from manufacturing to service processes will bring. The automation business is in a transformation which can take the base from many SMEs' business but on the other hand it can provide new opportunities for SMEs and whole nation. According to the report (Ylén et al. 2010, 82), SMEs can survive only with collaboration and networking because they have limited resources in many ways. SMEs should learn to utilize the Finnish innovation system which has many alternative ways for SMEs. The conclusions of the report can be shared also with this study, which provides some examples how SMEs can make fruitful collaboration with an applied research group.

Globalization has had an increasing influence to companies regardless of their size. Prahalad and Krishnan (2008, 11) argued: "No firm is big enough in scope and size to satisfy the experiences of one consumer at a time. All firms will access resources from a wide variety of other big and small firm- a global ecosystem." With advances in information technology, the whole world is now a marketplace and firms can catch resources, materials and components from multiple vendors around the globe. On the other hand, globalization exposes SMEs to new competitors from distant parts of the world and forces SMEs to rethink their existing competitive strategies (Bullinger et al. 2007). Agile and flexible SMEs can challenge conventional ways of doing business, especially when they are integrated to global supply chains (Kaplan & Palmer 2010, 16). However, as Burns (2011, 151) notes "there is a great deal of hullabaloo around globalization". Even if information technology has provided new global opportunities for small firms, new challenges and problems have also appeared. The changes in global economy can have surprisingly dramatic influences as in autumn 2008 when the global economic crises decreased the numbers of orders to almost zero in a month also for many Finnish firms. Globalization is here to stay and even small firms have a wide range of challenges when learning to operate flexibly in a fast moving global economy. On the other hand, they must consider the important local economic contexts. Porter noted that the competitive advantage is created at home where selections for strategy, product and process technology are made and where the actual production takes place (Porter 1990 / 2008, 207-211).

Globalization has taught the importance of flexibility and agility for production-oriented SMEs of this study. About ten years ago, some of the firms made 80-90% of their production to one or two big global customers. In a few year's time, these big companies shifted to use manufacturing companies mainly in low cost areas in eastern Europe or the Far East. This caused enormous challenges for both the small firms of this study and applied research groups which were trying to help the firms survive and develop in the new situation. Therefore, it can be concluded that globalization has had a great importance to the direction and progress of this study.

Even if most production-oriented SMEs of this study are willing to work with national dealers when buying components, equipment or machinery, many of them have been used for many years to buy these items from multiple vendors around the world. That progress will continue and it will in the future cover more their own product deliveries and even maintenance and spare part services for the customers which can be operating around Europe or sometimes even around the globe.

Sustainable growth and sustainability have become as an essential part of globalization. The attitudes that underrate the significance of sustainability have changed to become a global interest. Sustainable growth can be seen as a source of innovation which can lead to many new sustainable products, processes and services in the future. Hautamäki (2008) argues in his recent report that sustainable innovation can in the future be a competitive advantage for companies, especially in so-called cleantech markets. Tidd and Bessant (2009, 580-581) list five types of environmental issues for sustainable innovations. First, cleaner products will have a lower impact over their life cycle. Second, more efficient processes can minimize waste and make recycling possible. Third, alternative technologies based innovations can reduce emissions or provide renewable energy. Fourth, new services can replace or reduce consumption of products. Fifth, systems innovation can measure and monitor environmental impact or they can lead to new socio-technical systems. All of these types can provide new business opportunities also for SMEs.

Sustainability has in many ways an increasing influence to the production-oriented of SMEs in this study. The global interest for sustainable growth can provide new business opportunities for new sustainable products, processes or services in the future. On the other hand, the requirements for sustainable growth have brought new regulations which SMEs have to take into account, especially if they are operating internationally or as a part of an international supply chain. These regulations may be a driving force for establishing a new company as was the case in the collaboration projects. A new firm and factory was started to respond to the regulations of recycling hazardous batteries and accumulators in an environmentally sustainable manner. This new plant is an answer to the battery and accumulator EU directive that became effective in Finland in September 2008. The directive will obligate manufacturers to recycle all their batteries and accumulators, regardless of their shape, size, composition, or intended use. The firm had collaborated with CENTRIA and Central Ostrobothnia University of Applied Sciences in the design and implementation phase of the new plant and process.

The reports *Europe 2020* (2010) and *Innovation Union* (2010) forecast that Europe is facing a moment of transformation based on the ageing of population and strong competitive pressures from globalization. Europe' s future economic growth and jobs will increasingly have to come from innovation in products, services and business models. The Europe 2020 strategy (2010) puts forward three mutually reinforcing priorities. *Smart growth* refers to developing an economy based on knowledge and innovation, *sustainable growth* promotes a more resource efficient, greener and more competitive economy, and *inclusive growth* is fostering a high-employment economy delivering social and territorial cohesion. The seven EU flagship initiatives of the Europe 2020 Strategy are Innovation, Education, Digital society, Climate, energy and mobility, Competitiveness, Employment and skills, and Fighting poverty. Most of these initiatives are also near the focus of this research, especially initiatives under Innovation, Competitiveness, Digital Society and Education.

Demographic change will be dramatically increasing the number of elderly people in the next decades, especially in the EU, USA, and Japan. The population pyramids will become less pyramidal in the future as shown in the population projection 2030 for Finland presented in FIGURE 16. According to the recent population projections, Europe will really be the Old Continent, as it is often called. In the EU area, the old age dependency ratio (65 and + / 15-64 years old) was 24.5% in 2009, and it will be 33.2% in 2030 and 38% in 2060 (Demography Report 2010). FIGURE 16 also presents the trends of the demographics dependency ratio in Finland. This ratio describes the number of children and elderly people per 100 persons of working age. Currently this ratio is little more than 50%, but after ten years it will be over 60%, and after twenty years, more than 70%.

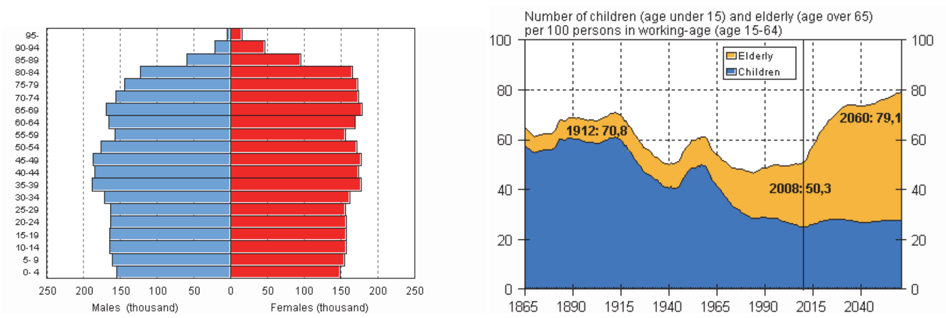

FIGURE 16 Population pyramid projection for Finland in 2030 and trends of demographic dependency ratio in Finland during 1865-2060 (Statistics Finland 2010)

In the next few years, population ageing will be faster in Finland than in most other EU Member States. By 2020, Finland will have the oldest population in the EU measured in terms of the old-age dependency ratio. The working-age population, i.e. 15-64-year-olds, has already been decreasing since 2010. (Demography Report 2010)

As Drucker (1985, 1998) stated, remarkable demographic changes and changes in industry or market structures are always also sources of innovation opportunities. As a result of these demographic changes, there will be a demand for new solutions to support elderly people in leading independent lives. Older adults can be supported with technology that helps ease the problems of social isolation which may stem from mobility problems or from the need to care for a seriously ill spouse or partner full time (Graf & Staab 2009; Pollack 2005, 10-11). In addition, personnel in facilities for the elderly and in hospitals need every possible technological aid to help ease the burden of increasing numbers of elderly people to care for.

Population ageing will be a challenge for production-oriented SMEs in several ways. In some technology areas there will be a shortage of experienced staff when current craftsmen and experts are retiring. That means a necessity to expand the use of new automation solutions. On the other hand, the demand for new solutions to support elderly people and their caretakers will provide new business opportunities. However, it is not easy for production-oriented SMEs to change from factories to develop solutions for hospitals, service houses or home environments.

2.7 Summary of Chapter 2

Innovations, entrepreneurial success and competitiveness are tightly related. New automation technologies bring possibilities which can help production-oriented SMEs find new business opportunities and enhance their innovation capabilities. In this chapter, the relations between innovations, innovativeness, innovation capability, entrepreneurship and competitiveness were examined first generally and then especially from the view of SMEs. Examinations of competitiveness and innovativeness were presented and considered from the firm-level to the regional, national, European and global levels. Finland has succeeded well in international comparisons of competitiveness and innovativeness, but there are still things which could be better for production-oriented SMEs. Technology transfer, better local suppliers, marketing and organizational innovations are examples of areas which need to be developed. Innovation capability and innovativeness are difficult to measure reliably because they are not directly observable or identifiable. Examples of innovation capability and innovativeness assessments presented in the literature were introduced in this chapter and their suitability for production-oriented SMEs was assessed. Current trends in business opportunity literature were also reviewed in this chapter and they were compared to the endeavors of this study. The chapter ended in a discussion of current and future innovation challenges of production-oriented SMEs. This consideration was an integration of views available in the recent literature and of the author's view based on the experiences of this study.

3 APPLIED RESEARCH CASES OF ROBOTICS AND SIMULATION

3.1 Research progress in research of robotics and simulation

The research progress in cases of robotics and simulation followed the research phases discussed in Chapter 1.6 and presented in FIGURE 4. In the first phase, needs of SMEs for robotics and simulation were examined with questionnaires and interviews which were compared with the data of questionnaires and surveys carried out in other projects and found in the literature. Technology development and the status of technology were monitored from several sources including continuous follow-up of conferences and publications, analysis of statistics, future trends and roadmaps, and by conducting visits to conferences, exhibitions, universities and companies. In the third phase, the research team first learned how to use the most advanced technology and then started to adapt and develop methods suitable for local SMEs. The fourth phase in the projects was collaborative planning of pilot projects or technology demonstrations based on needs of SMEs. In the fifth phase, the plans were implemented either in SME production facilities or in CENTRIA's laboratories. The last phase, the analysis of business opportunities and innovation capabilities, was carried out in 2010 and 2011. It is presented later in this chapter and in Chapters 4 and 5.

The collaborating companies in the projects of this study were mainly SMEs: 85% of them fit the EU definition (see Chapter 1.4). Most of the remaining 15% were local units of SMEs which operate as actual SMEs in their business. Microenterprises (fewer than five employees) had a share of about 15% of the total number of participating companies. Almost 95% of the companies which participated in projects of this study can be described as production-oriented SMEs (see *Definition 5* in Chapter 1.4).

Almost 40% of the companies came from various areas of metal products and engineering industries, including heavy mechanical engineering, sheet metal production and machinery construction. About 15% of the companies operated in the design and planning of products or production solutions. The numbers of companies from the electrical/electronics industry and wood product industry were about the same, consisting together almost 25% of the total number of companies. The remaining part, slightly more than 20% of the companies, came from various fields, including the shoe, food, boat, mining and exploring industries, and health care. Regionally, 85% of the companies came from the Central Ostrobothnia or Oulu South regions.

The questionnaires and interviews carried out in this study can be described to follow the spirit of Schein's (2009) *helping relationship* and *humble inquiry*. According to Schein, helping is a complex process, since building a helping relationship is not an easy task. It includes building trust, cooperation, collaboration, teamwork, leadership, and change management. In helping relationships, the crucial issue is not the client's problem or helper's expertise but the communication process that will enable the two parties to figure out what is actually needed (Schein 2009, 66). According to Schein, the key to building and maintaining the helping relationship is something he calls humble inquiry (Schein 2009, 66-84). In humble inquiry, the first interventions should consist of careful observation and listening because the expectations of the two parties may be incorrect. This can progress to mutual trust, which can create a helping relationship, where both parties are willing and able to give and receive help on the same level.

Technology development monitoring in robotics and simulation included analysis of strategic research agendas (SRAs) and roadmaps, such as presented in EUROP (2009) and Manufuture (2006) SRA publications and in surveys, for instance, presented by Goodrich and Schultz (2007). The typical conference visits were to robotics, automation, mechatronics and technology conferences. Exhibition excursions included visits to general technical exhibitions, such as the Hannover Fair and special exhibitions like the Automatica Fair, which is focused on automation, robotics, computer vision and wireless technologies. A remarkable way for networking has taken part in the international WAMS seminars, organized three times in Ylivieska as discussed earlier in Chapter 1.6. The results from technology development monitoring have been reported to SMEs in steering group meetings of collaboration projects or in reciprocal meetings or discussions.

The project implementations of robotics and simulation always started with laboratory tests and then continued with technology demonstrations or pilot projects. The spirit of helping relationship and humble inquiry has been maintained in discussions during collaboration projects. In the beginning, the focus was on how to find suitable cases for pilot projects or technology demonstrations. Later these discussions expanded to evaluations about the modifications needed for utilizing these technologies in SMEs' own production or in their customer projects. Examples of the technology demonstration results are stored in the virtual digital media library of CENTRIA, which contains media files (including video or simulation clips, 3D models, and digital photos) that can be viewed with smart mobile phones, tablet PCs or laptops. Some of them can also be seen in YouTube (search *centriard*).

Prahalad and Ramaswamy (2004) presented their concept of co-creation between a customer and a firm as a new approach for value creation. In this study, those co-creation principles were applied to collaboration involving the applied research team and SME. As Prahalad and Ramaswamy argued, in co-creation, the customer is not a king and always right, and the firm's role is not all the time to try to please the customer. Co-creation should be joint creation of value starting from joint problem definition and problem solving. These same co-creation principles have been applied to the collaboration involving SMEs and the applied research team. The pilot projects and technology demonstrations have provided innovating experience environments, which are important for new co-creation experiences (Prahalad & Krishnan 2008, 8-9). Helping relationship integrated with these innovating experience environments has provided a favorable background for fruitful collaboration projects in applied research cases of robotics and simulation. The principles of helping relationship and co-creation can pave the way to a collaborative culture, which according to Wong (2006) is characterized by being empowering, supportive, trusting, unifying and professional. The helping relationship has also been found important inside the applied research team. In fact, experiences of this study verify Schein's (2009, 106-126) arguments that only team players with a mutual helping attitude will succeed year after year in development groups. The transformation to a collaborative culture takes time in same way as creating helping relationships and other cultural changes in organizations (Schein 1992; Schein 2009; Wong 2006). The effects of collaborative culture, co-creation and helping relationships are discussed further in Chapter 5.

The author's role in the collaborative research projects has been focused on planning, selecting and coordinating the research activities. The author was responsible for documentation of the projects where he acted as project manager. In the list of articles, the author was responsible and the main writer in robotics and simulation articles I, IV and IX. In other articles, the author participated in the design of the article contents, introduction and conclusions and was a co-author in these parts and in topics concerning robotics and simulation applications.

3.2 Research findings concerning the cases of robotics and simulation

In this chapter, the research findings of robotics and simulation technology from the original articles and other related articles by the author are presented. The perspective for introducing the research findings is the business opportunity creation view combined with innovation capability enhancement. The chosen research findings can be considered as examples of ***proactive***

combination innovations defined in Chapter 1.4 (see FIGURE 2). In this chapter the technology advances are introduced; the evaluation of business opportunities of all these 12 research results is presented in Chapter 3.3. The evaluation of innovation capabilities in robotics and simulation technology is presented in Chapter 3.4.

The list of research results under consideration is presented in TABLE 9. The first three of these research findings are related to robot programming: robot offline programming, robot work cell calibration and easy robot programming methods. Next, the results from NC or production simulation are introduced. Virtual design has been used successfully in production equipment design and layout design and simulation, and also the research experiments from laser scanning based virtual modeling are introduced. The research findings from remote robot monitoring and control are followed by the results from developing hybrid mobile robot navigation and user interfaces for robots or machines. The last two research findings are concerning service robot developments.

TABLE 9 Research findings concerning the cases of robotics and simulation

RoboSimu1	Robot off-line programming (OLP)
RoboSimu2	Robot work cell calibration for OLP
RoboSimu3	Easy robot programming methods
RoboSimu4	NC or production simulation
RoboSimu5	Virtual production equipment design
RoboSimu6	Virtual layout design & simulation
RoboSimu7	Laser scanning based virtual modeling
RoboSimu8	Remote robot monitoring and control
RoboSimu9	Hybrid mobile robot navigation
RoboSimu10	User interface for robots / machines
RoboSimu11	Service robot for elderly people
RoboSimu12	Service robot for guiding tasks

Robot offline programming (OLP) methods were created to make programming more efficient and to enable remote programming. Robot programming with the conventional teaching method is usually a tedious and time consuming task. In the teaching method, the robot is driven in the desired positions with the help of a control panel and every position is stored in robot controller memory. After this, the commands for robot programming are completed and parameterized either with the control panel or with an external PC. One disadvantage of robot programming with the teaching method is that it occupies the robot and the surrounding production equipment for the whole programming time and thus prevents their use in production. For robotized press-braking tasks, this may take hours, sometimes even the whole eight hour work shift. Another disadvantage of robot programming with the teaching method is the need of expertise and experience by the operator. Program logic and calculations are not easy to program with the current robot programming languages. These languages have no standard structures or semantics, which has led to a situation where every robot manufacturer has their own robot language. Robot programming styles of different operators can vary so much that it is often not easy for one operator to continue or modify the robot program created by the other. It is a fact in industry that due to time pressures, robot programs are often poorly documented. Robot movements during programming and testing are for safety reasons made with slow motion, typically 25% of the maximum speed. This procedure increases the robot programming and testing times when the robot work cell cannot be used for production.

Robot offline programming software can also be used for the design and simulation of tasks in a robot work cell. The use of simulation in the development process of production significantly decreases the risk of design errors, and it can save time, decrease the ramp-up times between production changes, and this increases productivity. The applications of robot simulation and offline programming are presented in original articles I-IV and in a number of other conference proceedings (Pieskä, Sallinen, Kaarela, Honkanen & Sumi 2004; Kaarela, Pieskä, Savukoski & Uusitalo 2007) The implementations have been carried out in robotic press braking, robotic welding, robotic material handling work cells, and in a multifunctional robot work cell. The applications also include solutions how the developed framework for teleoperation can be applied in robot programming and monitoring of robot work cells either with fixed monitoring devices or mobile robots. The research findings confirm that the most important advantage of offline programming is that it does not occupy production during programming process. Furthermore, productivity can be increased and ramp-up times between production changes can be considerably decreased when simulation is used in a proper way in the development process. The successful implementation of offline programming also enables profitable manufacturing of small series with robot systems.

The robot offline programming applications developed in this study are typical examples of *proactive combination innovations* defined in Chapter 1.4 (see FIGURE 2). They represent a new type of products which also change the robot programming process and enable new services: profitable robot utilization even in small series production. Offline programming provides a possibility for organizatorial innovations because programming is no longer tied to a certain time in a certain place (the robot work cell). The 3D models and simulations created for robot offline programming can also be used innovatively in marketing. The proactive view was taken into consideration in the development process: in the beginning of this study, it could be expected that product designers will create more complicated product designs with their new 3D software. These products are hard to manufacture profitably without a robot, and robot programming is hard to carry out in the conventional way. Another proactive view was the trend for small series production, which is related to the general development towards personalized co-created experiences, as discussed by Prahalad and Krishnan (see Chapter 1.1).

Robot work cell calibration for OLP is needed to match the simulation model and the real world. Calibration of the geometrical dimensions of the robot work cell has a very essential role when applying offline programming in robotic production cells because the simulation model is always only an estimation of the real world. Offline programming can be facilitated by user-friendly interfaces where 3D models of products and robot programs can be generated automatically. Using traditional methods, the calibration process produces several hours of down time in the production cells. To speed up the calibration process, an advanced calibration method with 3D measurement arm and a virtual design based calibration method were introduced in original article II and in the Automation Days seminar article (Pieskä, Kaarela, Rahja, Honkanen & Viklund 2005). The importance and applications of the robot work cell calibration are also discussed in original articles I and IV.

A comparison of calibration methods developed is presented in FIGURE 17, which is modified from the presentation slides of original article II. The presented results and shutdown times are mainly based on experiences from the calibrations of robotic bending work cells. In the advanced calibration method, an external measurement device, a 3D measurement arm, is used to speed up the calibration measurements and to improve the accuracy of calibration. ***The advanced calibration*** method decreased the calibration time in the experiments to less than half of traditional calibration. However, robot programming was carried out with the online teaching method. This meant that the work cell and robot programmer had to be reserved for the whole calibration process. In the ***virtual design based calibration*** method, a 3D measurement arm is again used for measuring the dimensions offline. With the virtual design based calibration, all the calibration measurements of the robotic work cell could be carried out in 1-2 hours. This was based on advance measurement design and robot offline programming: all the 3D arm measurements and robot programs for calibrations were planned in advance. The calibration measurements can also be divided to many sessions, which can be made at the most suitable times for other production activities. This new calibration method is very useful especially in recalibration tasks when the robot work cell model is built approximately correctly and with virtual design based calibration measurements it can be completed accurately enough.

	TRADITIONAL CALIBRATION	ADVANCED CALIBRATION	VIRTUAL CALIBRATION
MEASUREMENT DEVICE	ROBOT	EXTERNAL	EXTERNAL
PROGRAMMING	ONLINE	ONLINE	OFFLINE
APPROXIMATE SHUTDOWN TIME	8-16 HOURS	3-5 HOURS	1-2 HOURS
PROS AND CONS	+ No need to invest on measurement equipment + Can be done by one expert - Very long shutdown time - Inaccurate - Vulnerable to errors - Robot may prove too inaccurate for measuring	+ Shorter shutdown time + Accurate calibration result - Expensive equipments - Requires more than one expert	+ Minimal shutdown time + Accurate calibration result + Errors can be avoided beforehand - Expensive equipments - Requires more than one expert

FIGURE 17 Comparison of robot work cell calibration methods

The virtual design based calibration method developed for robot offline programming is another example of proactive combination innovations because it has the same effects for robot work cell calibration as robot offline programming has for traditional robot programming. It is a new method which changes the calibration process, leading to a process resulting in organizatorial innovations. Additionally, it can be used in innovative marketing endeavors. It fulfills the proactive view in the same way as offline programming: it suits for calibration of more complicated, multifunctional robot work cells used in small series production.

Robot work cell calibration has been developed further in 2011 with CENTRIA's new 3D measurement device (NDI Optotrack). The technology demonstration of the calibration measurements in VTT's robot cell is also saved in the CENTRIA virtual digital media library, and it can be viewed in YouTube (search *centriard*).

Easy robot programming methods were developed to enable robot programming even for operators who are not experts on robotics. In the most successful implementations, robot operators can use their robot with no programming at all. The development of easy robot programming methods started from creating user-friendly interfaces for offline programming presented in original articles II-IV. As an example, a robotic flange welding application with parameter based offline programming was designed to enable rapid production changes with a user-friendly graphical user interface. The application software provided guided help to the operator with macro functions, starting from the creation of a product model where the macro function automatically generated parametric polygon geometry from the given product dimensions. Automatic robot program creation also included simulation of welding tracks before the program was translated to the real robot. The whole robot program creation took no more than five minutes, so the developed user interface was found very effective and easy to use.

Easy robot programming methods were extended first to remote monitoring and control of industrial robots (see original articles I-IV) and later to remote monitoring and control of mobile robots (see original articles IV-VI).

In the last few years, the development of easy user interfaces for robot operators has lead to solutions where no actual robot programming is needed. The applications included industrial, mobile and service robots with multi-modal user interfaces, including graphical user interfaces, a multi-touch screen, voice control and pointing devices. FIGURE 18 shows one example of CENTRIA's development where a simple 3D measurement arm is used in generating complex-shaped robot tracks (SISU 2010, 111). The user does not have to take care of the robot commands; the user only shows the tracks he/she wishes the robot to move along. The demonstration of easy robot programming technology is saved in the CENTRIA virtual digital media library and it can also be seen in YouTube (search *centriard*). The idea of external measurement device based interaction in robot programming is not new (Halme, Heikkilä, Torvikoski 1987; Hasegawa 1982; Manninen 1984; Pieskä et al. 1988), but in the 1980s there was lack of feasible measurement devices, lack of computer power and industrial robot control systems were at that time not open enough for external programming. VTT has also recently been developing a method based on an interactive 3D sensor system for robotic applications (Heikkilä, Ahola, Viljamaa, Järviluoma 2010). In the European SME Robot project, a digital pen was developed to be used as a robot programming device (Pires, Godinho, Nilsson, Haage, & Meyer 2007).

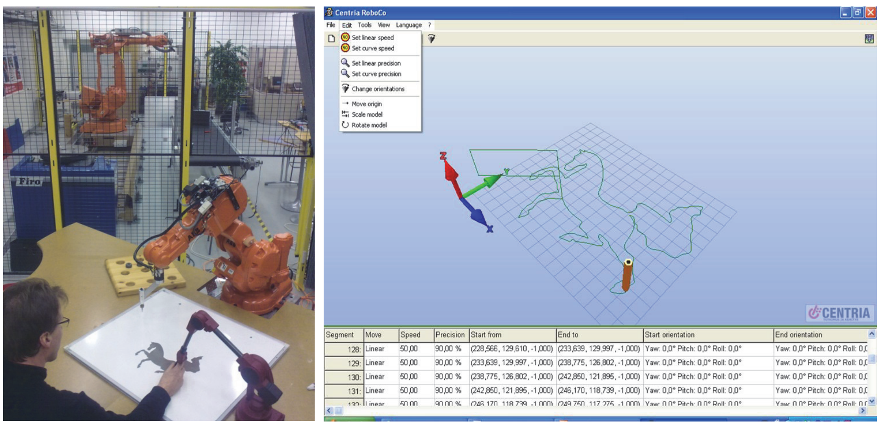

FIGURE 18 CENTRIA's RoboCo software: an easy way for robot programming

The easy programming methods developed during this study, such as the one presented in FIGURE 18, are also examples of proactive combination innovations because they may totally change the way robot programming is carried out. The development goes in the no-programming direction, where the robot operator no longer has to be a robot expert. The developed solutions can be used for innovative marketing and they may lead to organizatorial innovations. Easy robot programming methods also proactively support the possibilities for individual product manufacturing, which are consequences of the trend towards personalized co-created experiences, as proposed by Prahalad and Krishnan (see Chapter 1.1).

NC or production simulations are an essential part of digital manufacturing where the goal is to use 3D CAD models all the way from design to manufacturing. NC and production simulations can be proactive combination innovations which change the design, manufacturing and marketing processes as has happened in the automotive industry. Many automotive manufacturers have reported that no actions in the manufacturing line will be started before they are properly simulated. Results of virtual design and simulations are often used in marketing, for example in TV advertisement spots.

The verification of NC programs with simulation is important because problems with NC programs may lead to collisions or unsatisfactory manufacturing results that cause remarkable delays and costs. Many advanced CAM software products provide the ability to visualize or simulate the software's own program code, but not the verification of the actual machine code sent for the milling machine. Research findings from the NC or production simulations are presented in original articles I, II and IV. An example of NC program simulations is the virtual model of CENTRIA's milling machine which was constructed together with a so-called mimic file for the controller. The virtual model and the mimic file were utilized for the verification of the NC program of mold parts.

Production simulations are often needed to a larger extent than only an NC-machine or a robot with accessories. Simulations of production lines, multifunctional robot cells, warehouses or even the whole logistics inside and outside the factory can bring a lot of information and lead to remarkable savings in the increasingly complicated and frequently changing production systems. Examples of production simulations presented in original articles I, II and IV, and in the conference articles (Pieskä 2003; Pieskä et al. 2004) include production lines or multifunctional work cells in the metal, electronics and wood industries and in glass manufacturing.

Virtual production equipment design was used for developing components or whole machines for production components. A typical example is the virtual design of grippers based on the 3D product models. These were used in robotic press brake cells. Virtual design was also used for equipment needed in element assembly at a prefabricated house factory and for production equipment in timber machining. Examples of virtual production equipment design are presented in original articles I-IV and in the conference article (Pieskä 2003). Collaboration with the research team and SMEs in virtual production equipment design led to a patented solution for a driving unit for borehole measurements (Kaarela 2010).

Virtual layout design and simulation provide an effective tool to examine the effects of layout changes before implementing them or layout alternatives before the construction of a new factory, a new production line or a new production cell. Examples of virtual layout design and simulation are presented in original articles I-IV and in the conference articles (Pieskä 2003; Pieskä et al. 2004) and in the final report of the SISU 2010 technology program by Tekes (SISU 2010, 111-114).

FIGURE 19 presents an example of results from the collaboration project for designing and manufacturing a robotized work cell for log building production. The collaboration project changed the SME's regular design process because virtual design and simulations were used from the early design phase to manufacturing and export with the help of the research team. The actual work cell was constructed, tested and finalized after some modifications in collaboration at the SME's factory after some modifications. After successful tests, the SME's customer delivered it abroad.

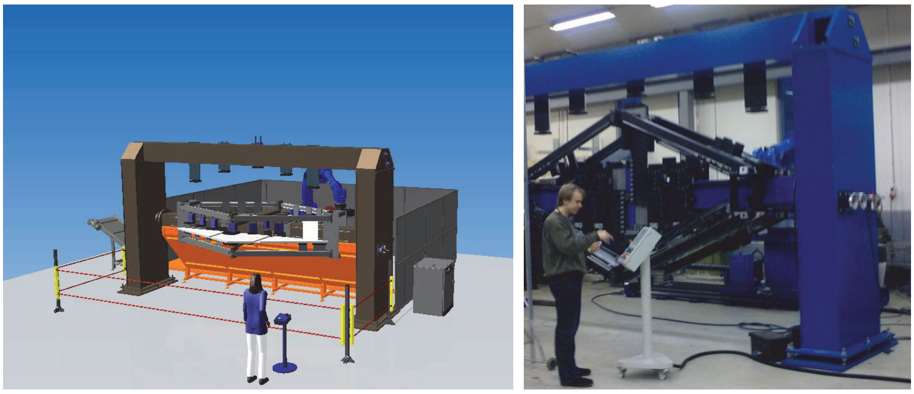

FIGURE 19 Virtual design and simulation was used in the development of a robotic log building work cell

Laser scanning can be integrating into virtual modeling. The procedure starts by measurements that sweep an area and return an accurate 3D point cloud, a high-definition map of surfaces. From that point cloud, a 3D model can be created with feasible image processing software. Laser scanning based virtual modeling has previously been used mainly when collecting detailed digital information of large objects such as buildings or bridges. It was also used in community planning for environmental modeling, for example to find the best locations for roads.

The proactive combination innovation with laser scanning based virtual modeling was to use it in production facilities modeling and to utilize the resulted 3D model in mobile devices such as smart phones. Conventionally, accurate 3D modeling of a factory hall with equipment may take several work weeks or months with 3D modeling software. With laser scanning and feasible software, the modeling time can be reduced even to 1-2 weeks' work. This laser scanning based virtual modeling thoroughly changes the design and modeling process and facilitates its use in marketing and remote demonstrations. For example, the accurate 360 degrees panorama photos added with work cell simulations are an efficient way to introduce production facilities. Proactive elements include the preparation for 3D map based navigation and monitoring of mobile robots or transporters.

CENTRIA started to use laser scanning for virtual modeling of production facilities in 2009. The first case was CENTRIA's production engineering laboratory (FIGURE 20) and after this, two production facilities of SMEs were modeled in the same way. The results of laser scanning based virtual modeling can then be used when planning layout changes or they can be used as a 3D map for navigation of mobile work machines or robots as presented in FIGURE 20.

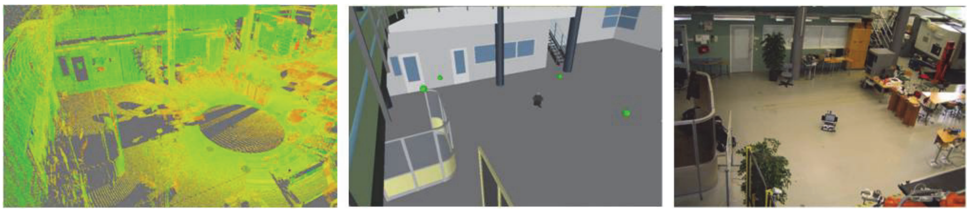

FIGURE 20 Laser scanning based virtual modeling of CENTRIA's production engineering laboratory: a point cloud, a 3D model and a photo

Examples of technology demonstrations about laser scanning based 3D modeling were also saved in the CENTRIA virtual digital media library and some of them can be accessed via YouTube (search *centriard*).

Remote robot monitoring and control provides a possibility to easily check the status of the robot work cell from other parts of the factory. Via mobile phone or web applications, monitoring is possible in other places, even from the other side of the world. In remote robot control, safety issues are important, and usually remote control is applied only for testing or for stop commands. Examples of remote monitoring and control include applications for both industrial robot work cells and mobile robots. The mobile robot can be remotely monitored and controlled, and due to mobility it can also be used for monitoring several work cells. The results of remote robot monitoring and control experiments are presented in original articles I-V and in the conference articles (Sallinen & Pieskä 2004; Sallinen, Pieskä, Sumi, Saavalainen & Kaarela 2004; Luimula, Pieskä, Sallinen, Alaspää & Saukko 2007; Luimula, Sääskilahti, Partala, Pieskä, Alaspää, & Lof 2007; Pieskä, Luimula, Sallinen & Tervonen 2007). Software development in these applications has proactively used solutions which are easy to move from one equipment and application environment to another. This has been very useful when handheld mobile devices, such as tablets and smart phones, have developed to reach the usability level where they can be used as user interface devices.

Hybrid mobile robot navigation means the utilization of two or more navigation techniques at the same time. Hybrid solutions are often needed in dynamic working environments where satisfactory results are not found when using only one technique. Indoor navigation techniques used in this study include integration of internal measurements (odometer and angle measurements) of mobile robots with RFID technology, wireless local network and wireless sensor network based measurement. In outdoor applications, GPS navigation is integrated to RFID technology and map based navigation with a Locawe platform which will be discussed further in Chapter 4. Examples of hybrid mobile robot navigation experiments are presented in original articles V, VII and IX and in the conference articles (Luimula et al. 2007; Pieskä et al. 2007; Pieskä, Luimula, Alaspää, Pitkäaho & Tervonen 2009).

User interfaces for robots or machines have often the most significant effect to usability. A fundamental function for the user interfaces should be to allow the operator, in a natural and easy way, to define the task for the machine, and to control and monitor it. Original articles from II to IX and the conference articles (Luimula et al. 2007; Pieskä et al. 2007; Pieskä et al. 2009) present many examples of accomplished user interfaces for robots or machines accomplished in collaboration projects. An example is shown in FIGURE 21. Some of the recent studies include also usability evaluations (see original articles V, VIII and IX and the conference articles Luimula et al. 2007; Luimula et al. 2009). In the future, the role of the user interface becomes even more important when robots develop towards socially interactive robots (Fong, Nourbakhsh & Dautenhahn 2003). The proactive elements in the collaboration projects are focused to facing the fact that in the future socially interactive robots should be able to operate as partners or assistants, and therefore social human–robot interaction is essential (Fong et al. 2003; Graf, Parlitz & Hägele 2009; Halme, Sievilä, Kauppi & Ylönen 2003; Severinson-Eklundh, Green & Hüttenrauch 2003; Suomela & Halme 2004). Socially interactive robots will need a remarkable degree of adaptability and flexibility to cope with the interaction with a wide range of humans.

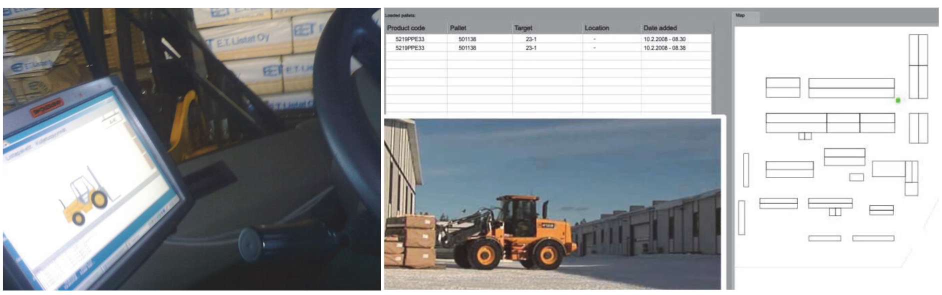

FIGURE 21 User interface of the smart wheel loader working in the outdoor warehouse area of wooden products

Service robots for elderly people have been the object of growing interest for many research groups around the world (Fong et al. 2003; Graf et al. 2009; Granata, Chetouani, Tapus, Bidaud, Dupourqué 2010; Harmo, Taipalus, Knuuttila, Vallet & Halme 2005; Pollack 2005; Severinson-Eklundh et al. 2003), because demographic changes will be causing increasing problems in elderly care in the next few years and decades. The aging world phenomenon has resulted in demands for new technical aids for elderly houses and hospitals and for new solutions to support elderly people to live independent lives in their private homes as long as they wish. Interactive service robots and other technical aids are one way to meet this challenge. However, the effect of ongoing demographic change is so dramatic that it requires all possible actions concerning public and private social and health care, education, and legislation. It will thus provide sources of innovation opportunities as Drucker (1985) has argued. The ongoing demographic change also offers potentials for a wide range of proactive combination innovations.

Interactive service robots used in everyday life must be particularly simple to operate because the users are normally no technical experts. When the users are elderly people, their inexperience with technology can cause extra challenge for development efforts. The safety aspects of service robots are considerably different from those of industrial robots. When the main safety purpose of the industrial robots is to keep the human operator away from the working area, service robots usually perform tasks near or even in contact with humans. Therefore, traditional safety methods for industrial robots are not adequate for service robots. Safety aspects must be considered in all steps of the design, and this requires plenty of experimental testing during development.

Technology solutions for the mobile interactive robots of this study were introduced in original articles V and VII and in conference articles (Luimula et al. 2007; Pieskä et al. 2007; Luimula et al. 2009). A recent publication (original article IX) presents further information about CENTRIA's service robot Kaveri (FIGURE 22) and experiments with it. The first experiments and usability examinations with elderly people have been promising. The picture on the right side in FIGURE 22 is taken from a video clip which can be seen in YLE Areena, the digital media library of the Finnish national broadcasting company. The video clip clearly shows the functionality of human-robot interaction with the developed multimodal user interface with integrated voice and multi-touch screen control. Examples of technology demonstrations with the service robot Kaveri are also saved in the CENTRIA virtual digital media library and some of them can be viewed in YouTube (search *centriard*).

Service robots have also been used ***for guiding tasks*** in museums and other public establishments in many countries, for example in Germany, Japan and USA (Faber, Bennewitz, Eppner, Görög, Gonsior, Joho, Schreiber & Behnke 2009; Graf et al 2009; Nourbakhsh, Kunz & Willeke 2003; Shiomi, Kanda, Ishiguro & Hagita 2007). The first experiments were started more than a decade ago. Museum robots typically move autonomously among the visitors, and they try to communicate and interact with them. Guide robots have also been used as platforms for studies of social human-robot interaction (Faber et al. 2009; Fong et al. 2003; Gockley, Forlizzi, Simmons 2006; Severinson-Eklundh et al. 2003). The CENTRIA research team has used the ER1 platform based mobile robot Erkki for guiding production engineering laboratory tours for many years (Luimula et al. 2007; Pieskä et al. 2007). The CENTRIA research team has also carried out first experiments how service robot can be used for guide tasks in museums, tourist centers and restaurants.

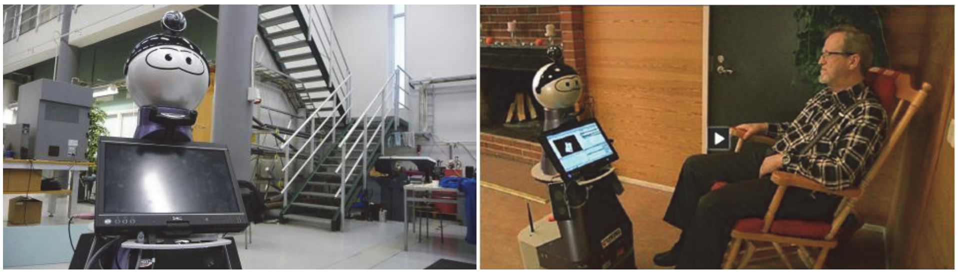

FIGURE 22 CENTRIA's service robot Kaveri: from laboratory environment to elderly people

3.3 Evaluating business opportunities of robotics and simulation research results

The evaluation of the business opportunities of the applied research results was carried out by a team which can be called a focus group of experts. The method applied for the evaluation can be considered a combination of focus group interviews, scenario development and the Delphi technique (Burns 2011, 178-180; Ovaskainen 2010, 81-83; Tidd & Bessant 2009, 346-348). The evaluation team consisted of the author and four other CENTRIA experts who had worked during this study in close cooperation with the SMEs and participated in the applied research team and also acted as co-authors in some of the original articles. The team members had thus expertise both on the trends of the latest advanced technologies and needs of the SMEs, and they also participated in the implementations of the practical solutions. The author acted as a moderator in the evaluation team and originally created the tools (tables and figures) used in the analysis. Both the structures and contents of evaluation were discussed in the team, which gave valuable comments for completing the tables and figures. Evaluation of business opportunities in robotics and simulation is presented in TABLE 10 and evaluation of technological innovation capability in the same areas in FIGURES 23 and 24. The same kind of evaluations concerning RFID and WSN technologies are presented in Chapter 4.

In TABLE 10, the main research results presented in Chapter 3.4 are listed in the first column. The next column informs which original articles they are related to. The third column presents the result of the business potential assessment for SMEs. The scale goes from *Small or no business potential* (*) to *Excellent business potential* (*****). The fourth column shows the stage of practical implementations. The scale goes from *Method tested only in laboratory* (+) to *Already in wide use* (+++++). The fifth column presents the assessment about the development need for the current technology used in the applied research of this study. The sixth column describes the consideration how much SMEs would need to invest for the technology to get the results usable for their business. The seventh column shows the results of estimations of how much SMEs should increase their competence to enable the use of these new solutions. The last three columns use a scale which starts from small (1) and going via minor(2), moderate(3) and major (4) to extensive (5).

To conclude from TABLE 10, it can be observed that the higher the rating in columns three and four, and the smaller numbers in columns 5, 6 and 7, the better business opportunities the research result has. However, the issue is not so straightforward because of interconnections between the objects considered.

TABLE 10 Evaluation of business opportunities based on robotics and simulation research results

Robotics & Simulation Business Opportunities for SMEs	Relating articles	Business potential for SMEs	Stage of practical implemen-tations	Technology development needed by suppliers or research	Investments needed for technology in SMEs	Increase of competence needed in SMEs
Robot offline programming (OLP)	I-IV	***	++++	2	4	4
Robot work cell calibration for OLP	I, II, IV	**	++++	2	3	4
Easy robot programming methods	II-IX	***	++++	2	2	1
NC or production simulation	I, II, IV	***	+++	2	4	4
Virtual production equipment design	I-IV	****	++++	2	2	2
Virtual layout design & simulation	I-IV	****	++++	2	2	3
Laser scanning based virtual modeling	VIII, IX	***	+++	3	4	5
Remote robot monitoring and control	I-V	***	+++	3	3	3
Hybrid mobile robot navigation	V,VIII, IX	**	++	4	3	4
User interface for robots / machines	II-IX	****	++++	2	2	2
Service robot for elderly people	V, VIII, IX	*****	++	4	3	5
Service robot for guiding tasks	V, VIII, IX	*****	++	4	3	5

	Business potentials for SMEs		Stage of practical implementations		Others
*	=Small or no business potential	+	= Method tested only in laboratory	1	= Small
**	=Latent business potential	++	=Demonstrations in laboratory or in production	2	= Minor
***	=Moderate business potential	+++	=Pilot cases in production environments	3	= Moderate
****	=Good business potential	++++	=Have been used for some period in production	4	= Major
*****	=Excellent business potential	+++++	=Already in wide use	5	= Extensive

Even a quick look to TABLE 10 reveals the potential ideas for business from the different research results. The cases chosen for evaluation can be considered as seeds for proactive combination innovations. One remarkable observation from TABLE 10 is that half of the results have already been used in the production of SMEs for some period of time. However, no case has progressed yet to wide use. This relates to the fact that in the projects – as it is typical in current applied research projects in Finland – resources or expertise have not been focused for wider commercialization. The commercialization endeavors will be left after the projects to potential spin-off firms or collaborative SMEs, which usually have a lack of resources and expertise in commercialization. However, CENTRIA's applied research team has also collaborated with SMEs in minor updating of their products which are already in wide use, but they are not presented in TABLE 10. During the study, three new firms were also established so that they either utilized CENTRIA's virtual design or simulations in their start-up phase or had got positive assurance from the technology demonstrations of robotics and simulation technology. Two firms found new business areas for them, and virtual design and simulations help them in this process.

Robot offline programming is a technology which has been developed about twenty years. It has been used successfully in Finland in some robotics areas, for example in robotic welding, but there are many robotics areas where it is used quite rarely. In Finnish industry, robot bending and robot press-braking are typical areas with only few examples of the successful use of offline programming. The problems are related to the availability of expertise and knowledge needed to apply robot offline programming for the process. For example, in offline programming for robot bending, the user must be an expert of bending, materials, robots, sensors, robot programming and offline programming. There is no standardization in robot offline programming tools; the same situation applies to robot programming languages. Every major robot manufacturer has its own robot programming language and offline programming software, which makes the situation challenging for the robot users, especially if the firm is using products from more than one robot manufacturers. However, there are some offline programming software solutions which can be used with different robots. These general purpose robot offline programs are usually so expensive that SMEs cannot afford them. Often this has led to a situation where the SMEs typically use robots and programming software from one dealer because the training and increasing the competence for many robot types will be expensive.

Robot offline programming has been found to be a difficult business area. There are some entrepreneurs who have started a firm providing robot OLP, but they have had to expand their business or to give up. In Finland there will be no continuous business flow. If the firm's business flow is based on only robot offline programming, it will have trouble due to economical fluctuations. OLP projects are typically irregular: during investment boom periods there could be more work than a small enterprise can handle, and in periods of recession it is impossible to find customers. However, robot offline programming can be an additional business branch for an SME which works on production automation and needs OLP also in its own business. It can sell OLP services to other firms directly or in cooperation with robot dealers. For the SMEs, close cooperation or partnership with major companies can be a way to ensure the continuity of projects on robot offline programming.

The development work of robot offline programming in this study has led to practical implementations also in the challenging area of robot press-braking of sheet metals in production-oriented SMEs. The minor technology development need (2), as shown in TABLE 10, comes from the fact that robot offline programming technology is usable in production even today, but it needs a major competence increase (4) by the production-oriented SMEs of this study because they usually have no experience in offline programming. The software for OLP is quite expensive, which requires major investments for technology if the SMEs are going to use robot offline programming.

Robot work cell calibration is closely related to robot offline programming and so are the business opportunity assessments. The customer needs of robot work cell calibrations are even more irregular than robot offline programming. Therefore, the assessment for business potential for the SMEs is smaller than for robot offline programming. The development in this study has led to practical implementations also in robot work cell calibrations. Therefore, it is estimated that there is only a minor technology development need by suppliers or research. Investments needed for robot work cell calibrations for offline programming are estimated to be moderate because offline programming software often includes software tools for calibration, and external measurement devices can be rented if they are to be used instead of the robot itself. Robot work cell calibration for offline programming requires at least the same competence as or even more than offline programming.

Easy robot programming was estimated to have a moderate business potential, and it could rise to the level of good business potential with successful networking. The practical implementations (see for example FIGURE 18 and FIGURE 22) have got positive feedback for their usability. They have shown that there are only minor technology development needs for the methods. The easy robot programming methods developed in this study would be suitable for the SMEs because the needs for investments and increase of competence are on a minor level. However, robot dealers do not currently support this new easy programming method, which makes the SMEs feel that they are risky choices.

In ***NC or production simulations***, close cooperation or partnerships with major companies is essential for the SMEs to ensure the continuity of projects; the same challenge which was mentioned with robot offline programming. The assessments in TABLE 10 follow those of robot offline programming, the reasons mainly being the same: no standardization for NC production simulation software makes them troublesome and risky, and SMEs need major investments in software and training to be able to use NC or production simulation.

Virtual design and simulation for ***production equipment*** and ***layouts*** are areas where implementations of the applied research team with collaboration of

SMEs have led to successful practical solutions. It can be estimated that with advanced software tools, virtual programming has good business potential for production-oriented SMEs. The prices of virtual programming tools have also developed in a positive direction in the last few years. There are only minor needs for technology development, investments and increase of competence for virtual design; virtual simulation needs a moderate increase of competence. If virtual modeling uses laser scanning technology, it increases the amount of investments needed for a major level. The increase of competence needed in the SMEs can be estimated to rise to the highest level. However, the successful practical implementations carried out in this study have assured that it has a moderate business potential, and with appropriate networking it could be estimated even a good one.

Remote robot monitoring and control via web technology was quite new in the first projects of this study, but it has become a common option which robot manufacturers offer to be integrated in industrial robot control systems. These remote monitoring and control systems are not always flexible to use in robot work cells where they need customizing. Often other machines in the work cell have their own monitoring systems, and it is important to integrate these monitoring systems so that the remote monitoring and control of the work cell will remain user-friendly. This offers a business potential where SMEs have to make continuous cooperation with robot and work machine manufacturers or dealers. Sometimes for usability reasons it may be wise to construct specific remote control and monitoring systems for work cells which only have interfaces to the robot and work machine control systems. Mobile robots and work machines have different requirements than stationary industrial robots and machines. This may also offer a business potential in the future.

The remote monitoring and control systems have been verified with pilot cases in this study. Based on these experiments, their business potential has been estimated as moderate. Also technology development and investment needs as well as needs to increase competence in SMEs have got a moderate assessment.

Hybrid mobile robot navigation can be considered a special area of remote control and monitoring systems. It needs a great deal of expertise in many technology areas where the production-oriented SMEs have little experience. Therefore, their business potential is currently latent but in the future for example some breakthroughs in indoor positioning methods could offer better business potentials for SMEs. Practical implementations of this study have stayed in the level of technology demonstrations. Technology development and increase of competence in SMEs will need a major contribution. The level of investments depends on the technologies chosen for the hybrid mobile navigation. With appropriate wireless sensor networks, the investments may stay in the minor or moderate level, but some technologies may raise it from moderate to the major or even to the extensive level.

User interfaces for robots and machines have got the best assessments concerning the business opportunities for SMEs. Some of the user interfaces for robots, machines and work cells have already been used successfully in production of SMEs or their customers during this study. The applications have varied very much, and they have been used for example in the metal, wood, plastic and shoe industries. There is a remarkable business potential for customized user interfaces which utilize the latest technologies. The implementation solutions used in this study need only minor investments or technology development from SMEs. Also the need to increase the competence in SMEs stays in a minor level.

Service robots have the best business potentials for SMEs in the future. Bill Gates (2007), co-founder and chairman of Microsoft, argued in 2007 that personal service robots will be in the next few decades the same kind of large business area as personal computers in the last 30 years. Gates also reminds that people did not believe in the 1980s that personal computers could come to homes around the world. Service robots at home can be used for assisting, monitoring and guiding tasks, mainly for the elderly or disabled persons. One area where service robots also have excellent business potential is in guiding or monitoring tasks at public places such as museums, tourist centers and restaurants.

Demographic change, as discussed earlier in Chapter 2.6, is increasing the number of elderly people dramatically in the next few decades. This will offer huge business opportunities for service robots in hospitals, elderly service houses and homes. Therefore, the development of everyday helping technology for elderly people is under growing public interest. The first demonstrations with CENTRIA's service robot Kaveri (FIGURE 22) started in April 2011. They have got very much interest from media, including newspapers, professional magazines, Internet video clips, radio and TV broadcastings. Service robots can offer SMEs new business models, which are not based on traditional product sales but providing services with monthly or annual charging. The first attempts for this kind of business models have already started at least in the USA and in Sweden.

Service robots use many technologies which are not common for the production-oriented SMEs. Also, their unstructured and dynamic application environments are mainly outside of factories which set a lot of challenges and require an extensive increase of competence both in SMEs and applied research groups. Technology development needed by suppliers or research is assessed to be on the major level both for service robots working in elderly care or in guiding tasks. Investments needed for service robot technology have used to be on a very high level. In the last few years, the prices for service robot platforms have decreased so the investments needed for service robots applicable to elderly care or guiding tasks have been estimated to be on a moderate level.

3.4 Evaluating innovation capabilities in robotics and simulation technologies

The focus group of experts introduced in Chapter 3.3 also evaluated the innovation capabilities of the SMEs in robotics and simulation technologies. The evaluation results are presented in FIGURES 23 and 24. The inner lines present the situation in 2002 when the applied research collaboration projects were started in robotics and simulation technologies. The outer lines present the corresponding situation evaluated in April 2011. Ten key factors were evaluated. The five first ones came from the technological innovation capability needed in the applied research cases of this study: robot programming, virtual modeling and simulation, remote monitoring and control, user interface development, and service robot technology. The next four factors were related to the undergoing transformation of business as discussed by Prahalad and Krishnan (see Chapters 1.1 and 2.6): convergence of technology, digital competitiveness, ubiquitous connectivity, and globalization. The last three are connected to collaboration, co-creation, helping relationships and creative social processes (see Chapters 2.4 and 3.1): networking with suppliers, networking with R&D units, and cooperation with customers.

The radar chart in FIGURE 23 shows how the innovation capabilities of collaborating SMEs have been developing during this study. In the initial situation, robot programming and virtual modeling and simulation were estimated to have the highest level of the five technological innovation capabilities but still remaining at a level which is half the maximum rating. They have developed further so that there are many firms which are now able to utilize them in their everyday tasks. In user interface development and remote monitoring and control, the development has been identical; the starting level in the initial situation was somewhat lower. Most of the SMEs did not know anything about service robots in the initial situation, and they are currently still far away from being able to utilize service robots in their business operations.

In the case of the next four topics, the SMEs had started to develop their competence in the initial situation in convergence of technology, digital competitiveness and globalization while their competence in ubiquitous connectivity was on a very low level. Pressures from customers and suppliers have partly influenced their interest to develop these issues. Especially digital technology has become a necessity for the SMEs to be able to work in supply chains of major, usually international companies. The pilot projects and technology demonstrations in the collaboration projects have brought them a great deal of information which they may have complemented with the information from suppliers.

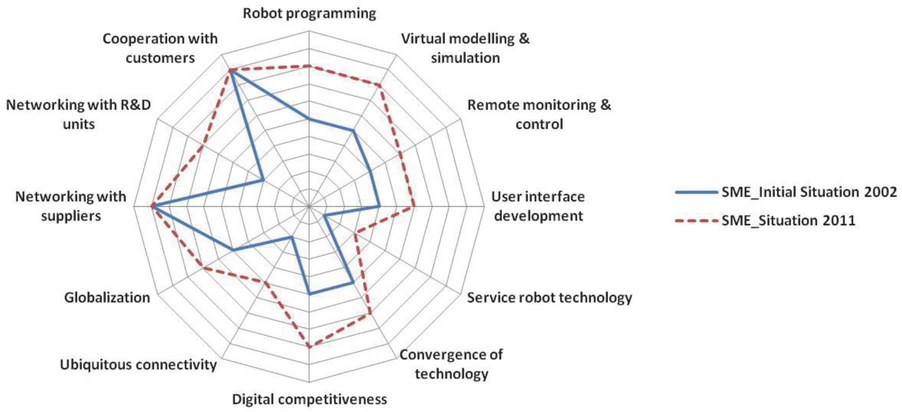

FIGURE 23 Development of SME innovation capability in robotics and simulation technologies

In the last three topics, the SMEs had already in the beginning a well functioning cooperation with customers and suppliers, but they had little experience of cooperation with R&D groups. Networking with R&D units has developed considerably during this study and not only with CENTRIA's research team but also with other research groups from VTT and the universities. Some of the SMEs have taken their first steps in participating also in international R&D projects, but this is an area which requires further work with attitudes and resource planning. The SMEs have been able to keep their cooperation with customers and their networking with suppliers in a high level. The major change in these collaborations is internationalization: more suppliers and customers are coming from abroad and the SMEs have learned to gather information from international web sites, companies and exhibitions.

The radar chart in FIGURE 24 shows how the innovation capabilities have been developing in CENTRIA's applied research team during this study. In the initial situation, robot programming was one of the strengths of CENTRIA's research team. With the practical pilot projects and knowledge from the SMEs, suppliers and customers, the know how is now on a high level, with ability to use several robot offline programming software tools for different robots. The main problems come from narrow resources; every now and then CENTRIA has not been able to accept all the offered robot programming projects when all the resources are already used for working in other projects. The irregularity of robot offline programming projects discussed earlier prevents the increase of resources for the applied research team. Virtual modeling and simulation as well as remote monitoring and control have developed to a good level where the applied research team can help SMEs in these areas. The biggest steps further have been taken in user interface development and in service robotics.

In user interface development, CENTRIA's applied research team carried out many succesful projects which were also taken into production use of the SMEs. In the last few years, CENTRIA's applied research team has developed its knowhow in service robot technology to be able to provide help to firms willing to utilize service robots in their business.

In the case of the next four topics, CENTRIA's applied research team has made the biggest steps in ubiquitous technology where it had little knowledge in the initial situation. The knowhow in convergence of technology, digital competitiveness and globalization was on a satisfactory level in the initial situation, and good progress has mainly been made because of the experience gained from the collaboration projects.

In the last three topics, CENTRIA's applied research team has learned a great deal from the collaborating SMEs about networking with customers and suppliers while it has been helping the SMEs in networking with R&D groups. In robotics and simulation technology, it has been found that the applied research team should collaborate not only with the SMEs but also with the equipment and software suppliers because this clearly shortens the delay times from ideas to innovations.

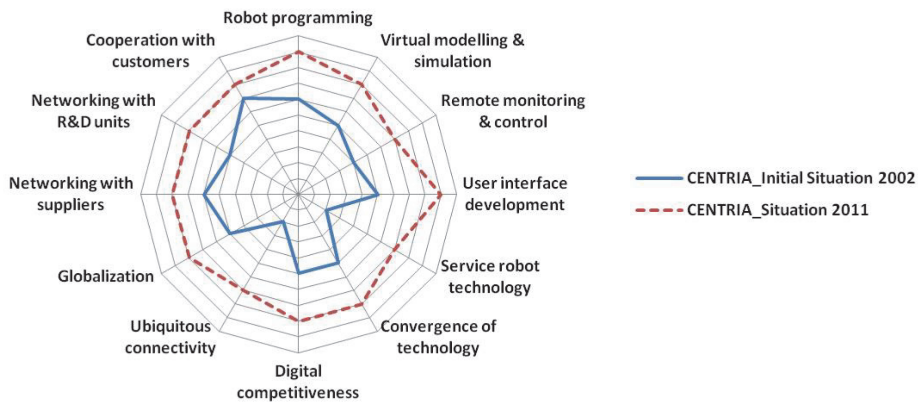

FIGURE 24 Development of CENTRIA's innovation capability in robotics and simulation technologies

As FIGURES 23 and 24 show, innovation capabilities have developed favorably both in the SMEs and the research team during the applied research projects of robotics and simulation. The main reasons can be found in succesful collaboration involving the SMEs and the applied research team. In collaboration, co-creation and helping relationships have provided an innovative and fruitful environment for challenging research and development tasks. Also, effective mutual helping in the development team has been important for getting the succesful results. These backgrounds for effective collaboration will be further discussed in Chapter 5.

3.5 Summary of Chapter 3

The applied research work carried out in cases of robotics and simulation was presented in this chapter, which began with a general description about the research progress of these subjects in this study. The first subchapter also described how the collaborative culture of SMEs and the applied research team has developed. The main technology advances and twelve research findings of robotics and simulation technology in the original articles were presented and summarized in TABLE 9. The results were also illustrated in several figures to visualize their practical applicability. The business opportunity evaluation process of the robotics and simulation research findings was discussed and the results were summarized in TABLE 10. The evaluated factors of research results are the following: their business potential for SMEs, stage of practical implementations, technology development needed by suppliers or research groups, investments needed for technology in SMEs, and an increase of competence needed in SMEs. The taxonomy used in evaluation was also presented in this chapter. The business opportunity evaluation shows that five of the research findings are assessed to have good or excellent business potential. Half of the research results (6) have already been used in production in the SMEs of this study. The innovation capability assessment process of SMEs and the applied research team was described and the results presented in FIGURE 23 and in FIGURE 24, respectively. Ten key innovation capability factors were evaluated: five from the technological innovation capability, four from the undergoing transformation of business and three from creative social processes. The figures show that innovation capability has made remarkable progress during the study in all the key factors both for SMEs and the applied research team.

4 APPLIED RESEARCH CASES OF RFID AND WSN TECHNOLOGIES

4.1 Research progress in research of RFID and WSN technologies

The research progress in cases of RFID and WSN technologies followed the research phases presented in Chapter 1.6 and in FIGURE 4, the same way as was with robotics and simulation in the previous chapter. In the first phase, needs of SMEs for RFID and WSN technologies were examined mainly with interviews and discussions because in the beginning the SMEs had little or no knowledge about these technologies. The results of interviews were compared with the reports concerning the technological needs of the SMEs in wireless automation. Technology development and state-of-the-art were again monitored from several sources including continuous follow-up of conferences and publications, analysis of statistics, future trends and roadmaps, and visits to conferences, exhibitions, universities and companies. In the third phase, the research team first learned how to use the most advanced technology and then started to adapt and develop methods suitable for local SMEs. This took quite a long time because of the great diversity of technologies in RFID and WSN. The research team had to learn how to use many of them because one solution which works properly in one industrial environment does not suit to another. The fourth phase in the projects was the collaborative planning of pilot projects or technology demonstrations based on the needs of the SMEs. In the fifth phase, the plans were implemented either in the SMEs' production facilities or in CENTRIA's laboratories. The last phase, the analysis of business opportunities and innovation capabilities of RFID and WSN technologies, was carried out in 2010 and 2011 in the same way as with robotics and simulation. The results of this evaluation are presented later in this chapter and in Chapter 5.

Technology development monitoring in RFID and WSN technology included analysis of state-of-the-art surveys, strategic research agendas (SRAs) and roadmaps, such as those presented in ITU Internet Reports (2005), the Manufuture SRA publication (2006) and in the articles by Heinrich (2005) and

Roussos and Kostakos (2009). Typical conference visits were made to wireless automation, ubiquitous and pervasive technology conferences. Exhibition excursions included visits to technical exhibitions such as Hannover Fair, CeBit and Automatica, where the focus is on wireless automation, mobile devices and in ubiquitous technologies. An important scene for networking has been the international WAMS seminars, which have been organized three times in Ylivieska as discussed earlier in Chapter 1.6. The results from technology development monitoring of RFID and WSN have been reported to the SMEs in the steering group meetings of the collaboration projects and in reciprocal meetings or discussions.

The project implementations of RFID and WSN technologies always started with testing the equipment and developed embedded software first in the laboratory, and then they continued with technology demonstrations or pilot projects. At the beginning, the focus of the collaborative discussions with the SMEs was on how to find suitable cases for pilot projects or technology demonstrations. Later these discussions expanded to evaluations about the modifications needed for utilizing these technologies in the SMEs' own production or in their customer projects. Like technology demonstrations of robotics and simulation, some examples of these technology demonstrations are stored in the virtual digital media library of CENTRIA, and some of them can also be viewed in YouTube (search *centriard*).

The research process of RFID and WSN technologies progressed in the same spirit of collaboration, co-creation and helping relationship as described in Chapter 3.1. The pilot projects and technology demonstrations have provided environments for innovative experiences, which have been found important to wake the interest of SMEs.

The author's role has been focused on planning, choosing and coordinating the research activities in the same way as discussed with robotics and simulation in Chapter 3.1. The author participated again in planning the contents, introductions and conclusions of the articles and was a co-author for these parts and in topics concerning industrial RFID and WSN applications.

4.2 Research findings concerning the cases of RFID and WSN technologies

In this chapter, the research findings concerning RFID and WSN technologies are presented. These research results are from the original articles and other related articles by the author. The perspective for introducing the research findings is again the business opportunity creation view combined with innovation capability enhancement. In this chapter, the technology advances are introduced. The evaluation of business opportunities of all these ten research results is presented in Chapter 4.3. The evaluation of innovation capabilities in RFID and WSN technologies is presented in Chapter 4.4.

The list of the research findings of RFID and WSN is presented in TABLE 11. The first three of the research findings are related to RFID-based mobile robot navigation including obstacle avoidance. After these, two results concerning the use of RFID technology in production are introduced. The research findings of the location aware system and mobile user interface are related to both RFID and WSN technology. The last three research findings deal with the use of WSN in instrumentation for harsh industrial environments, indoor positioning and mobile robot navigation.

TABLE 11 Research findings concerning the cases of RFID and WSN technologies

RFID_WSN1	RFID-based navigation of a mobile robot
RFID_WSN2	RFID-based navigation of a transporter
RFID_WSN3	RFID-based obstacle avoidance
RFID_WSN4	RF-identification of objects in harsh production environments
RFID_WSN5	RFID-based tracking and tracing in production
RFID_WSN6	Location aware system with RFID or WSN
RFID_WSN7	Mobile user interface with RFID and WSN
RFID_WSN8	Reliable WSN-based instrumentation for harsh industrial environments
RFID_WSN9	WSN-based indoor positioning
RFID_WSN10	WSN-augmented navigation of a mobile robot

RFID-based navigation has been quite rarely applied in autonomous or semi-autonomous navigation from point A to B, which is one of the main control problems of ***a mobile robot***. If a robot is used with a remote control by the user, the fundamental task in the remote control of the mobile robot is to navigate it to the goal as quickly as possible with a minimum number of collisions. This requires that plenty of information about the environment should be visualized for the user. The RFID-augmented smart environment has been used to give information about the environment for the mobile robot and to the user. RFID tags were placed on the floor for recalibration of the position of the robot. In the tests there were almost 100 tags on the floor of the laboratory office to increase the accuracy of the mobile robot. RFID tags were also used to give information about the environment; these tags included obstacle tags, and they were positioned at a height of 60 cm. The tags in the experiments were of the UHF type. The mobile robot carried the UHF reader with three antennas: one pointing front, one back and one down. The mobile robot used in these experiments was a laptop mobile robot called Elviira, constructed on the basis of Evolution Robotics' ER1 platform. Remote control was experimented with different mobile devices. A tablet PC was chosen as a mobile device for usability tests because it had a larger display than others, but it was still easily held in hand. Remote controlled navigation was implemented in three alternative ways: a camera with the robot's own position information, RFID information with the robot's position information, and the robot position information augmented with both RFID and camera technology. FIGURE 25 shows the basic components used in RFID-based navigation

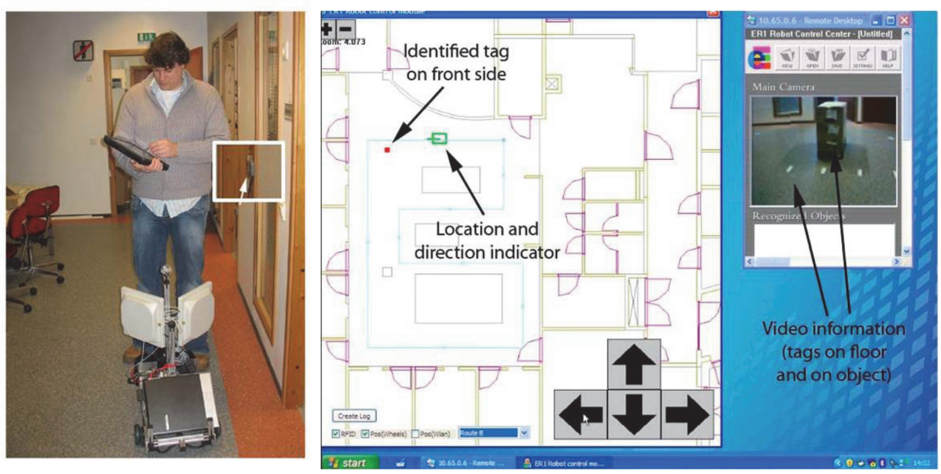

FIGURE 25 RFID-based navigation of the CENTRIA's mobile robot

RFID-based navigation has recently been developed also in cooperation of CENTRIA's research team and a Japanese research group from Ochanomizu University. In that cooperation, the so-called ObjectFinder was developed and it was later updated to ItemFinder. This is an application which has been implemented both in the Ochanomizu University and CENTRIA Wifibot robots. This robot is able to help users find items in a room by using UHF-based RFID technology and the robot's laser scanner. RFID technology has been used for detecting objects and giving additional information for navigation, which is mainly based on laser scanning and the robot's internal position measurements. (Luimula, Pieskä, Jämsä, Siio & Komatsuzaki 2011; Komatsuzaki, Tsukada, Siio, Verronen, Luimula & Pieskä 2011).

Experiments from RFID-based mobile robot navigation are presented in original articles V, VIII and IX, and in four conference articles (Luimula et al. 2007; Pieskä et al. 2007; Luimula et al. 2011; Komatsuzaki et al. 2011).

RFID-based navigation has also been applied for outdoor applications ***of a transporter*** working in the wood industry. The smart wheel loader developed is based on a location aware system platform, which has a map about the outdoor warehouse area and a GPS system for localization. RFID technology is used both for pallet identification and positioning inside the 27 covered warehouse buildings. In the technology demonstrations of this study, when the wood packages were left inside the warehouse, GPS technology could not be used. Therefore, the location of that storage point was read from the RFID tags placed in the ceiling (FIGURE 26, left). RFID tags were placed in the ceiling because in harsh winter conditions the spike tires in the wheel loader prevented the use of floor tags. One antenna was placed in the roof of the wheel loader's cabinet (FIGURE 26, right). In the tests, all RFID tags could be read from the ceiling. In the first experiments there was some overlapping with the neighboring storage point's RFID tags, but that could be solved by decreasing the signal level of the transmitter.

The main idea in the developed solution is that the operator neither has to leave his wheel loader to scan the product labels nor manually give information about the unloading point and package leaved there. Currently the operator must first halt the wheel loader, hop off and manually scan the bar codes located on the product packages before loading or unloading them. The developed navigation concept for transporters also fulfills the definitions of *proactive combination innovations* (see FIGURE 2 in Chapter 1.4). It is a new type of solution, which can also change the operator's work task and transportation process in the factory. It also provides a possibility for organizational innovations because there is no more need for the personnel to unpack information from the data collectors of the transporter drivers and feed them in the enterprise database. The proactive view was taken into consideration in the development process: the developed RFID based solution is currently too expensive to be used only in warehousing with tens of thousands of items. In the future, if also production, suppliers or customers can utilize RFID information, it will be a profitable solution for all partners.

Examples of the RFID based transporter navigation experiments are presented in original article V and in the conference articles (Luimula et al. 2007, Pieskä et al. 2007, Pieskä et al. 2009).

FIGURE 26 RFID-based navigation of a transporter inside the warehouse

RFID-based obstacle avoidance solutions were tested in experiments with CENTRIA's ER1-based mobile robot, with the Wifibot mobile robots in the CENTRIA - Ochanomizu University cooperation project, and with CENTRIA's service robot Kaveri. When obstacles are marked with RFID tags, the robot takes care of collision avoidance and also creates a strategy about the best way how to pass the obstacles. The obstacles in the experiments could be stationary or moving objects. The usage of RFID technology is limited in cases where obstacles could be marked beforehand. Experiments from RFID-based obstacle avoidance are presented in original articles V and IX, and in the conference articles (Luimula et al. 2007; Luimula et al. 2011; Pieskä et al. 2007).

RF-identification of objects has been tested ***in harsh production environments*** in a pipe production factory, in a metal factory using electrolysis, and in maintenance tasks of a peat power plant. The main research challenges in these cases included ensuring adequate RFID tag mounting on metal objects or close to them, and coping with the harsh conditions of the industrial environment. As a consequence, one task was to develop protection methods allowing usage of common low-cost RFID tags in harsh conditions. This development led to a patented solution (Seppälä & Pieskä 2008) where multilayered heat-resistant RFID tags can be used in surface treatment processes where temperatures can temporarily rise up to several hundred degrees.

RFID technology was also used for *smart touch* type actions where the user can easily get the essential information about products just by bringing the handheld RFID reader near the object (FIGURE 27). When the RFID reader was integrated into the production management system, the integrated solution could provide guidance efficiently after identification. For example, the embedded application could open the right drawing just in seconds even if the electronic manual could be hundreds of pages in PDF format. Normally this could have taken time from the user from tens of seconds to several minutes when using manual search. The smart touch type actions were experimented in getting information of products or transport case contents. The results could be drawings or 3D models for work instructions or instructions assembly, processing or maintenance instructions.

FIGURE 27 RFID-based smart touch actions tested in the laboratory and verified in the industrial environment of pipe production

Experiments from RF identification of objects in harsh production environments are presented in original article VI and in conference articles (Luimula et al. 2007; Luimula, Pieskä, Pitkäaho & Tervonen 2009; Pieskä et al. 2007).

RFID-based applications were extended also to ***tracking and tracing in production***. Pipe production required an exceptionally long period of testing because it was a very challenging environment for RFID technology: there were a lot of metal surfaces, dust, high temperatures, and vibrations. Testing of RFID technology started in separate work cells but continued to tracking and tracing of pipe components through the whole production process and to delivery and transportation to the customer. RFID-based tracking and tracing were also tested in anode tracking to get maintenance information about the condition of anodes when they were in the washing lines. RFID technology was integrated successfully with computer vision technology in experiments. One technology demonstration carried out in the laboratory environment also integrated vision, barcode and RFID technologies in warehouse management. A mobile robot functioned as a transporter carrying the objects with RFID tags through the RFID gate which recognized them. The vision system was placed above the warehouse area. This technology demonstration of warehouse management was also saved in the CENTRIA virtual digital media library and can be viewed in YouTube (search *centriard*).

Examples of experiments from RFID-based tracking and tracing in production are presented in original article VI and in the conference articles (Luimula et al. 2007; Luimula et al. 2009; Pieskä et al. 2007).

Location aware systems with RFID or WSN technologies can remarkably increase the flexibility and applications of mobile work machines. Mobile robots and transporters need location awareness to be able to carry out tasks in dynamic environments. CENTRIA's research team has developed its own software platform called Locawe (Luimula 2010; original article V) for mobile location-aware systems. The Locawe platform is a client-server solution for outdoor and indoor conditions. The platform consists of mobile units and servers for services such as tracking and communication. It is possible to create user interfaces which include video, location and identification information on the map or on the floor plan. Locawe has been used, as discussed earlier in the remote navigation of a mobile robot in a RFID augmented environment. Locawe can be used with various software and hardware combinations. These features include the use of GPS, RFID and WSN technologies. These have been tested in several field experiments and industrial pilots. Locawe also has support for 3D map-based applications.

Examples from experiments of location aware system with RFID or WSN are presented in original articles V, VI and VIII and in the conference articles (Luimula et al. 2007; Luimula et al. 2011; Pieskä et al. 2009).

Mobile user interfaces with RFID and WSN provide new possibilities for human robot interaction and control of other work machines. The recent developments in the area of ubiquitous computing have made the construction of different kinds of smart environments possible. These smart environments often contain RFID and WSN technologies, and often there is a need for implementing hybrid solutions utilizing many technologies. This makes the software development for these applications challenging. It is still a demanding task to design an efficient user interface which gives the user information both about the location and movements of the robot or work machine and also about the environment in which the robot or work machine is located. There is quite a variety of mobile devices and software platforms and languages, which have been used during the projects of this study. Some of these devices are presented in FIGURE 28 while more examples can also be found in FIGURES 18, 21, 22, 25 and 27. The experiments have shown that in every case the usability of devices has to be tested carefully because without knowing the details of the work task, it is impossible to select the right device and develop an embedded application for it.

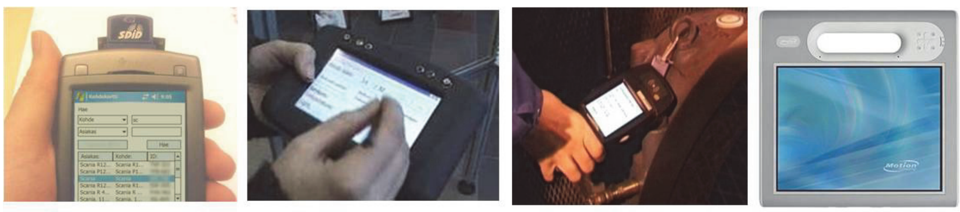

FIGURE 28 Examples of mobile devices used to develop mobile user interfaces with RFID or WSN technology

Examples of the developed mobile user interfaces with RFID and WSN technologies are presented in original articles V-VIII and in the conference articles (Luimula et al. 2007; Luimula et al. 2009; Pieskä et al. 2007; Pieskä et al. 2009).

Reliable WSN-based instrumentation has for a long time been a wish from the industry especially ***for harsh industrial environments*** where cable damages cause much trouble. In the projects of this study, successful experiments have been carried out in demanding environments of the metal industry where metallic fences, toolboxes and racks make continuous static disturbance and moving machines cause dynamic disturbances. Also work activities such as welding or plasma cutting may cause high electromagnetic disturbances. However, in the experiments of this study, they did not prevent the throughput of radio packets in wireless sensor networks. For example, the plasma cutting caused a reduction of about 10 dB in the received angle measurement signal power, which was still on a satisfactory level for data transmission.

Examples from experiments of reliable WSN-based instrumentation for harsh industrial environments are presented in original articles VI-VIII and in three conference articles (Luimula et al. 2007; Luimula et al. 2009; Pieskä et al. 2007).

WSN-based solutions can also be used for ***indoor positioning,*** which is a key factor for successful navigation of mobile robots or work machines inside buildings. Positioning is usually difficult in harsh industrial environments where a great deal of metallic parts can prevent or reflect signals. Steel walls, plates in storage areas, and sheet metal stacks cause reflections and prevent line-of-sight propagation of the signal. Welding machines and plasma cutters cause noise and interference to radio waves. Most of the received signals are reflected and a straight route near the floor cannot be used. In the collaboration projects of this study, a reliable positioning system was developed using a 2.4 GHz wireless network with Chirp Spread Spectrum (CSS) modulation. One advantage of CSS technology is that due to a relative large bandwidth (80MHz) CSS pulses are insensitive on electromagnetic distortion and without multi-path fading.

One focus in the WSN-based technology development was also user interaction. The statuses of sensor nodes were visualized for the user in a 3D map-based user interface, which was created on CENTRIA's Locawe platform. The system was successfully tested first in CENTRIA's production engineering laboratory and after that in two metal factories, where plasma cutters and welding machines commonly cause radio interference (FIGURE 29). The results were promising and showed that the proposed method can be applied for the coarse indoor positioning of mobile robots, autonomous transporters or working machines. It can be part of a hybrid positioning system, where accurate positioning is based on the sensor fusion of the proposed coarse positioning, 2D or 3D map data, the robot's own sensor data and external sensor data from smart sensors such as vision systems, optotrackers or accurate laser scanners. One advantage of WSN based indoor positioning is that it does not need fixed structures because it also provides a possibility to use temporary sensor networks.

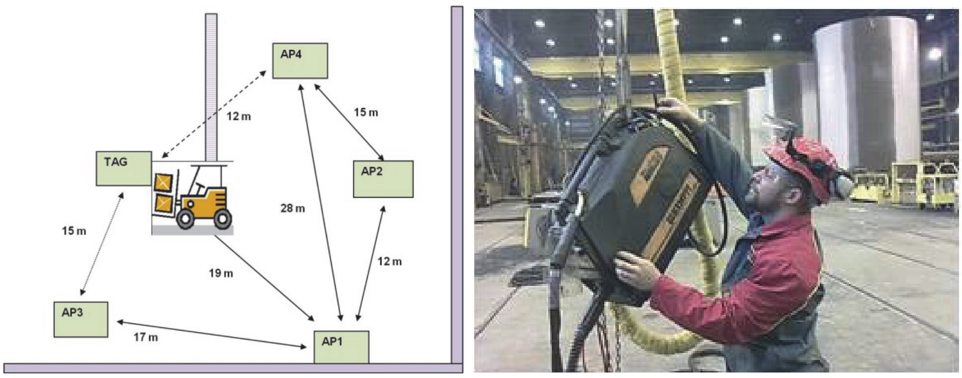

FIGURE 29 Examples of measurement arrangements for indoor positioning in a heavy metal factory

Details of the WSN-based indoor positioning solution and experiments are presented in original articles VII-IX and in two conference articles (Jämsä, Luimula, Pieskä & Saukko 2012, Luimula et al. 2007; Pieskä et al. 2007).

WSN-augmented navigation of a mobile robot was tested in CENTRIA's production engineering laboratory with CENTRIA's mobile robots (see FIGURES 20, 22, and 25). WSN-augmented navigation used CSS technology as a coarse positioning system for the robot, and it was supplemented by the robot's own positioning sensors and positioning systems for more accurate positioning and navigation. The sensors included the robot's internal sensors (odometer and angle measurements) and a laser scanner. The accurate service robot movements used Kompai's navigation software (Granata et al. 2010). In Kompai robots, the laser sensor is placed on the lower part of the robot. This means that only the obstacles situated at the height of the laser plane (about 60 cm) are detected. This has to be taken into account in path planning and obstacle detection, which may need additional sensors in many environments.

The background and experiments of WSN-augmented navigation of a mobile robot are presented in original articles VI-IX and in the conference articles (Jämsä et al. 2012; Luimula et al. 2007; Luimula et al. 2009; Pieskä et al. 2007).

4.3 Evaluating business opportunities of RFID and WSN research results

The evaluation of the business opportunities of the RFID and WSN research results was carried out with the same method and by the same focus group of experts as the robotics and simulation research results (sees Chapter 3.3). Evaluation of business opportunities in RFID and WSN technologies is presented in TABLE 12, and the evaluation of technological innovation capability of these areas in FIGUREs 30 and 31. The same kind of evaluations concerning RFID and WSN technologies were presented in Chapter 3.

The structure and form of TABLE 12 is similar to TABLE 10, which presents the evaluation of robotics and simulation research results. In TABLE 12, the first column lists the ten main research results presented in Chapter 4.2. The second column refers to the original articles where they have been discussed. The third column presents business potential assessments using the same scale as used in TABLE 10. The fourth column conveys the stage of practical implementations with the same scale used in TABLE 10. The fifth column presents the assessment of the technology development need by suppliers or research groups. The sixth column estimates how much SMEs would need to invest in the technology to make the results usable for their business. The seventh column shows the results of a consideration how much SMEs should increase their competence to enable the use of these new solutions. The fifth, sixth and seventh columns use again the same scale (from 1 to 5) as TABLE 10.

A quick look at TABLE 12 reveals that the best business potentials can be found in the same way as in TABLE 10: the higher number of marks in columns three and four and the lower numbers in columns 5, 6 and 7, the better business opportunities the research result has. Again, the evaluation is yet not so straightforward because of the interconnections between the objects considered. Three of the research results have already been used in production for some period, but none of them has directly led to wider use. However, during the course of this study, two new firms were established, which had got positive assurance from the technology demonstrations in RFID and WSN technologies. The applied research projects of this study have partly contributed to the development of new products in the collaborating companies. These products belong to the areas of location aware systems, mobile user interfaces and WSN-based instrumentation.

TABLE 12 Evaluation of business opportunities based on RFID and WSN research results

RFID & WSN Business Opportunities for SMEs	Relating articles	Business potential for SMEs	Stage of practical implemen-tations	Technology development needed by suppliers or research	Investments needed for technology in SMEs	Increase of competence needed in SMEs
RFID-based navigation of a mobile robot	V,VIII	**	++	4	3	4
RFID-based navigation of a transporter	Ch4,V	**	++	4	3	4
RFID-based obstacle avoidance	V, VIII	**	++	3	2	3
RF-identification of objects in harsh production environments	VI,Ch4	****	+++	3	4	3
RFID-based tracking and tracing in production	VI, Ch4	****	+++	4	4	3
Location aware system with RFID or WSN	V, VI, VIII	***	++++	3	3	2
Mobile user interface with RFID and WSN	V-VIII, Ch4	****	++++	2	2	2
Reliable WSN-based instrumentation for harsh industrial environments	VI-VIII	****	++++	3	3	3
WSN-based indoor positioning	VII, VIII	*****	+++	4	4	4
WSN-augmented navigation of a mobile robot	V, VIII	**	++	5	4	4

	Business potentials for SMEs		Stage of practical implementations		Others
*	=Small or no business potential	+	= Method tested only in laboratory	1	= Small
**	=Latent business potential	++	=Demonstrations in laboratory or in production	2	= Minor
***	=Moderate business potential	+++	=Pilot cases in production environments	3	= Moderate
****	=Good business potential	++++	=Have been used for some period in production	4	= Major
*****	=Excellent business potential	+++++	=Already in wide use	5	= Extensive

RFID-based navigation of a mobile robot or ***a transporter*** and ***RFID-based obstacle avoidance*** are all business areas which provide the best business potential if SMEs can create partnerships with the control system providers for mobile robots or transporters. Practical implementations of RFID-based navigation have been during this study only demonstrations in a laboratory or in the production sites of companies. The experiments show that RFID-based navigation most often needs customization and technological development when it is applied in new machines or new environments. The lowest prices of RFID tags have dropped to tens of cents which means that the investments needed for the technology can stay on the minor level (obstacle avoidance) or moderate level (RFID-based navigation). RFID readers are currently still relatively expensive, which increases the whole investments costs. SMEs have currently little or no readiness for business operations with RFID-based navigation technologies, which means that they need a major increase of their competences.

RFID-based navigation systems may in the future be examples of technologies which will be part of transformation from manufacturing to the service process, which was discussed earlier in Chapter 2.6. A customer may require a certain capacity of an autonomic transportation service per work shift and is not willing to buy transporters, robots or their navigation systems. This means the networking with mobile robot or transporter dealers and control system providers is a vital condition for business of SMEs.

RF identification of objects in harsh industrial environments is a business area where the SMEs could find potential customers with special RFID tag based technologies. These special tags could be applied to certain industrial environments or applications. They could for example endure high temperatures, surface treatments or toxic materials. RFID tags have been tested successfully during this study in the pilot experiments in harsh industrial environments of heavy metal factories. The experiments, including a patented solution (Seppälä & Pieskä 2008), show that solutions can also be found for hard environmental challenges with reasonable technology development. With skilled partners, only a moderate increase of competence is usually enough for SMEs to work successfully with RFID technology in harsh environments. Severe conditions usually increase the investment costs to a major level.

RFID technology can be extended from one work cell to ***RFID-based tracking and tracing in production***. This brings more requirements for technology development because the local RFID solutions must be integrated to the ICT system of the company. Otherwise the needs and business potential are at the same level as for other RFID solutions for harsh industrial environments. The developed RFID-based tracking and tracing solutions have been tested successfully in the pilot cases during the study.

Location aware systems with RFID or WSN technologies have progressed to solutions which have already been in use at production sites, and their business potential can be estimated as moderate. If SMEs start with a platform like CENTRIA's Locawe (Luimula et al. 2009; Luimula 2010), the need for technology development and investments stay on a moderate level, and the need to increase competence is minor.

Location aware systems with RFID or WSN technologies have often been integrated with ***mobile user interfaces*** which increase their usability and flexibility. The developed mobile user interfaces can also be used for many other tasks including monitoring, instructing and maintenance. This raises their business potential assessment from moderate to good. Most mobile user interface devices in the market are no more prototypes, and there is a minor need for technology development or increase of competence in the SMEs to apply them. The prices of mobile devices have decreased in the last few years so that the investments needed for the technology can be assessed as minor.

Reliable WSN-based instrumentation has a good business potential especially in harsh industrial environments where the frequently occurring cable damages are troublesome. Successive practical implementations have given a positive sign for the initial stage SMEs using WSN technology. Technology development, investments and increase of competence in the SMEs can all be estimated moderate because software tools and instructions for applying WSN components have developed more to become user-friendly, and their component prices are relatively low. Experiments with wireless sensor networks have also opened collaboration channels from CENTRIA to the University of California at Berkeley with bidirectional research exchange.

WSN-based indoor positioning is assessed to have an excellent business potential. There is an outstanding need for reliable and accurate indoor positioning technology in the industry where mobile work machines and mobile robots are more common than in the last few decades. In the metal industry, indoor positioning is usually difficult because a lot of metallic parts can prevent or reflect signals and machinery causes interference and noise. Based on the practical experiments of this study WSN-based indoor positioning need still major technology development to be accurate and reliable enough. As shown by the experiments of this study, wireless sensor networks can already be applied for coarse positioning, and they can be used as a part of hybrid positioning methods. The accuracy and reliability of WSN-based positioning methods have developed significantly in the last few years, and this development is expected to continue. Needs for investments and the increase of competence are estimated to be on the major level, even if also the moderate level could be possible for some products on the market.

WSN-augmented navigation of a mobile robot is assessed to have currently a latent business potential because there are still many technological questions to be solved before it can be utilized reliably in everyday industrial work environments. However, the practical experiments of this study give a positive sign about the possibilities of this technology. Needs for investments and the increase of competence are estimated to be on the major level after the extensive level technology development needs are fulfilled. WSN-augmented navigation may face the same transformation from manufacturing to the service process which was discussed with RFID-based navigation. Collaboration and networking with mobile robot dealers and control system providers will then be extremely important for business of SMEs.

4.4 Evaluating innovation capabilities in RFID and WSN technologies

The evaluation of the innovation capabilities of the SMEs in RFID and WSN technologies was carried out by the same focus group of experts as evaluations discussed in Chapters 3.3, 3.4 and 4.3. The results are presented in FIGUREs 30 and 31. The inner diagrams present the situation in 2005 when the applied research collaboration projects were started in RFID and WSN technologies. The outer diagrams present the corresponding situation evaluated in April 2011. The ten key factors were evaluated the same way as with robotics and simulation in Chapter 3.4. The five first came again from the technological innovation capability needed in the applied research cases of this study. These five evaluation objects were: wireless technology in industrial applications, wireless tracking and tracing in production, wireless positioning and navigation, location aware technology in wireless applications, and mobile user interfaces in wireless applications. The next four came again from the undergoing transformation of business as discussed by Prahalad & Krishnan (see Chapters 1.1, 2.6 and 3.4): convergence of technology, digital competitiveness, ubiquitous connectivity, and globalization. The last three are connected with collaboration, helping, co-creation and creative social processes (see Chapters 2.4 and 3.1, 3.4 and 4.1): networking with suppliers, networking with R&D units, and cooperation with customers.

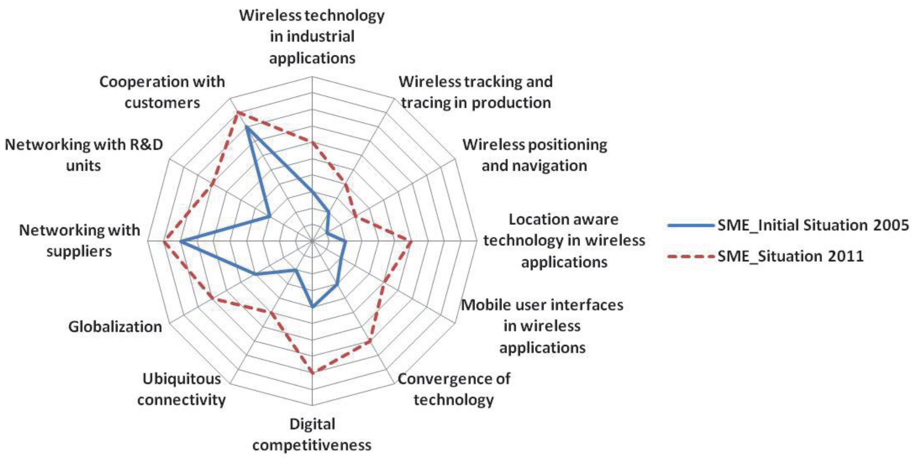

FIGURE 30 Development of SME innovation capability in RFID and WSN technologies

The radar chart in FIGURE 30 shows how the innovation capabilities of collaborating SMEs have developed during this study in the area of RFID and

WSN technologies. In the initial situation, RFID and WSN technologies were new for the SMEs which can be seen from the inner line assessment. Wireless technologies have become more common for SMEs; for example, wireless local area networks (WLAN) have been taken into use, and wireless monitoring has become possible for some production equipment. The use of wireless tracking and tracing is still unusual with SMEs. Wireless positioning and navigation technology is even more rare, and in these first SMEs, it is currently only on an experimental level. Wireless location aware solutions and mobile user interfaces are also not yet common in SMEs, but some collaborating SMEs of this study have succeeded in launching new products with location aware capabilities.

In the next four topics, the initial situation with SMEs was much lower in RFID and WSN technology than for robotics and simulation. Some SMEs had started to test their first web-based monitoring and maintenance tools to enhance their digital competitiveness and globalization, but ubiquitous connectivity and convergence of wireless technology were on a low level. Digital technology and globalization have become necessities for the SMEs to be able to work in international supply chains; wireless technologies have increased their flexibility for using digital solutions in these global chains. The pilot projects and technology demonstrations in collaboration projects have brought a great deal of information for SMEs on how RFID and WSN technologies could enhance ubiquitous connectivity and technology convergence. Some SMEs have taken moderate steps in convergence of RFID or WSN technologies with their own technology competences.

In the last three topics, the SMEs initially had a long experience in networking with customers, and also many of their familiar suppliers could provide wireless solutions. This collaboration has developed further when the SMEs have got more information and competence in RFID and WSN technologies. In the beginning, the SMEs had very little experience of cooperation with R&D groups in RFID or WSN technologies. Networking with R&D units have developed a great deal during this study and not only with CENTRIA's research team but also with other research groups in VTT and the universities. Internationalization has been a big change also in networking with these wireless technologies: more suppliers and customers are from abroad and the SMEs have learned to gather information from international web sites, companies and exhibitions.

The radar chart in FIGURE 31 shows how the innovation capabilities have developed in CENTRIA's applied research team in RFID and WSN technology related topics during this study.

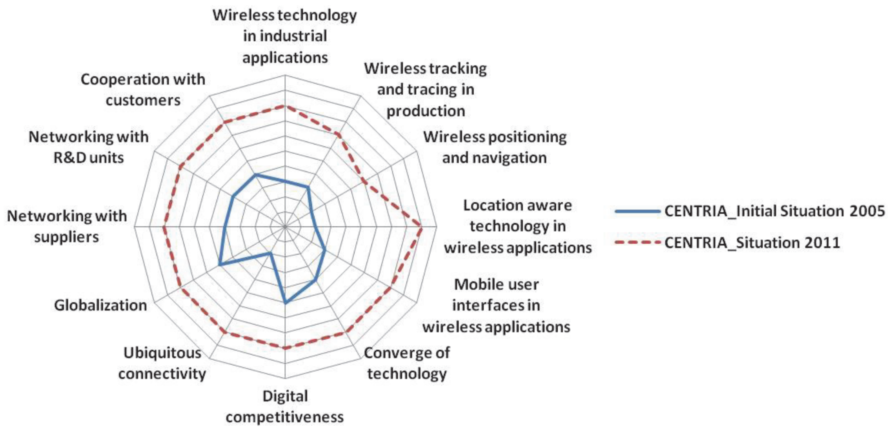

FIGURE 31 Development of CENTRIA's innovation capability in RFID and WSN technologies

In the initial situation, CENTRIA's researchers had basic knowledge about wireless technologies but the practical knowhow to utilize them in the SMEs applications was far from sufficient. In 2005 CENTRIA started to mix expertise and capabilities of different research teams. Experts from mobile programming, mobile user interfaces, location aware technologies, smart environments and hardware and software design for wireless sensor networks were used in the collaborative production automation projects with the SMEs. This extended expertise was further supplemented with cooperation networks consisting of suppliers, SMEs and research organizations, especially of the University of Oulu and VTT. The advantages of this development can be seen in FIGURE 31: innovation capability in wireless technologies is assessed to achieve a good level. The positive results which can be seen in FIGURE 31 could not have been reached without mixing the expertise and capabilities.

In the next four topics, CENTRIA's applied research team had made the biggest steps in ubiquitous technology where it had relatively little knowledge in the initial situation. The knowhow of convergence of technology, digital competitiveness and globalization have made good progress from a satisfactory level to a good level mainly because of the experience from the collaboration projects.

In the last three topics, CENTRIA's applied research group had to build the networks in wireless technology during this study with the SMEs and their customers, suppliers and other R&D groups. CENTRIA's research personnel has learned a great deal from the collaborating SMEs about networking with customers and suppliers while it has helped the SMEs in networking with R&D groups. In RFID and WSN technologies, it is important to work not only with the collaborating SMEs but also with equipment and software suppliers and other R&D groups because this clearly shortens the delay times from ideas to innovations.

4.5 Summary of Chapter 4

The collaborative research work carried out in cases of RFID and WSN technologies was presented in this chapter in the same way as in the previous chapter which dealt with robotics and simulation. The chapter began with a general description of the research progress of RFID and WSN technologies in this study. The main technology advances and ten research findings of RFID and WSN technologies in the original articles were summarized in TABLE 11. The practical results were visualized in several figures. The business opportunity evaluation process of RFID and WSN research findings was described and the results were presented in TABLE 12. The evaluated factors of the research results and the taxonomy used in evaluation are the same as with robotics and simulation as described in Chapter 3. The business opportunity evaluation shows that half of the research findings (5) were assessed to have good or excellent business potential. Three of the research results are already used in production by the SMEs of this study. The innovation capability assessment of the SMEs and the applied research team was described and the results presented in FIGURE 30 and in FIGURE 31, respectively. Ten key innovation capability factors were evaluated. The five technological innovation capability factors were different from those used with robotics and simulation. The four evaluated factors from the transformation of business and three from the creative social processes were the same with robotics and simulation, but the evaluation was based on different pilot cases and different firms. The figures show that innovation capability has again made remarkable progress during the study in all the key factors both in the SMEs and in the applied research team.

5 CONCLUSIONS AND DISCUSSION

5.1 Main research findings

The focus of this study has been the challenge of how to enhance the competitiveness and innovation capability of SMEs and the applied research group. The first research question with its subquestions as presented in Chapter 1.2 was:

Q1: *What business opportunities have risen from the collaborative research projects involving the applied research team and SMEs in the selected areas?*

What business opportunities have risen from the robotics and simulation research cases and to which extent have they already been utilized?

What business opportunities have risen from the Radio Frequency Identification (RFID) - and Wireless Sensor Network (WSN) -based wireless technology cases and to which extent have they already been utilized?

In Chapters 3 and 4, twenty-two research results were presented and their business opportunity evaluated. Twelve of them came from the fields of robotics and simulation and ten from the RFID and WSN technologies. Six of the robotics and simulation results and three of RFID and WSN results have already been applied successfully in production in SMEs. Collaborative applied research has led to two patented solutions and to one utility model. Altogether more than 50 SMEs were interested to participate in applied research projects; for most of them participation in R&D projects was a new experience. The technology demonstrations and pilot cases paved the way for applying new technology, especially in enterprises which were in their starting phases. The technology demonstrations and pilot projects were also utilized for educational purposes in order to increase knowledge about technology trends and to enhance generic abilities and proactive learning processes. Detailed information about the solutions developed and demonstrated can also be found from the articles presented in the List of Original Articles and in other author's references.

One research outcome was the creation of CENTRIA's collaborating network with SMEs, suppliers and other R&D units. In the beginning, cooperation with the R&D units was limited to national groups but it has extended during the study to include research groups in several European countries and also research groups from USA and Japan. This cooperation network contributed to knowledge transfer in a crucial way, and this in turn resulted in the collaboratively created business opportunities.

The second research question with its subquestions as presented in Chapter 1.2 was:

Q2: *How has collaborative applied research increased innovation capability and what are the main factors to enhance innovation capability in SMEs and small research groups?*

How has collaborative applied research increased the innovation capability of the SMEs of this study?

How has collaborative applied research increased the innovation capability of the applied research team of this study?

What are the main factors to enhance the innovation capability of SMEs and small research groups based on the findings and experiences of this study and compared with related literature?

Answers to the first two subquestions were presented in Chapters 3.4 and 4.4 where FIGUREs 23, 24, 30 and 31 summarize the results from the evaluation of how innovation capabilities have been enhanced in SMEs and in the applied research team. All the assessed innovation capability objects have progressed remarkably during the projects in this study. In the figures, the assessed objects can be divided into three categories: starting from up and moving clockwise, the first five belong to *technological innovation capability*, the next four to *transformation of business* based on the concepts presented by Prahalad and Krishnan (see Chapter 1.1) and the three last to *creative social processes*.

In the SMEs of this study, the biggest steps forward in *technological innovation capabilities* of *robotics and simulation* technologies were taken in robot programming and virtual modeling and simulation. The innovation capabilities of these technologies have progressed in SMEs to a level where several companies can currently apply them in their production. In the *transformation of business,* digital competitiveness and ubiquitous connectivity have progressed most and also are now in the development stage where the several SMEs use them in their production. In the *social creative processes* SMEs had frequent collaboration with customers and suppliers already in the initial situation and this has remained and developed further. Networking with R&D units has taken big steps from the initial low level.

The biggest development steps in the *technological innovation capabilities* of *RFID and WSN technologies* in SMEs were taken in location aware technologies, but also other wireless automation applications have developed remarkably from the low initial level. In the *transformation of business*, convergence of technology has taken the biggest steps due to the rapid development of mobile multifunctional devices. In addition, digital competitiveness has progressed significantly and is currently in a development stage where SMEs can utilize it in their everyday operations. In the initial situation *of social creative processes*, the SMEs depended in the RFID and WSN areas only upon the experience of suppliers or customers, but now they can utilize also R&D units. However, there is much to do in these processes and also in most of the evaluated areas because the initial level was lower than in robotics and simulation technologies, and applied research projects in RFID and WSN technologies started only in 2005.

In the applied research team, *technological innovation capabilities* of *robotics and simulation* advanced most in user interface development and service robot technology; the latter mainly due to its low initial level. These both areas are in the focus of the SME's innovation challenges as discussed in Chapter 2.6. User interface development and robot programming advanced to an expert level where the applied research team can now provide solutions also to very demanding problems of SMEs. In the *transformation of business,* ubiquitous connectivity in robotics has developed most due to mixing the expertise and capability of three formerly different teams of CENTRIA; the initial level was also very low in the area of ubiquitous robotics. Digital connectivity, convergence of technology and globalization have developed to a level where the applied research team can provide help for the SMEs in most problems they encounter. In the *social creative processes*, networking with other robotics and simulation R&D units developed most and it is in the same advanced level as networking with supplier and cooperation with customers.

As to the applied research team, the most impressive development steps in the *technological innovation capabilities* of *RFID and WSN technologies* were taken in location aware technologies, which developed to an expert level. Also mobile user interfaces and wireless solutions in industrial applications reached a level where the applied research team can provide help for the SMEs in most problems they encounter. In the *transformation of business*, ubiquitous connectivity developed most and it is now one of the leading concepts of the applied research team. The s*ocial creative processes* of the applied research team in RFID and WSN technologies developed from the low initial level to an effective collaboration level as a result of successful collaboration in the applied research projects.

The results of the collaborative applied research projects also brought new possibilities to develop engineering education in the university of applied sciences. The advanced equipment and software obtained in the projects gave the students a possibility to study with the newest high-technology equipment. The educational processes were able to be directed for learning by doing (Kolb 1984), open innovation (Chesbrough 2006), meta-learning (Vilalta & Drissi 2002) and meta-engineering (Callaos 2008). The new approach for learning processes can be described as a combination of learning-to-learn and learning-to-engineer. The students participated in projects mostly in the final phases of their studies and when they have moved to local SMEs after graduating, they have introduced to their SMEs the knowledge about the possibilities of new technologies. The laboratory environments developed during this study to *living lab* (Følstad 2008) direction where not only the students but also personnel from firms can come to test the possibilities of new technology. This opened new channels for collaboration of the SMEs and the applied research team.

Based on the experiences of this study and compared with related literature (for example Prahalad & Ramaswamy 2004; Sarasvathy et al. 2003; Schein 2009; Shane & Eckhardt 2003; Wong 2006), the main factors to enhance innovation capability in SMEs and small research groups are collaboration, co-creation, trust, and helping relationships combined with technology and business knowledge, in addition to the proactive needs of current and future customers. FIGUREs 32 and 33 show how the collaboration developed considered from the bird view. The triangle connecting technological innovation capability, transformation of business and creative social processes was quite small in the beginning because cooperation of SMEs and the applied research persons was rare and random. With collaborative applied research projects the triangle area has widen remarkably. The skylark above the fields as discussed in Preface can sing more cheerfully when it sees the area of new grass growing.

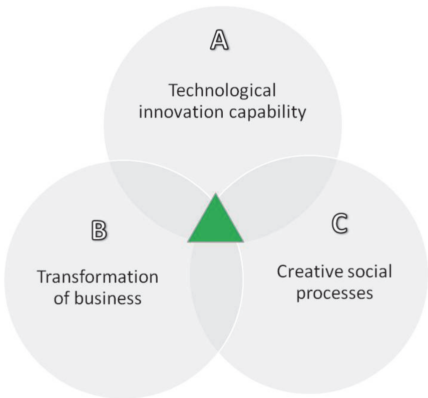

FIGURE 32 Initial situation from a bird's view: rare and random collaboration of SMEs and the applied research staff

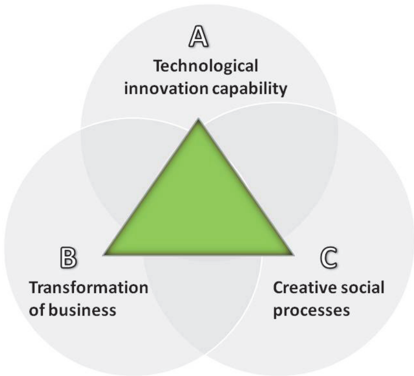

FIGURE 33 Collaborative applied research projects extending the common triangle area

The most significant development in the social creative processes took place in the collaboration of the applied research team and SMEs in the spirit of helping relationship and collaborative culture as discussed in Chapter 3.1. This led to the situation where SMEs and applied research teams better understand the dual push and pull perspective of successful innovating. The push comes from new technologies and technological innovation capability, and it can be described as an enabler and resource-based driver. The pull comes from the transformation of business with more and more globalizing market trends, and it can be described as a market-based driver. The creative social processes include both push and pull components and their role is catalytic and collaborative. The spirit of helping relationship and collaborative culture has created an innovative interaction which has led to successful research results. There has been a definite turn of operations to collaborative interaction. Collaboration made it possible to match technology push and market pull. The dual perspective was also used to match theory and practice in SME-oriented applied research.

5.2 Contributions of the study

This study contributes to filling the gap that exists in the literature of applied research: multiple technology push and market pull views with interaction in the actual research collaboration have not yet been reported. Technical studies usually concentrate on technology solutions and methods while economics and business studies are focused on business opportunities or business model creation. As discussed in Chapter 1.5, this is a mixed multi-case, multiphase research study where action research and developmental research are also integrated. This study can be considered to follow the principles of the novel entrepreneurial method proposed by Sarasvathy and Venkataraman (2011).

This study also has a strong practical contribution in technological issues: 22 research results with advanced technology were presented and their business opportunities evaluated. Almost half of them have already been use in production of the collaborating SMEs. Patented solutions created during the collaborative applied research projects provide evidence of practical innovativeness.

The contribution of developing the collaboration with SMEs and an applied research team results from the introduction of helping relationships and the construction of a collaboration culture within the team and with the SMEs, supplier and other R&D groups in Finland and abroad.

When considering the competitiveness analysis of Finnish SMEs based on the Global Competitiveness Index (see Chapter 2.2), the endeavors of this study have positive influence on the issues which need further development: FDI and technology transfer and local supplier quantity (TABLE 5).

The contributions of this study can be examined from three TPE-perspectives presented in FIGURE 34: **T**heoretical, **P**ractical and **E**ducational. *Theoretical* refers to a new scientific value, *practical* to contributions which have practical, business related implications, and *educational* refers to the development of solutions which create improvements for learning processes either in educational organizations or in companies. As can be seen from FIGURE 34, these three TPE perspectives overlap each others to some extent.

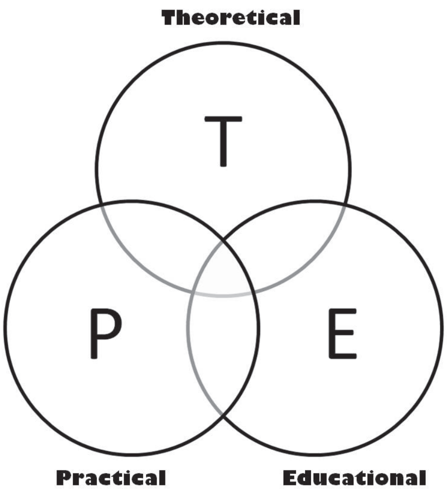

FIGURE 34 TPE perspectives for contribution evaluation

The *Proactive Combination Innovation* concept presented in Chapter 1.4 (FIGURE 2) brings a theoretical contribution (T) to this study and its applicability was validated in development work carried out in the applied research cases.

The improvements of learning and development methods for technology education and collaborative applied research have a theoretical contribution (T) because the development of the methods was carried out following principles of open innovation, living lab, meta-learning and meta-engineering and it integrates these as a combined learning-to-learn and learning-to-engineer concept. This concept was tested in education and learning processes both with students and the SME personnel. This brings a practical (P) and educational contribution (E) to this study.

In the collaborative applied research projects, tens of technology demonstrations were implemented, which have brought about a practical contribution (P). The direct feedback from SME personnel or engineering students was used to develop technology demonstrations clearer, more concise and comprehensible. The results of the technology demonstrations were distributed by using different digital media including video clips and simulations for smart phones, Internet web pages and digital video libraries such as YouTube. The technology demonstrations thus brought educational contribution to this study (E).

The monitoring tools which were developed to evaluate the technology development needs bring a theoretical contribution (T). These tools were presented in Chapters 3 and 4. They were used in assessments of this study and thus they also brought a practical contribution (P).

Taxonomy development for business opportunity assessment in the monitoring tools brought a theoretical (T) contribution. The developed taxonomy was also tested successfully by the focus group of experts which brings a practical (P) contribution. In the future it will also be adapted for education which will create an educational contribution (E).

Chapters 3.4 and 4.4 present the evaluation of innovation capabilities of the SMEs and applied research team based on objectives derived from technological innovation capability, transformation of business and creative social processes. The development of this evaluation model brought a theoretical contribution (T). The model was also tested successfully in this study by the focus group of experts which brings a practical (P) contribution. In the future it will be modified also for educational purposes which in turn will create an educational contribution (E).

Last but not least, this study has brought contributions related to establishing creative social processes and cooperation of the SMEs and applied research groups. The integration of theories on collaboration, helping, co-creation and creative views on business opportunities gave a significant theoretical contribution (T) which can be applied widely in collaboration with the SMEs and applied research groups. These creative social processes were used successfully in the collaborative projects which provides a practical contribution (P). The positive experiences of these creative social processes have already been transferred to engineering project studies, and this has changed the contents of these studies which brings an educational contribution (E). The educational contribution also includes the collaborative learning processes which the personnel of SMEs and applied research team have encountered during the study.

5.3 Limitations and critical evaluation

This study is multidisciplinary, multiple-case study where various elements of technological, business and entrepreneurship research are integrated. The study is also a synthesis of different research methodologies and methods as discussed in Chapter 1.5. Therefore, the scope of the research becomes so wide that several limitations are inevitable.

This study used the multiple-case study method. It is commonly recognized that the possibility to generalize from case study results is limited (Kontinen 2011; Yin 2009). Direct generalization of the research findings and contributions of this study presented in previous chapters is also limited but the approach and some of the methods can be applied in many types of applied research endeavors. One can argue that the analysis of research material of this study includes a reasonable amount of subjectivity, but it is complemented with literature comparisons and considerations. As discussed in Chapter 1.5, the entrepreneurial approach for research should be inter-subjective and include action, interaction, reaction, transformation and explicit co-creation (TABLE 3). The cross-case evaluation carried out in Chapters 3 and 4 increases the reliability of the research interferences. For engineering education the results of this study have strong pragmatic validity.

This study is limited to investigating the collaboration of an applied research team and SMEs, and thus it does not involve a wider examination of innovative organization structures, strategies and methods in research organizations or in SMEs. Based on literature (Bullinger et al 2007; Govindarajan & Trimble 2010; Prahalad & Ramaswamy 2004; Prahalad & Krishnan 2008; Schein 1992; Schein 2009; Wong 2006) the proposed cultural changes of collaboration involving SMEs and applied research groups can be extended to the organizational level, but it not an easy task, and it should be started stepwise from the most potential groups. However, the collaboration considerations involving SMEs and applied research teams presented in this study have many issues which can be generalized and applied widely.

The technological area of this study is delimited to certain areas of automation technology: case projects are concerning robotics, simulation and wireless automation based on RFID and WSN technologies. Direct generalization of results to other technological areas can sometimes be misleading. The participating firms of this study have been mainly production-oriented SMEs and some generalization to automation endeavors of other production-oriented SMEs can be made. The culture of large companies, even if they would be production-oriented, is, however, often so different in SMEs that there is no sense to extend generalizations in this direction.

This study has concentrated on business opportunity evaluation, and it has not taken into consideration business model creation, which is an essential but wide part of research result commercialization. Especially business models for SMEs which are transforming from manufacturing to service business (see

Chapter 2.6) should be examined more in the future. Service robotics is an example of future areas which needs development of new business models.

Sustainability will have an increasing influence to the production-oriented SMEs in this study. This study has taken sustainability issues into account only to that extent as they have appeared in the pilot cases of the collaboration projects. Sustainable innovation can in the future be a competitive advantage for SMEs as Hautamäki (2008) has stated.

This study has concentrated on enhancing innovation capabilities and business opportunities. Innovation management in an organization is a more extensive development task which goes beyond this study. The Fraunhofer model (Bullinger et al. 2007) for innovation management introduced in Chapter 2.3 gives insights on how extensive task the innovation management tool for organizations is and what parts are needed in successful innovation management. The same focus group of experts which was used in the evaluations of innovation capabilities in Chapters 3.4 and 4.4, also carried out an upper-level self-evaluation about the organization level of CENTRIA based on the Fraunhofer model categorizations. The evaluation utilized the ten innovation management areas and key success factors presented in TABLE 6. These innovation management areas were assessed first in the initial situation and then in the situation of April 2011. The results of this self-evaluation are presented in FIGURE 35.

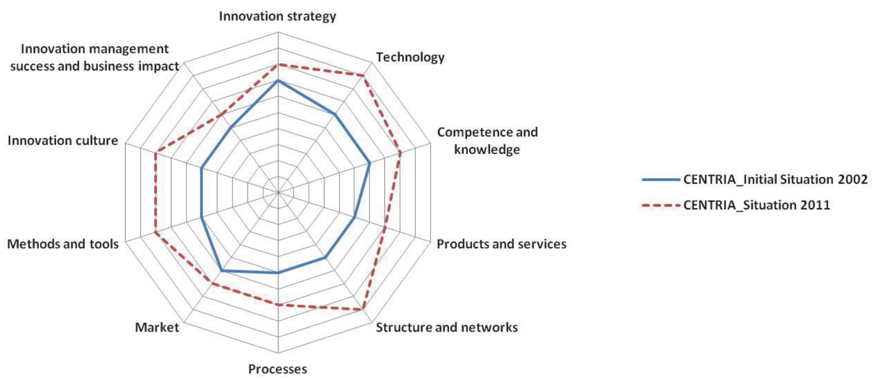

FIGURE 35 An upper-level self-evaluation of CENTRIA's innovation capability in the Fraunhofer model

FIGURE 34 shows that innovation capability in the organizational level has had an encouraging development. The biggest steps were taken in the area of innovation management of structure and networks, which include successful external cooperation with SMEs and other research organizations and internally networked organizations. It is now at the same level as innovation capability of technology.

As mentioned above, self-evaluation is only an upper-level assessment and was not carried out using the three phases of Fraunhofer model: *Innovation audit*, *Design phase* and *Innovation card and implementation*. To create and develop comprehensive innovation management for the organization, the innovation audit should be carried out by external experts. Performance indicators and innovation audit scorecards should also be developed. All the involved persons in the organization should be participating in interviews and in datacollecting. This would require considerable resources for the innovation capability evaluation of the whole oragnization using this model. The Fraunhofer researchers told that the success can be achieved only if participants are aware of the relevance of innovation management and are highly motivated to conduct an innovation audit and to implement an innovation card. They add that it is necessary to ensure the selection of at least one representative business unit that reflects the company and its business activity and of interview partners from different hierarchy levels and organizational functions. (Bullinger et al. 2007)

In Chapter 2.4, it was already stated that the Fraunhofer model is quite a complex and time-consuming method. It could be modified and applied in a lighter version for local purposes, but it would anyway take a huge amount of work, and it was therefore out of scope of this study. Even if the modified innovation model would be created, it might still be hard to find production-oriented SMEs which are eager to commit themselves to developing their innovation management based on the modified model.

5.4 Discussion, recommendations and future research needs

As discussed in Chapter 1.2, the task of any research is to ask and attempt to answer questions about the world. This study has sought answers for the more and more important question of how to enhance the competitiveness of SMEs by creating new business opportunities and developing their innovation capability. SMEs are generally recognized as key drivers for economic growth, innovation and employment. They are now extremely important in Finland where big companies are employing fewer people. This study has proved that the collaborative research involving an applied research team and SMEs can indeed provide positive answers to questions how to enhance innovation capability and business opportunities. The topics of the collaborative research projects have included contemporary and interesting subjects such as digital and ubiquitous technologies, wireless automation, location-aware technology, user interaction, and the convergence of technologies. It was discovered that the development of helping relationships, collaborative culture and co-creation has a crucial role for the execution side of innovations. The same collaboration issues and creative views are important to both organizations, i.e. the SMEs and applied research units. The development towards a collaborative helping culture is important also inside both organizations, especially in their development teams. This study has shown that innovative people, cooperation based on helping relationships and the entrepreneurial spirit may help to achieve success in spite of the lack of experience in the initial stages as discussed in Chapter 1.1.

This study has reinforced Frankelius' criticism about too technologically oriented research presented in Chapter 1.1. Research in R&D projects has in fact almost always been technological, but in the future, applied research projects should be complemented with research in economics, marketing or commercialization of research. ***The first recommendation*** is that a concrete business opportunity evaluation should be included in the project plans of every applied research project.

The other criticism which Frankelius presented is the expectation that high-level knowledge needed for innovation should almost always be produced inside universities. The successful results of this study verify that collaboration with SMEs and local applied research groups can be much more valuable for SMEs than top level research in highly regarded universities. ***The second recommendation*** is targeted for public innovation policy, which should strengthen the collaboration possibilities for local R&D units and SMEs. This should not be against the endeavors of developing top class scientific universities in Finland. Local R&D units to be supported should have knowledge and competence for applied research and they should be networking with the best universities and research institutes. Technology transfer with technology demonstrations or pilot projecting should be carried out in collaboration with SMEs and these applied research groups. SMEs alone have no resources or experience to plan and execute these pilot projects or technology demonstrations, and they do not have a tendency to do continuous collaboration with research groups situated far from them. The related literature and experiences of this study reinforce the importance of closeness of SMEs and applied research groups for continuous successful collaboration. This was found to be extremely important in production-oriented SMEs of this study.

When considering organizational issues of applied research, it can be concluded that currently there is too much bureaucracy and hierarchy in many organizations which are carrying out research, development and educational tasks. However, even if the organization does not fulfill the criteria of an innovation organization, an applied research team inside it can create innovative collaboration with firms if the organizatorial structures and modes of action do not directly prevent it. On the other hand, frequent useless and obligatory meetings and bureaucracy can kill the innovating spirit in applied research groups. Change to a collaborative culture proposed by Wong (2006) and the helping relationship attitude proposed by Schein (2009) should be introduced in research organizations so that it covers the whole organization. Schein speaks about humble leadership which is a proper choice for an innovative expert organization. Schein (2009, 143) advices leaders that the best way to improve the organization is to create an environment of mutual help, and to demonstrate their own helping skills in their dealings with others in the organization. Members of applied research teams should also learn team play in the helping spirit and this should be extended to collaboration with firms and other R&D units. ***The third recommendation*** is that helping spirit should be introduced and maintained for applied research organizations; leaders and team members should learn to understand the importance of helping relationship in a team play which applied research in fact is. As Schein (2009, 157) claims this will improve life for all of us.

The fourth recommendation is targeted for SMEs. This study wants to encourage SMEs to seek continuous cooperation with innovative applied research groups which have gathered not only professional expertise but also understood the importance of collaborative culture and the principles of helping relationship. Local applied research groups can provide their own expertise and a link to wider national and international cooperation networks for the SMEs.

The results of this study would not have been reached without mixing the expertise and capability in CENTRIA Ylivieska. The production automation expertise and capability was mixed without prejudice with mobile programming, mobile user interfaces, location aware techologies, smart environments and hardware and software design for wireless sensor networks. This process brought succesful results which could not have been imagined in the beginning of this study. ***The fifth recommendation*** goes to applied research organizations: mix the expertise and capability inside your organization consciously and without prejudice.

Future needs for SME-oriented applied research come from the seven innovation challenges presented in Chapter 2.6: digitization, ubiquitous connectivity, convergence of technologies and industries, user-driven innovations, service business, globalization and sustainable growth, and demographic change. Even if most of these areas have already been topics in some research projects, the results are often far away from the needs of production-oriented SMEs. Collaborative applied research projects could give SMEs concrete help on how these innovation challenges can be turned into applications in everyday operations. The future role of automation should be user assisting and as invisible as possible: the best automation solutions are those which help the user who does not even notice their existence.

According to the Global Competitiveness Report (2011), Finland has taken the top positions in the availability of scientists and engineers and also university-industry collaboration is near the top level. However, the production-oriented SMEs have not been so eager to participate in R&D projects. Especially the production-oriented SMEs not located near universities or research units are often left outside of collaborative research projects. One future research need is to establish projects which encourage production-oriented SMEs to participate in national and international R&D collaboration because in the fast developing world it is their only way to survive and develop.

The technological research areas should in the future be complemented with economics studies to consider business opportunities and business models. Especially business models for SMEs transforming their processes from manufacturing to service business should be examined more extensively in the future. Also innovation management should be considered more widely in collaboration research involving SMEs and applied research teams; an innovation tool similar to the Fraunhofer model (which was discussed earlier in Chapters 2.3 and 5.3) could be created and modified for local circumstances.

From the entrepreneurial perspective, one interesting discovery of this study is the concept of the entrepreneurial method recently proposed by Sarasvathy and Venkataraman (2011). According to their proposition, entrepreneurship should be positioned analogous to the scientific methods. They claim that it should make a revolution in pedagogy, policy and practice. They also suggest that entrepreneurship should be taught not only to entrepreneurs but everyone, as a necessary and useful skill and an important way of reasoning about the world. One wider future research topic would be to find out how education and training based on the entrepreneurial method could be implemented in Finland and how it could be integrated in collaborative SME-oriented applied research projects. The entrepreneurial method could provide new perspectives and tools for constructing the new house of innovation discussed in the beginning.

YHTEENVETO (FINNISH SUMMARY)

Pienten ja keskisuurten yritysten kilpailukyvyn edistäminen on keskeinen haaste Suomen tulevaisuudelle. Pk-yritykset ovat avainasemassa Suomen taloudessa: viimeisimmän virallisen vuositilaston mukaan vuonna pk-yrityksiä oli yli 300 000 eli 99.8 % kaikista yrityksistä ja ne työllistivät 64 % yritysten henkilöstöstä. Tässä väitöskirjatyössä tutkitaan miten kilpailukykyä voidaan edistää pk-yritysten ja soveltavan tutkimuksen ryhmien välisellä yhteistyöllä.

Tämä tutkimus esittelee tuloksia yhteistyöprojekteista, joihin on osallistunut yli 50 pk-yritystä, jotka ovat olleet enimmäkseen tuotantoon suuntautuneita yrityksiä. Soveltavan tutkimuksen yhteistyöprojektien keskeiset tulokset esitellään väitöskirjatyön yhdeksässä julkaisussa ja niiden esittelyissä. Kehitystyön tuloksia arvioidaan liiketoimintamahdollisuuksien ja innovaatiokyvykkyyden kehittymisen näkökulmista. Keskeisinä tutkimuskysymyksinä tarkastellaan millaisia liiketoimintamahdollisuuksia projekteista on syntynyt ja miten innovaatiokyvykkyys on kehittynyt yrityksissä ja tutkimusryhmässä.

Työssä käytetty metodologia ja tutkimusmetodit ovat synteesi useista lähestymistavoista ja metodeista. Työtä voidaan kuvata pragmaattisista ja konstruktiivisista lähtökohdista tehdyksi, kymmeniin esimerkkeihin perustuvaksi tapaustutkimukseksi, jonka toteutustapa perustuu toimintatutkimukseen ja kehittämistutkimukseen. Työn toteutuksen voidaan kuvata myös noudattavan monia työssä esiteltävän, kirjallisuudesta löydetyn tuoreen teoreettisen viitekehyksen, yrittäjyysmetodin, piirteitä.

Työn perustana olevat yhteistyöprojektit pk-yritysten ja tutkimusryhmän välillä ovat tuottaneet 22 tarkasteltavaa liiketoimintamahdollisuutta. Tutkimuksessa arvioitiin näistä puolella olevan hyvä tai erinomainen liiketoimintapotentiaali ja yhdeksää näistä ovat tutkimuksen pk-yritykset jo soveltaneet tuotannossaan. Patentoidut ratkaisut ovat näyttönä tutkimuksen käytännönläheisestä innovatiivisuudesta.

Työ on tuottanut uutta tietoa miten pk-yritysten kilpailukykyä voidaan edistää näiden ja soveltavan tutkimuksen ryhmien innovatiivisella yhteistyöllä, jossa pyritään yhdistämään teknologia- ja markkinalähtöisyydet. Työssä on kehitetty menetelmä ja taksonomia yhteistyöprojektien tutkimustulosten liiketoimintamahdollisuuksien arviointiin. Teoreettisen arvon lisäksi menetelmän onnistunut soveltaminen on tuonut työhön myös käytännöllistä lisäarvoa. Menetelmää voidaan käyttää myös oppimisprosesseissa, mikä tuo sille koulutuksellista arvoa.

Työssä tarkastellaan innovaatiokyvykkyyden kehittymistä projektien aikana pk-yrityksissä ja soveltavan tutkimuksen ryhmässä. Innovaatiokyvykkyydellä tarkoitetaan kykyä sopeutua muuttuvaan toimintaympäristöön tekemällä uuteen teknologiaan, tietämykseen ja taitoihin perustuvia muutoksia nykyisiin toteutuksiin tai luomalla täysin uusia toimintatapoja. Työssä on kehitetty menetelmä ja arviointitapa innovaatiokyvykkyyden kehittymisen mittaamiseen työn kannalta kahdessa keskeisessä teknologia-alueessa: langattomassa automaatiossa sekä robotiikassa ja simuloinnissa. Kehitetystä menetelmästä on saatu teoreettisen arvon lisäksi myös käytännöllistä arvoa soveltamalla sitä tutkimukseen osallistuneiden pk-yritysten ja soveltavan tutkimuksen ryhmän innovaatiokyvykkyyden kehittymisen arviointiin. Menetelmää voidaan liiketoimintamahdollisuuksien arviointimenetelmän tapaan soveltaa myös oppimisprosesseissa, mikä tuo sille koulutuksellista arvoa. Tutkimuksen arviointien perusteella sekä pk-yritysten että soveltavan tutkimuksen ryhmän innovaatiokyvykkyys on kehittynyt merkittävästi. Tutkimuksen kokemusten perusteella keskeisin tekijä innovaatiokyvykkyyden edistämisessä on pk-yritysten ja soveltavan tutkimusryhmän välisen yhteistyökulttuurin luominen, jossa teknologisen asiantuntemuksen ja liiketoiminnan ymmärtämisen lisäksi tarvitaan yhdessä kehittämisen kulttuuria, luottamusta ja molemminpuoliseen auttamishaluun perustuvaa asennetta.

Työ on tuottanut teoreettista uutuusarvoa myös työssä esiteltävän proaktiivisen yhdistelmäinnovaation konseptilla, jonka käyttökelpoisuuden varmistavat kehitetyt ratkaisut. Teoreettista lisäarvoa tuovat myös työssä esitettyjen teknologiademonstraatioiden soveltaminen oppimisprosesseihin avoimen innovaation, metaoppimisen ja tekemällä oppimisen metodeja yhdistellen *living lab* –tyyppisesti. Teknologiademonstraatioiden toteutuksissa on käytetty myös monipuolisesti digitaalista mediaa, mikä mahdollistaa niiden ajasta ja paikasta riippumattoman hyödyntämisen. Metodia on käytetty sekä pk-yritysten henkilökunnan ja insinööriopiskelijoiden oppimisprosesseissa, mikä tuo sekä käytännöllistä että koulutuksellista arvoa.

Tutkimuksen johtopäätöksinä esitetään suosituksia innovaatiokyvykkyyden ja liiketoimintamahdollisuuksien edistämiseen liittyvistä toimista. Näitä ovat liiketoimintamahdollisuuksien arviointien sisällyttäminen kaikkiin soveltavan tutkimuksen projekteihin, pk-yritysten ja paikallisten soveltavan tutkimuksen toimintamahdollisuuksien edistäminen innovaatiopolitiikalla, yhteistyökulttuurin ja poikkitieteellisen osaamisen kehittäminen tutkimusorganisaatioissa sekä pk-yritysten rohkaiseminen osallistumaan tutkimus- ja kehitysprojekteihin.

Innovaatiohaasteita tuotannollisille pk-yrityksille tuovat jatkossa digitalisoituminen, ubiikki teknologia, teknologioiden konvergoituminen, käyttäjälähtöiset innovaatiot, palveluliiketoiminta, globalisaatio, kestävä kehitys ja väestörakenteen muutokset. Näihin aiheisiin liittyen tarvitaan pk-yrityksiin suunnattua soveltavaa tutkimusta, jossa automaation rooli tulisi olla täysautomaation sijasta käyttäjää avustavaa. Innovaatiopolitiikalla pitäisi tehdä tuotannollisille pk-yrityksille osallistuminen sekä kansalliseen että kansainväliseen tutkimus- ja kehitysyhteistyöhön mahdollisimman houkuttelevaksi, sillä uuden teknologian tehokas hyödyntäminen on elinehto niiden kehittymisessä ja selviämisessä kovassa kansainvälisessä kilpailussa.

Avainsanat: innovaatiokyvykkyys, liiketoimintamahdollisuudet, pk-yritykset, soveltava tutkimus, yhteistyö, robotiikka, simulointi, RFID-teknologia, langattomat sensoriverkot

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