IMPACTS OF RESEARCH TEAM DIVERSITY AND TOP MANAGEMENT ON RESEARCH COMMERCIALIZATION OF A PUBLIC RESEARCH INSTITUTE IN THAILAND

A Dissertation

Submitted to the National Graduate Institute for Policy Studies (GRIPS)

in Partial Fulfillment of the Requirements for the Degree of

Doctor of Policy Studies

by

Warangkana Punyakornwong

March 2019

Acknowledgements

First of all, I am deeply indebted to the Government of Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the National Graduate Institute for Policy Studies (GRIPS) of Japan for awarding a scholarship, which covered the admission fee, tuition fees, and all expenses while studying in Tokyo. Moreover, I am most grateful to the National Science and Technology Development Agency (NSTDA) and Dr. Chadamas Thuvasethakul, the NSTDA's Executive Vice President, for providing the opportunity to study for a doctoral degree in science, technology and innovation (STI).

Furthermore, I would like to express my sincere gratitude to my main adviser Professor Patarapong Intarakumnerd for the continuous support in my study and related research, for his patience, motivation, and immense knowledge. His guidance helped me throughout my research and in writing a proficient dissertation.

In addition to my main adviser, my appreciative thanks also goes to Professor Jun Suzuki, Professor Tateo Arimoto and Professor Hiroshi Nagano for their insightful comments and encouragement, for their kindness, continuous support and confidence in me. I will be forever grateful.

Moreover, I would like to thank my other committee members: Professor Masako Kurosawa, Professor Kumiko Miyazaki, Professor Tetsushi Sonobe, Professor Hisanori Nei, Professor Koichi Sumikura, Professor Tatsuo Oyama, Professor Takashi Tsuchiya, Professor Hozumi Morohosi and Professor Kanetaka Maki, for their direction and insightful remarks. I consider it a great honor and privilege to have received their advice.

My special thanks also go to Professor Yuji Kamiya, Professor Toshio Goto, Mr. Akihiko Tanaka, Mr. Koji Aribayashi, Dr. Thaweesak Koanantakool, Dr. Chatri Sripaipan, Ms. Thitima Chandanasotthi, Mrs. Tapanee Indradat, Ms. Thanyanan Kranlert, and all of the interviewees for the opportunity, valuable data, and knowledge given to me, as well as to the staff of the GRIPS Innovation, Science and Technology Policy (GIST), Nami Maeda, Miho Takahashi, and Kazuko Nakata, for their kind assistance.

Last but not the least, I would like to dedicate this thesis to my beloved parents and sisters who have always encouraged me at every stage of my education and were keen to see my achievement including their endless love. In addition, I would like to thank Ms. Dararat Rajadanuraks, Ms. Bung-orn Suwanphayakoon and Ms. Chanyabhak Nakvaree for supporting me spiritually throughout writing this thesis and my life in general.

Abstract

Public research institutes (PRIs) are facing demands both from governments and society to enhance their research performance, especially in terms of commercialization. As technology is becoming more complex and scientific disciplines are overlapping, a cross-functional teams (CFTs) approach is considered to be one method of innovation management in PRIs to increase research commercialization. Nonetheless, previous studies on CFTs focusing on the public sector are limited. Even though some PRIs have implemented CFTs, they have not objectively evaluated their impacts. As a result, this study aims to investigate the influence of team diversity on CFTs to enhance research commercialization in PRIs.

This study analyzes the team diversity of research and development (R&D) projects in different technological contexts: information and communications technology (ICT), biotechnology, materials technology and nanotechnology, and investigates how top management supports CFTs to enhance research commercialization. After analyzing 163 R&D projects of the National Science and Technology Development Agency (NSTDA), the largest public research institute (PRI) in Thailand by using the Poisson regression method, it has been found that the high diversity of the functions/departments, high diversity of educational fields, team size (as a control variable) and the timing of a project's completion (as a control variable) have had an influence on the number of license agreements. At the same time, the case studies confirm the regression results and cross-tabulation analysis in the four technological fields.

The results of this study have therefore contributed to the CFTs approach. The key findings prove that PRIs need diversified CFTs. This study explains the impacts of the technological fields, industrial sectors, top management and the middle level management, and different technology readiness levels (TRLs) on CFTs and research commercialization in PRIs. Finally, it proposes policy recommendations for the research management of PRIs.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Background

Cross-functional teams (CFTs) play a potentially important role in the innovation process enabling knowledge sharing, the development of trust, and overcoming spatial and organizational barriers (Love, et al, 2006). They comprise many forms and are often temporary task teams (Denison et al., 1996). A standard CFT is composed of those individuals from departments within a firm including members from operational units; such as, research and development (R&D), marketing, engineering and production. The role of CFTs is to facilitate the application of information derived from not only specific function sources, but also from external personal networks (Edmondson and Nembhard, 2009).

In the public sector, these CFTs are composed of personnel from various disciplines working together to make their organizations more competitive and successful. They coordinate together to develop new products and bring them to the marketplace, prepare a long-term corporate strategy, or upgrade service quality in a government entity using a procedure developed by the team (Halligan, 1997). These teams generally vary in size but typically have four to 10 members (Mat, 2008). Therefore, CFTs are thought to facilitate product development and marketing processes because they can solve information processing problems. That is, they bring people together from different disciplines and functions that have pertinent expertise about the proposed innovation problem (Galbraith, 1977; Kanter, 1988).

According to Mat, (2008), the differences in expertise allow members to access a broad array of external information and new knowledge (Cohen and Levinthal, 1990; Dahlin and Weingart, 1996). The combination of individuals with different expertise can also facilitate creativity (Woodman, Sawyer, and Griffin, 1993). Marketing and manufacturing representatives in new product teams can also assist product transfer, or the handoff of a newly developed innovation for production (Griffin, 1997). In terms of the public sector, Piercy et al. (2012) identified the four success factors of CFTs that included the need for the organizational leader to clearly support the team; cultural and structural issues that support cross-functional integration; funding support, and the need to break the status quo and overcome resistance to change. They found no evidence that these conditions could not be met in the public sector and suggested CFTs as a positive approach to be integrated in public sector change programs.

On the other hand, the study by Rivera (2007) focused on a single cross-functional project team in a multidisciplinary science and technology national laboratory, which provided a wide variety of services for the Department of Energy (DOE) in the United States. The study's findings indicated that management support for team networking determined the extent to which network engagement could influence group performance. Parker (1994) explained that the public sector with and/or without partnering with the private sector was making use of CFTs within its organizations. Governmental agencies were adopting this concept to develop new business strategies and to improve processes, reduce costs and provide better services to their customers.

In addition, Athanasaw (2003) argued that the public sector was increasingly implementing cross-functional approaches into its organizations, as evidenced in a shift away from large, top-down, centralized public bodies, following rigid procedures and reporting structures towards decentralized agencies operating integrated CFTs. The additional benefits of CFTs included increasing the skills of the human resources; the development of a common language and shared psychological models; an enhanced understanding of how the organization functions as a whole, and how employees fit within the organization. This in turn would increase an employee's feeling of worth and ability to work interdependently (Harman et al, 2002; Mendibil and Macbryde, 2005).

Although the public sector has recently started to apply the CFT approach, only a few studies have focused on public organizations. As a result, this study is organized to investigate CFTs as a method used by the PRIs for enhancing successful research commercialization.

1.2 Statement of the Problem and Research Contribution

Most governments are increasingly recognizing that promoting technology transfer and commercialization is the key factor for an innovative economy leading to wealth generation and job creation. Most public sector researchers have initiated projects without sufficient technical and market data, which have limited the success in commercializing the research results (Kamil, 2007). However, there have been observations about commercializing technology in PRIs.

In India, there have been many suggestions for national initiatives. For example, investing in creating a cadre of high-quality technology managers, investing in hands-on training as opposed to academic training of these managers through internships with experienced managers, minimizing bureaucracy in funding, reducing encumbrances on IP, and empowering PRIs and "technologists" to commercialize the technology, as they are in the best position to work toward the commercialization of innovations (Nandagopal et al., 2011).

Based on a survey of 5,232 projects implemented by the PRIs and universities during the Sixth and Seventh Malaysia Plans, the organizational practices in the form of financial support and non-financial support were found to have importance in facilitating the commercialization efforts in universities and PRIs. The identified barriers were an ineffective technology transfer office, inadequate financing to develop the invention for the market, poor industrial linkages, lack of market-oriented research, and inefficient and ineffective communication (Kamil, 2007).

In the European Union (EU), many PRIs have set up knowledge transfer offices in recent years aiming to improve collaboration and exploitation of research results and their absorption by business. Their success has been largely dependent on the skills and competencies of their staff as well as the strategic role assigned to them and their managerial autonomy. The personnel working on knowledge transfer must possess a wide range of skills in order to carry out their tasks effectively. However, relatively inexperienced staff is often appointed to such positions (European Commission, 2007).

In addition, PRIs have created reward systems whereby the inventor receives a share of any profits made from licensing or supplementary inventions. Although some financial incentives may apply, many staff remain reluctant to participate in such activities, especially as they are not taken into account for career progression. It is therefore important that the appraisal criteria also take into account other activities; such as, patenting, licensing, mobility and collaboration with industry[1] (ibid). On the other hand, senior management support in terms of both financial and 'political' assistance for technology transfer is critical. Such support is the most critical factor in the success of technology transfer/acceptance (Roupas, 2004).

However, PRIs as public sector organizations are differentiated in comparison with their commercial counterparts in the private sector. There is no profit maximizing focus, little potential for income generation, and no limitations against which performance can be measured (Boland and Fowler, 2000). The vast majority of PRIs still generate most of their income from the state. As a result, the need for project management expertise in public sector organizations has become fundamental in order to deal with the enormous responsibility of managing a number of projects (Rwelamila, 2007). The impact of team diversity on performance is of vital concern as today's organizations rely on teams to accomplish organizational goals (Poling, et al., 2006). Specifically, the effect of team diversity has become increasingly divergent, and several organizations rely on CFTs to handle complex and demanding issues (Nasta, et al., 2016). Moreover, there are two competing theories examining the relationship between team diversity and performance. The first is the similarity-attraction theory that suggests the similarity in interaction, value, and

[1] EUA Vienna conference conclusions – http://www.eua.be/fileadmin/user_upload/files/EUA1_documents/report_web%20221006.1161606166446.pdf

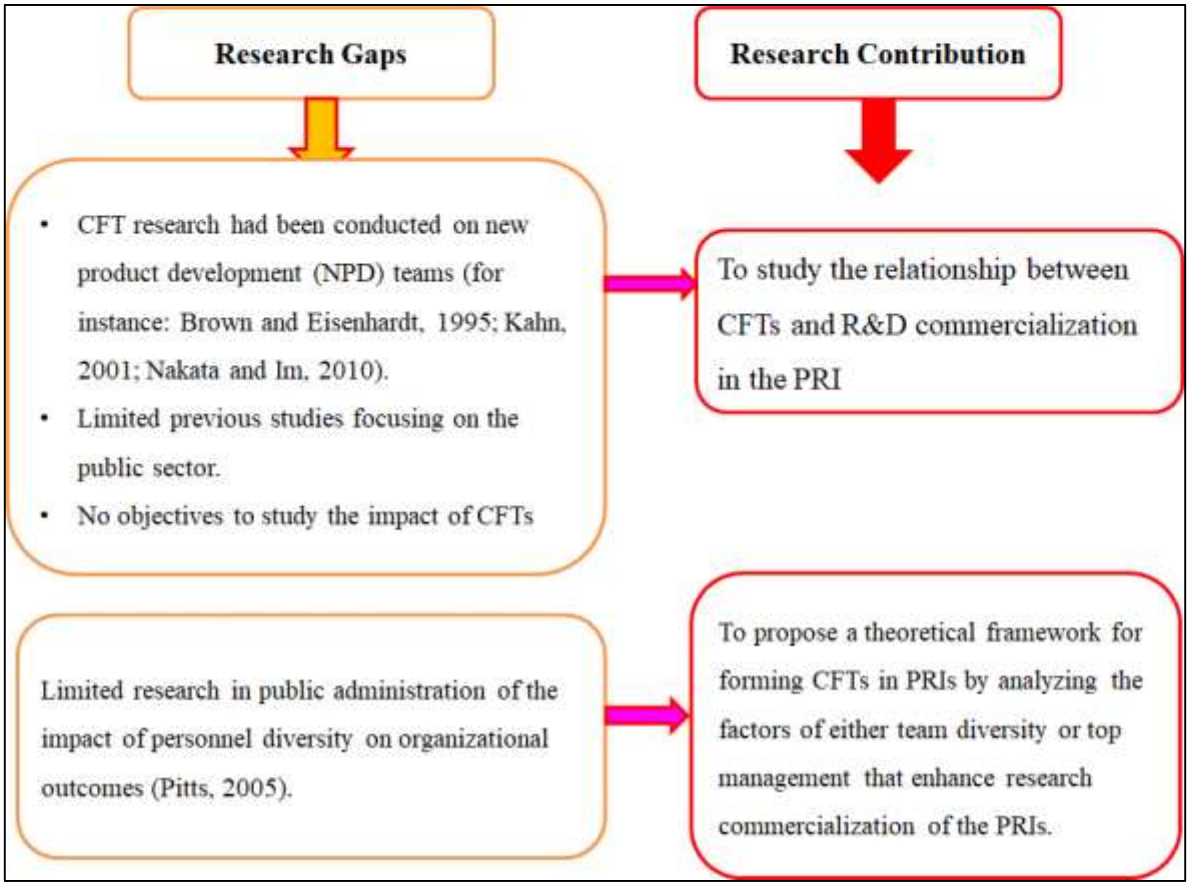
demographics are favored virtues in team composition, as they help maintain effective work environments (Byrne, 1971; Tziner, 1985). In contrast, the cognitive resource diversity theory (Cox et al., 1991; Guzzo and Dickson, 1996; Jehn, 1995) has argued that teams which consist of heterogeneous members can promote creativity, innovation, problem solving, and generate more informed decisions. However, evidence for the positive effects as well as for the negative effects of diversity are highly inconsistent (Bowers et al., 2000; Webber and Donahue, 2001; Williams and O'Reilly, 1998). As a result, this research uses the theoretical argument of the cognitive resource perspective that argues for the benefits of the diversity of teams and defines research commercialization in terms of R&D licensing of the PRI.

Team diversity is the individual differences of the members that also include explicit and implicit differences (Dongfeng, 2013). Arredondo (1996) considered member diversity in an organization as individual difference. This covered explicit differences (gender, age, race and other demographic characteristics) and implicit differences (attitude, belief, life-style, personality, and so on). Previous research on diversity has generally examined the demographic characteristics in groups, but the results linking group diversity and performance have been inconclusive due to mixed findings (Jackson, 1992; Tsui et al., 1992). Some studies have shown that diversity in tenure, educational background, functional background, and ethnicity improved group performance (Bantel and Jackson, 1989; Eisenhardt et al., 1997; Hambrick et al., 1996; O'Reilly, et al., 1997). Other studies have displayed that tenure, age, and ethnic diversity decrease performance (Michel and Hambrick, 1992; Zajac et al., 1991).

Although previous research has investigated the effect of team diversity in terms of functions, education background, and job/organizational tenure on the group performance (De Poel, Stoker, and Van der Zee, 2014; Ely, 2004; Jehn et al., 1999; Joshi and Roh, 2009; Milliken and Martins, 1996; Pelled et al., 1999; Van Knippenberg and Schippers, 2007; Williams and O'Reilly, 1998), the distinctions between various definitions of demography and the effect those definitions may have on organizational outcomes (Zenger and Lawrence, 1989). For instance, although Katz's (1982) and Zenger and Lawrence's (1989) research used demographic measures of tenure, the conceptual meaning of those measures differs. Katz examined group tenure, which was defined as the average time of the project-group members working together. The key dimension of group tenure was the length of time. In contrast, Zenger and Lawrence (1989) examined the similarities of organizational tenure, which represented the differences in organizational tenure among project-group members. The key dimension of this measure was similarity. However, little empirical research has been conducted on managing employee diversity in public sector organizations (Moon, 2016). A number of handbooks and desk references on diverse policies and programs have been directed more at practicing managers than the field of research and often do not address the public sector specifically (Fine, 1995; Gardenschwartz and Rowe, 1993; Loden and Rosener, 1991; Thomas, 1991; Wilson, 1997).

After reviewing the literature about CFTs, it has been found that there are two main research gaps. Firstly, most considerable research of CFTs had been conducted in the areas of new product development (NPD) teams, and previous studies on CFTs focusing on the public sector are limited. Although CFTs had been implemented in some PRIs, there were no objectives to study the impact of CFTs. Secondly, very little research in public administration has sought to understand the impact of personnel diversity on organizational outcomes (Pitts, 2005). Therefore, this research is intended to achieve two theoretical contributions consisting of studying the relationship between CFTs and research commercialization in PRIs, and proposing the theoretical framework for forming CFTs in PRIs by analyzing the factors of either team diversity or top/senior management that enhance research commercialization of the PRIs (Figure 1-1).

Figure 1-1: Contribution of the present study



Source: Author

1.3 Objective and Scope of the Study

The main objective of this study is to investigate the cross-functional teams (CFTs) based on the characteristic of public research institutes (PRIs); such as, structure and culture of PRIs, etc. This uses the cognitive resource approach in order to examine the impact of team diversity and top management supporting CFTs in PRIs to achieve successful R&D licensing. Finally, this study proposes a theoretical framework for forming CFTs in PRIs. Both qualitative and quantitative research methods are combined in the study to analyze both primary and secondary data. The indicator for measuring the success of research commercialization is the number of licensed projects. This study focuses on the following four research questions:

1. What degree does team diversity support CFTs to enhance successful research commercialization in a public research institute (PRI)?
2. What degree does team diversity influence on the duration for achieving the first license agreement?
3. To what extent do different technological contexts have an impact on CFTs in enhancing successful research commercialization in a PRI?
4. To what extent do different technological contexts have an impact on the duration for achieving the first license agreement?

This study uses Thailand as a case study because it is regarded as a typical developing country trying to upgrade the technical capability and reform PRIs. In terms of organizational level, the National Science and Technology Development Agency (NSTDA) is represented as the largest public research institute in Thailand in terms of budget and researchers, and a typical PRI trying to increase research commercialization. Although there are two significant channels, spin-offs and R&D licensing for research commercialization of PRIs, a recent survey carried out by the Organization for Economic Co-operation and Development (OECD) showed that in most countries, spin-offs remain rare and their economic impact is poorly documented[2]. As a result, the unit of analysis is R&D projects, and the scope of the study is potentially licensable R&D projects between 2011 and 2015 because licensing the intellectual property arising from the research results to a third party is relatively quick, and can produce a royalty income stream soon after licensing (European Commission, 2009). This research is based on Poisson regression analysis and applies a case study method to confirm the regression results.

[2] http://www.oecd.org/sti/sci-tech/introductionthenewspinonspin-offs.htm

1.4 Structure of the Study

The structure of this study is as follows:

- Chapter 1 introduces the background, statement of the problem and research contribution, objective and scope of the study, and structure of the study.
- Chapter 2 provides a literature review about three concepts: cross-functional teams (CFTs) concept, the roles of CFTs in the private sector, and using CFTs in the public sector and the roles of public research institutes (PRIs) in terms of transferring technology to companies, and using CFTs in the PRIs as one method to enhance research commercialization.
- Chapter 3 explains about the research methodology.
- Chapters 4 and 5 present the findings from the quantitative analysis and case studies about the degree of team diversity and executive management supporting cross-functional teams (CFTs) to enhance research commercialization.
- The study concludes with Chapter 6, which outlines implications for theory and further research.

Chapter 2

Literature Review and Research Gaps

2.1 Introduction

To identify the research gaps, the analysis of the existing research comprises four sections. Firstly, the analysis emphasizes on the literature review on the cross-functional teams (CFTs) concept. Secondly, it highlights the existing research on the roles of CFTs in the private sector and using CFTs in the public sector. Thirdly, it focuses on the literature review about the roles of public research institutes (PRIs) in terms of transferring technology to companies and using CFTs in PRIs as one method to enhance research commercialization. The research gaps are then summarized after discussing the existing research. At the end of the chapter, the concluding remarks are summarized.

2.2 Literature Review: Cross-functional Teams (CFTs) Concept

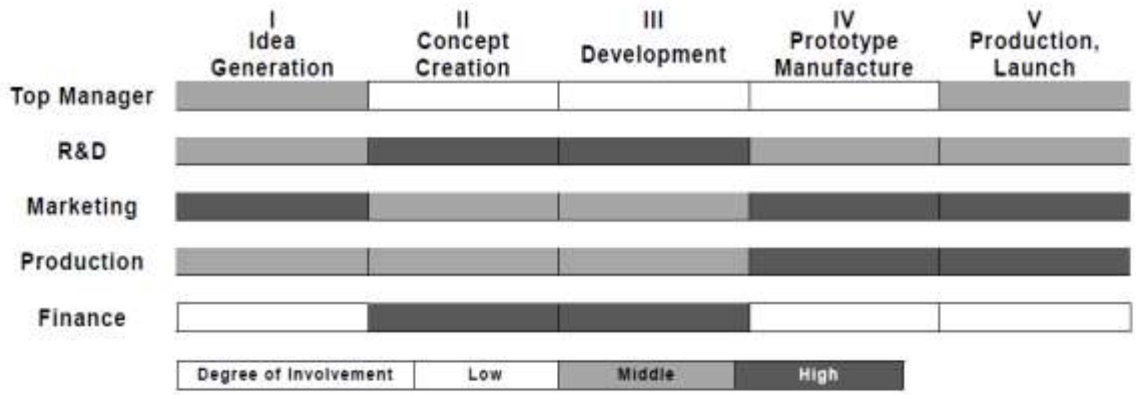
Innovation in a broad sense can be the management of all the activities involved in the process of idea generation, technology development, manufacturing and marketing of a new or improved product or manufacturing process or equipment (Trot, 2002). Innovation management forms an important part in the research and development (R&D) function in an organization. It captures the complete management process of innovation, which includes idea generation, the stages of product development, and the product’s launch in the market (Ojasalo, 2003). Successful innovation management is based on the supervision of the knowledge flow between the functions that are essential to the process of innovation, and should support and communicate with the environment in order to increase profitability, competitiveness, and the creation of business success (Ćirić et al., 2016).

The literature on innovation has advocated the use of cross-functional teams (CFTs) to allow for a smoother and higher performing innovation process (Christensen et al., 2004; Christensen and Raynor, 2003; Cooper et al., 2004). CFTs have been defined as a group of people with different functional specialties or skills that are responsible for conducting all phases of the innovation process (Roucan-Kane et al., 2011) including members from different functional departments; such as, R&D, production, logistics, quality assurance, procurement, and finance (Cooper and Kleinschmidt, 1995; McDonough, 2000), with likely pronounced functional identities (Ashforth and Mael, 1989). Many of the most innovative companies have found that a small CFT composed of employees from different backgrounds is the most effective organizational structure. From the project management perspective, the issues of CFT integration and the characterization of such teams by a clear understanding of a project's needs and expectations seem to be crucial for successful project management (Rauniar and Rawski, 2011).

The usefulness of CFTs in many diverse settings has been verified (Dougherty, 1992; Ittner and Larcker, 1997; Kahn, 2001; Leenders and Wierenga, 2002; Pinto et al., 1993) ensuring that interdepartmental collaboration is more important than just mere exchange. However, CFTs need both time and resource investments to generate a common commitment toward the achievement of both collective and individual goals. The benefits of CFTs include:

- To reduce hierarchical centralization, accelerate processes and increase market responsiveness (Henke et al., I993);
- To provide better quality decisions in comparison with individual decisions (Henke et al., I993);
- To establish informal networks that improve communication (Maltz and Kohli, 2000);
- To generate new ideas and solutions, as well as help employees understand each other's jobs better (Parker, 2003);
- To resolve problems and promote customer-oriented culture, as well as increase product quality and innovation (Parker, 2003).

Figure 2-1: Involvement of different functions in innovation management



Source: Xin Shen, 2002.

The innovation management process can set the stage for effective multifunctional teamwork in each stage of innovation development. The key functions of marketing: design engineering/development, manufacturing, procurement and/or materials, quality, and service or customer support should be represented in the core team. For example, in the first phase of the general five phases of innovation management, senior managers, R&D, marketing and production staff are involved in idea generation. Production must be actively involved in the 'Prototype' phase and 'Product launch' phase (Figure 2-1). Similarly, engineering must build very early prototypes to support marketing's desire to better understand customers' needs (Shen, 2002)

Establishing CFTs is only possible when the team members are disengaged from other commitments and daily tasks; such as, paper work, status reports and other job functions. To allow personnel the time to work on innovative projects, responsibilities for their jobs need to be re-evaluated, and some tasks possibly reassigned to others or eliminated (Riederer et al., 2005). Brown and Eisenhardt (1995) found that successful product development depended on the processes being implemented by "a competent and well co-ordinated cross-functional team". Griffin (1997) concluded that the best performance firm used CFTs more "extensively" than the poorer performers. Cooper and Kleinschmidt's (1995) findings demonstrated that the use of CFTs in new product development (NPD) teams resulted in better performance; especially, if every project had an assigned team of players, the team was cross-functional, all projects had identifiable and accountable team leaders, and the leaders and the team were accountable for all facets of the project from the beginning to completion. As a result, the juxtaposition of members with diverse knowledge sets would enable knowledge exchange for innovation. In essence, diversity allows group members to introduce unique opinions and perspectives, combine different ideas though discussion, and thereby facilitate innovation (Amabile, 1983; Amason, 1996; Kickul and Gundry, 2001; Northcraft et al., 1995).

CFTs are assigned unique, uncertain tasks, and are expected to produce non-routine products. Members are typically professionals brought together from a diversity of backgrounds. Moreover, CFTs conduct functions that the organization is not equipped to perform well (Cohen, 1993, p.206). These focus on the extent to which the characteristics of CFTs and the supporting contexts influence new product development making several contributions to both the marketing practice and theory (Sethi et al., 2001).

2.3 Literature Review: The Roles of CFTs in the Private Sector and Using CFTs in the Public Sector (see Appendix Table A1-1)

Existing research studies on the roles of CFTs in the private sector and using CFTs in the public sector were discussed and summarized in Figure 2-1. Most of them focused on the role of CFTs in the context of the private sector. A 1995 survey of US firms showed that over 84% of innovative product development projects used CFTs (Griffin 1997). A large benchmarking study of 103 new product projects in 21 divisions of major chemical companies found that 'true' CFTs were the top driver of a project's timeliness, and important drivers of profitability (Cooper, 1995). In another benchmarking study of 244 firms responsible for 80% of the R&D spending in Western Europe, Japan and North America, CFTs had the greatest statistical impact on the time to market for new products (Roberts, 1995). Service firms often use a formalized CFT as a tool for coordinating the actors and knowledge in the service innovation process (Fay et al., 2006; Hull, 2003) while the Ford Motor Company has taken a CFT approach toward process improvement and creation with workshops known as Ford RAPID. Ford considers that getting people from all parts of the process is the key for creativity and innovation (CEPT, 2001). In Samsung, the Catalyst Development Team creates CFTs from diverse backgrounds, which are chosen by project managers for their applicable skills to solve complex technical challenges and develop advanced materials; such as, a new high-performance catalyst for polypropylene, a widely-used polymer. Xie et al. (2003) examined an important challenge for effective cross-functional integration: goal incongruity among marketing, R&D, and manufacturing in new product development by collecting data from marketing managers in 1,083 firms in five culturally distinct countries: the United States, United Kingdom, Japan, Hong Kong Special Administrative Region of China, and Mainland China. In the American and British firms, goal incongruity generally was attributed to motivational factors. In addition, joint rewards and job rotation strengthened each other's tendency to reduce goal incongruity in all five samples. This result suggests that job rotation promotes the development of joint goals more effectively when it is accompanied by a joint reward system. Furthermore, studying 18 NPD projects in five different firms by Dougherty (1992) showed that those teams that used a highly interactive and iterative approach to overcome cross-functional barriers instead of 'over-the-wall' approaches were the ones that ended up with a successful product. Roucan-Kane et al. (2011) explained that food and agribusiness companies usually involved more than three departments/functional areas in the selection of product innovation projects. Researchers indicated that this was critical for managers to form CFTs that use a variety of selection methods to successfully assess product innovation projects.

In the Innobarometer (2009), commissioned by the European Commission, innovation trends were investigated between 2006 and 2009 in sectors of industry that were supposed to be innovative. There were differences between large and small companies. Of the large companies, 69% created cross-functional/departmental teams in innovation projects whereas only 28% of the small companies did so (Gallup Organization, 2009). This was also related to the findings by Gouanlong and Tsapi (2012). They studied the significant differences that existed between the perceived importance of cross-functional team composition and firm size. The results highlighted the virtual absence of cross-functional team formation by micro, small and very small businesses.

In terms of critical success factors of CFTs in firms, there are many studies. In electronic companies, the key success factors include “unified vision and goals”, “unified culture with partners”, and “building trust and cohesion”. This implies that teams require improvements in the climate of the work environment beyond supporting the system or infrastructure. Managers must consider the factors as collaborative conditions before embarking on a collaborative strategy for successful product development. Holland et al. (2000) used a heuristic team effectiveness model, which was categorized into six groups: task design, group composition, organizational context, internal processes, external processes and group psychosocial traits. The key success factors consisted of strategic alignment between the functions, climatic support of the teamwork and team-based accountability. Alexander et al. (2005) indicated the potential appropriateness of managerial interventions to encourage members’ investment in team processes while management support for team networking determines the extent to which network engagement may influence group performance (Rivera and Valdez, 2007). CFTs have an indirect influence on the continuous improvement of operational performance through the alignment between technological innovation effectiveness and operational effectiveness (Santa et al., 2011). In addition, the potential value of a CFT is to work in the more technical aspects of the innovation process, but the development of the market strategy should remain (Love et al., 2006). On the other hand, team performance, organizational performance and innovativeness are directly proportional to the CFTs’ capability levels (Sabir et al., 2014). In addition, Blindenbach-Driessen and Floortje (2015) summarized that the organizational context in which innovation teams operated thus matters.

Contrastingly, there are few studies that address the roles and functions of CFTs in the public sector. However, studies about CFTs in the public sector have shown that CFTs should not only continue in the public sector, but they should be a way of conducting business within agencies (Athanasaw, 2003). Piercy et al. (2012) identified four requirements for success. The first three concur with established private sector research on cross-functional work, which comprises the need for the organizational leader to clearly support the team; cultural and structural issues that support cross-functional integration, and funding support. Their research also uncovered a fourth critical requirement that is the need to break the status quo and overcome resistance to change. They found no evidence that these conditions could not be met in the public sector and suggested CFTs as a positive approach to be integrated in public sector change programs.

The study by Rivera (2007) focused on a single cross-functional project team in a national multidisciplinary science and technology laboratory, which provided a wide variety of services for the Department of Energy (DOE) in the United States with particular emphasis on the contribution of team member networks for the project's success. The study's findings indicated that management support for team networking, on the basis of conscious awareness of the importance of networks, determined the extent to which network engagement may influence group performance. A good example of CFTs in the civil service context is the project team proposed in Delivering Better Government (1996) to deal with cross-departmental issues; such as, childcare, drugs and employment, which can no longer be resolved from within a single department or agency.

In summary, CFTs are often seen as the key for innovation projects in firms (Blindenbach-Driessen and Floortje, 2015). Furthermore, 80% of companies with more than 100 employees use a team-based approach (Cohen and Bailey, 1997; Kratzer et al., 2004) to support innovation activities. Teams are also more diverse in terms of their function, purpose and structure. Although considerable work has been conducted in the area of CFTs, much of this has been limited to the private sector, notably the area of NPD teams (Brown and Eisenhardt, 1995; Kahn, 2001; Nakata and Im, 2010). Reports from both the National Science Foundation and the National Research Council of the United States indicate that the key for the management of technological innovation is the ability to leverage the contributions of technical professionals in CFTs (Katz, 2003). However, a limited number of CFT studies have been conducted in the public sector (Athanasaw, 2003; Gulledge and Sommer, 2003; McAdam and Donaghy, 1999; MacIntosh, 2003; Sundberg and Sandberg, 2003); thus, there is a research gap.

2.4 Literature Review: The Roles of Public Research Institutes (PRIs) in Terms of Transferring Technology to Companies and Using CFTs in PRIs as One Method to Enhance Research Commercialization (see Appendix Table A1-2)

State-sponsored public research plays a key role in innovation systems and decision-making processes. It is a source of new knowledge, especially in areas of public interest; such as, basic science or fields related to social and environmental challenges, which businesses are not always well equipped or motivated to invest. Sufficient investment in public research is important to realize the benefits of these technologies for future growth and well-being. Therefore, public research institutes (PRIs) are actors that undertake longer-term and higher-risk research. They also conduct a considerable amount of applied research and experimental development that has more immediate potential for translation into tangible societal benefits (OECD, 2016).

The major significant contribution of public research to innovative research, design and development (RD&D) has two distinctive elements: (a) as a source of new knowledge in specialist fields of science and engineering, and (b) as a source of practical assistance including the area of instrumentalities. The contribution of public research to instrumentalities in biotechnology and ceramics supports the claim of de Solla Price (1984) that this is a crucial area to both public research and 'industrial innovation', which should be supported by governments (Faulkner and Senker, 1995). As a result, the commercialization of public research has become a major goal of national science, technology and innovation policies in both developed and developing countries.

Knowledge transfer and commercialization of public research refer in a broader sense to the multiple ways in which knowledge from universities and PRIs can be exploited by firms and researchers themselves, so to generate economic and social value and industrial development.

Channels for knowledge transfer can be categorized as either informal channels; such as, staff exchanges or networks that involve tacit flows, or formal channels that involve a contract between the PRIs and the firm, a license, joint patent, or participation in a university spin-off. Channel formalization refers to the extent to which the interaction is institutionalized and/or guided by formal rules and procedures (OECD, 2013). However, patenting and licensing are very important for researchers working in the materials sciences whereas these channels are less relevant for computer scientists. The most relevant channels in the social sciences and humanities are personal contacts and labor mobility (Bekkers and Bodas Freitas, 2008). As engineering sciences, or the so-called "transfer sciences"; i.e., computer, aeronautical, and mechanical engineering, as well as the social sciences support gradual and tacit transformation due to the characteristics of knowledge in question, tensions over proprietary rights are expected to be weaker than in the sphere of the natural and physical sciences (OECD, 2013).

Most of the existing studies focus on the research commercialization of universities. In addition to the importance of the effect of external factors on a university's ability to commercialize technology, there are internal university factors that can also have an effect. Various studies indicate that the three most important factors as internal university factors are the university's entrepreneurial activity, technology-transfer policy, and technology-transfer organization (Bercovitz et al., 2001; Breznitz, 2011; Clark, 1998; Etzkowitz, 1998; Link and Scott, 2005; O'shea et al., 2005; Shane, 2004). Although both universities and PRIs have researchers, they have different characteristics between them. Higher education scholars and administrators define teaching, research, and off-campus services as the main functions of modern universities. Teaching is a major function of higher learning institutions; however, most contemporary research is unlikely to find its way into classrooms. Many instructors are researching narrow disciplinary topics focused on analytical method-related issues rather than the social relevance of the research, especially in the social sciences, which pursues commercially-oriented research, etc. Research was one of the major functions in the 19th century when the modern university emerged, and the role and relative weight of research has continued to increase. On the other hand, social and industrial problems are becoming more complicated, and the demands for better technology and better quality of life are growing exponentially because universities perceive research as a channel to generate resources rather than as a source of education (research-driven teaching), particularly when budgets are under threat. Finally, the service function can be approached from two points of view. One is to focus on service as a "university function in society" and the second is to emphasize service as an aspect of "faculty evaluation." The complexity of defining service functions is caused by faculty evaluation, which focuses mainly on research and teaching. Because of the importance of evaluation, instructors want to count their "other activities" as an aspect of their academic record under the broader and ambiguous term "service" (Shin, 2013).

The personal preference is affected by many factors; such as, the required class hours, their evaluation, the reward systems, as well as their internal preference. Most universities set a minimum required number of teaching hours and some higher education systems and/or universities require a minimum number of publications for promotion and tenure. In contrast, PRIs have a main function in research. As compared to universities, PRIs, and government research institutes (GRIs) must specialize in the advancement of science in areas where academic excellence is not a driver; e.g., where publication opportunities are fewer, and/or where research requires intensive advanced specialized engineering; the provision platforms for fundamental, precompetitive technological development; the maintenance of specialized applied research capabilities, and the provision of technical facilities and instruments for the diffusion of technology in areas of the market or system failure (Guinet, 2010).

In the context of PRIs, existing studies on their research commercialization were discussed and summarized in Figure 2-2. Gulbrandsen, and Rasmussen (2008) explained how the picture of commercialization of public research varies based on the indicators that are used. Recommended core performance indicators for the PRIs are research agreements, invention disclosures, patent applications, patent grants, licenses executed, license income earned, and spin-offs established (European Commission, 2009). Moreover, there are key success factors of technology commercialization at foreign universities and PRIs (Lee and Kim (2013) :

- They possess an abundant volume of excellent technologies (intellectual properties) and manage intellectual properties strategically.

- Organizations in charge of technology commercialization are independent and specialized.

- Stable funding for technological commercialization is provided by raising its own investment funds.

- Education and training as well as incentives are being offered to nurture entrepreneurship.

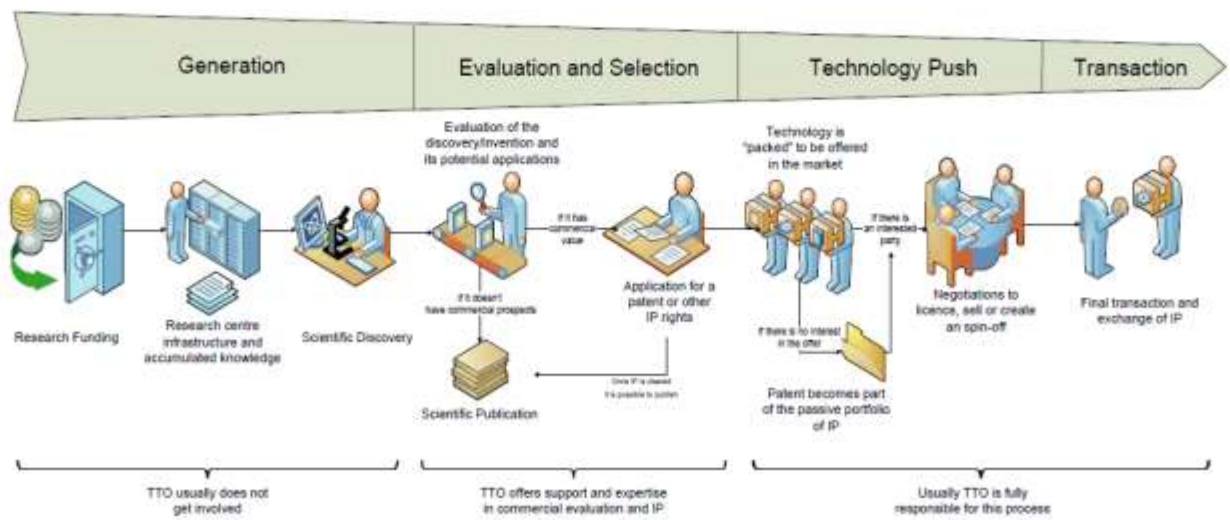
An important issue highlighted by several evaluations was that research alone does not necessarily add value. Thinking about how results would be converted into further research advances or innovations must be an important part of the design of PRIs and their programs (OECD, 2009). By establishing better foundations for successful research partnerships and knowledge exchange, it reinforces the value of the PRIs within society, thereby enhancing the prospect for continued top-quality research and education. One of the most critical points is to find a convenient balance point between the need for a wide diffusion of the research results, especially through scientific publications, and the need for careful protection of confidential information and the adoption of patent strategies for commercial purposes (European Commission, 2012). Furthermore, national policies and strategies for the commercialization of public research should be strengthened not only with regards to patenting and licensing efforts, but especially towards emerging channels like student entrepreneurship (OECD, 2013).

Developing countries have also started to pay more attention to research commercialization although contextual conditions, in terms of both scientific and innovation competencies, differ widely from those of developed countries (WIPO, 2011). In developing countries, most technology transfer activity occurs through informal mechanisms. Technology collaboration is often limited to ad hoc, short-term, and small-scale consultancy projects based on isolated initiatives and does not follow an institutional approach to technology transfer (Arza and

Vazquez, 2010; Costa Povoa and Rapini, 2010; Dutrenit et al., 2010; Intarakumnerd et al., 2002; Rapini et al., 2006). Although at present, certain PRIs have staff that actively pursue linking with industry, they have to ensure that such skills are made more widely available throughout the research institutions (European Commission, 2007). At the same time, these pressures for the research commercialization of PRIs have increased in industrialized economies. For Asian economies, the above two parallel processes have engendered a similar range of challenges to the role and functioning of PRIs. The weak institutional frameworks for research and the lack of the absorptive capacity of the potential users remain endemic in developing and emergent economies, and PRIs have had to adjust their approaches to these conditions (Sharif and Baark, 2011). Thus, the patenting of basic research and patenting by PRIs raises new issues regarding the conditions of access to the outcome of that research, particularly in developing countries where the systems of finance and innovation are immature. When buying technology, instances and threats of restricted access; for example, for genetic testing to proprietary research tools create the risk of slowing research and raising costs in developing countries (Heller, 1988).

The technology transfer process of PRIs should be planned from a research project design (Bassi et al., 2015). Rosa-Neto (2006) stated that the technological development process should be viewed overall by observing the adaptability conditions of access and interest of the target audience in order to identify the demands to facilitate the decision by the research in relation to the generation/adaptation of new technologies. Furthermore, Dereti (2009) suggested the inclusion of technology transfer action plans from the design of R&D projects to increase the transfer effectiveness. This also needs to take into consideration the participation of the potential users and the identification of the transfer opportunities for the development of technologies. Moreover, technology transfer depends on contextual factors including adequate financing mechanisms and the presence of a strong intellectual property rights (IPR) regime. Additionally, the limitations of scientists in PRIs to engage in entrepreneurial endeavors and technology commercialization activities must be addressed. Most importantly, the stock of human capital and the diversity of skills are necessary for effective technology transfer (Zuniga and Correa, 2013).

Figure 2-2: Traditional technology transfer funnel



Source: Ruiz, 2010

The main mission of PRIs is to conduct research and commercialize knowledge and R&D in order to contribute to the technological and economic development of a society. In developed countries, the commercialization knowledge generated by PRIs is an important driver of economic growth since the innovative activities of firms are often dependent on access to related academic research with innovations in some industries significantly affected by research (Cohen and Levinthal, 1990; Jaffe, 1989; Mansfield, 1995). The inflow of knowledge from PRIs is especially important for firms operating in fields with high rapid technological change like biotechnology, new materials and nanotechnology (Cockburn and Henderson, 2000; Pavit, 1998; Zucker et al., 1998). Researchers may be directly engaged in commercialization activities like patenting, join research with private firms, contract research and undertake consulting (Bönte, 2011). For the traditional technology transfer process in PRIs, technology transfer officers (TTOs) usually do not get involved in the generation phase, which consists of the concept development, research, prototype testing and research findings. However, they offer support and expertise in commercial evaluation and intellectual property (IP) from the evaluation and selection phase to the transaction phase (Figure 2-2). In fact, if researchers know the market's needs before doing research and prepare for technology transfer, this will lead to successful research commercialization. Moreover, according to the European Commission (2007), PRIs need to play a more active role in their relationship with industry in order to maximize the use of the research results. This new role requires specialist staff to identify and manage the knowledge resources with the business potential; i.e., how best to take a new idea to the market, ensure appropriate resources like funding, support services, etc. to initiate it, and to obtain adequate purchasing by all stakeholders. Therefore, the role of CFTs is the key factor to drive research commercialization in PRIs. For the successful application and development of the results of the research, those engaged in marketing and production should preferably be requested to join the research group at the earliest possible stage. These people should be made fully aware that the job is their own. It is of great significance for the non-research members to join the research group for their own satisfaction, as this eliminates problems, which could occur at a later stage (Sakakura and Kobayashi, 1991).

In short, researchers, TTOs, personnel of sections related to the market, skilled in the collection of information, of the production section and experts need to work together in order to enhance research commercialization. Although there are several studies on research commercialization in universities and PRIs, there is a lack of research on the role of CFTs to enhance successful research commercialization in PRIs. Most importantly, the commercialization of scientific research is particularly risky and uncertain; thus, a strong scientific workforce, in terms of their qualifications, critical mass, age and available equipment would provide an important signal of scientific credibility and capability to any anticipated commercialized venture or project (Audrestch et al., 2006).

The need for project management expertise in public sector organizations has become fundamental in order to deal with the enormous responsibility of managing a number of projects (Rwelamila, 2007). The impact of team diversity on performance is of vital concern as today's organizations rely on teams to accomplish organizational goals (Poling et al., 2006). Team diversity is the individual differences of the members, including explicit and implicit differences, which differs from business management and product diversity (Dongfeng, 2013). Arredondo (1996) considered member diversity in an organization as individual difference, which covered explicit differences (gender, age, race and other demographic characteristics) and implicit differences (attitude, belief, lifestyle, personality, and so on). Previous research on diversity has generally examined the demographic characteristics in groups and related this to various group outcomes, but the results linking group diversity and performances are inconclusive due to mixed findings (Jackson, 1992; Tsui et al., 1992). Some studies show that diversity in tenure, educational background, functional background, and ethnicity improve group performance (Bantel and Jackson, 1989; Eisenhardt et al., 1997; Hambrick et al., 1996; O'Reilly et al., 1997). Other studies show that tenure, age, and ethnic diversity decrease performance (Michel and Hambrick, 1992; Zajac et al., 1991). However, the present study uses the theoretical argument of the cognitive resource diversity theory. Researchers in this area have argued that diversity has a positive impact on performance because of the unique cognitive resources that members bring to the team (Cox and Blake, 1991; Hambrick, et al., 1996). The underlying assumption of value in diversity is that teams consisting of heterogeneous members promote creativity, innovation, and problem solving, hence generating more informed decisions.

Although previous research investigated the effect of team diversity in terms of functions, education background, and job/organizational tenure on group performance (De Poel, Stoker, and Van der Zee, 2014; Ely, 2004; Jehn et al., 1999; Joshi and Roh, 2009; Milliken and Martins, 1996; Pelled et al., 1999; Van Knippenberg and Schippers, 2007; Williams and O'Reilly, 1998), the distinctions between the various definitions of demography and the effect those definitions may have on organizational outcomes need to be examined (Zenger and Lawrence (1989). However, little empirical research has been conducted on managing employee diversity in public sector organizations (Moon, 2016). Although some PRIs employed CFTs, they did not analyze the effects of CFTs:

- In 2006, the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia assembled research teams to address the issues of sustainable bioenergy in that country. The project team consisted of researchers with expertise in forestry, agronomy and farming systems, ecology, economics, soil science and hydrology, spatial modeling, life cycle analysis, climate change and policy analysis. Knowledge gaps were filled by fostering collaborations and working closely with colleagues in related projects with expertise in process engineering and biotechnology. CSIRO had a core of 10–12 people who had more than a half-time commitment to this project and invited other specialized expertise outside CSIRO (O'Connell et al., 2013).

- The National Aeronautics and Space Administration (NASA) of the United States formed a CFT in the New Horizons project, which included scientists, researchers, engineers and other departments from world-renowned institutions; such as, the Johns Hopkins University Applied Physics Laboratory (APL) and the Southwest Research Institute (SwRI). In addition, other partners and co-investigators like Boeing, Lockheed-Martin, Stanford University, etc. joined in the effort bringing valuable expertise in specific fields and helping the whole operation run as smoothly as possible (Voica, 2015).
- The Industrial Technology Research Institute (ITRI), as the largest PRI in Taiwan implemented the Dechnology project, which was launched in 2010 to introduce design thinking into the organization's existing R&D process with the support from Taiwan's Ministry of Economic Affairs. Dechnology projects are joined by multiple stakeholders from the fields of technology (T), business (B), and design (D). All stakeholders engage in a new form of product/service development by using a multidisciplinary commercialization design workshop. The technology researchers (T), designers (D), and business specialists (B) have four months of intense discussions and close interactions

in workshops. In 2013, a total of eight groups entered this model for trials, and the relevant implementation content (Yang et al., 2015).

Furthermore, very little research in public administration has sought to understand the impact of personnel diversity on organizational outcomes (Pitts, 2006). As a consequence, the objective of this study is to try to fill this research gap.

2.5 Concluding Remarks

After reviewing the literature of the three sections, there are two research gaps, which can be summarized as follows:

Firstly, most companies consider that the effective implementation of CFTs is critical to new product success (Holland et al., 2000). However, most studies of CFTs have been investigated in the context of the private sector and a limited number of studies have been conducted in the context of the public sector. This is the first research gap because the organizational context in which CFTs operate thus matters. Moreover, recent theory on group effectiveness has increasingly recognized the significance of a supportive organizational context, and this is particularly pertinent for CFTs (ibid). Specifically, there are differences between the private sector and PRI as seen in the public sector context summarized in Table 2-1. Although CFTs are being applied in some PRIs, there are no objectives to study the effect of CFTs.

Table 2-1: Difference between Private Sector and Public Research Institute Context

	Private Sector	PRIs
1. Mission	Pursuit of profit and stability of revenues	Promoting R&D, and transferring technologies to the local industries
2. Budget	Flexibility	Inflexibility

	Private Sector	PRIs
3. Management Issues	• The low level of corporate bureaucracy • The substantial material benefits and promotions for the successful managers	• Strong bureaucratic attitudes • The lower material benefits for the successful managers • The high levels of political scrutiny
4. Relations with end-users	Consumers considered as the end-users	• The general public/citizens considered as the end-users • The underdeveloped customer relations, with an assumption that public servants know best about what services are required.
5. Time Horizon	Typically producing innovations in the short term	The difficulty to assess the consequences of innovation in the short term.

Source: Hsu and Yeo, 1996; Halvorsen, et al, 2004; GovLeaders, 2014

Secondly, little empirical research has been conducted on managing employee diversity in public sector organizations (Moon, 2016). Therefore, this is the second research gap. In addition to team diversity and senior management support, this current study examines other important factors affecting the characteristics of CFTs; such as, technology context, sector context and absorptive capacity of firms because the influences of cross-functional working depend on the type of market and technology opportunities being pursued, specifically as high levels of cross-functional cooperation and project teams are most beneficial for innovations characterized by high levels of technological and market risk (Gemser and Leenders, 2011).

Chapter 3

Research Methodology

This chapter includes the research methodology and is divided into six main sections. Section 3.1 explains the research objective and Section 3.2 provides the research questions and hypotheses. Section 3.3 describes the research framework including the definition of cross-functional teams (CFTs), effect of team diversity, and the effect of senior management on successful CFTs. Section 3.4 identifies two levels of analysis: the organizational level and project level. Section 3.5 presents the two research methods used in the study. These consist of quantitative research, which is analyzed by using the Statistical Package for the Social Sciences (SPSS) analysis software, and qualitative research by applying case study research. Finally, the concluding remarks are provided in Section 3.6.

3.1 Research Objective

The main objective of this paper is to investigate the CFTs model based on the characteristics of public research institutes (PRIs) by using the cognitive resource approach. This examines the relationship between CFTs and other factors that influence research and development (R&D) commercialization in PRIs, and proposes a theoretical framework for forming CFTs in PRIs. The cognitive resource perspective argues for a positive effect of diversity. This refers to a team's means in terms of their combined knowledge, skills, and ability (KSA), experiences and perspectives. Diversity in terms of task-related attributes is assumed to increase the consolidated cognitive resources that can draw on a larger pool of expertise. The wider breadth of cognitive resources is suggested to benefit team performance in that the members are more creative and effective in new product development (NPD). When individuals based on the same organizational function are probable to have similar networks within the organization, people from different functions are likely to have non-overlapping social networks that help the team to access a larger network (Fay and Guillaume, 2007).

This study assumes that R&D licensed projects used CFTs because research teams have to work together with analysts from the Research Support Division, technology transfer officers (TTOs) and the Legal Division before licensing to beneficiaries. With the exception of Halligan's (1997) definition, definitions of CFTs in general may exist within the private sector context that have focused on different functions/departments, divisions or disciplines, status of CFTs, size, and the product development phase. Therefore, this article employs the definition of CFTs adopted from Figure 3-1.

Definition of CFTs in this study

"A cross-functional team (CFT) is to form a team by drawing personnel from various functions and various disciplines not only researchers from different disciplines but also engineers, research assistants, technical staff, supporting staff, and technology transfer officers (TTO) working together to develop prototypes or research results to answer research questions about particular phenomena and bring them to commercialization."

Table 3-1: General Definitions of CFTs

Focused area	Definition of CFTs
CFTs based on the characteristic of the public sector	CFTs are composed of personnel from various disciplines working together to make their organizations more competitive and successful. Members work together to develop new products and bring them to the marketplace, prepare a long-term corporate strategy, or upgrade service quality in a government entity by using a procedure developed by the team (Halligan, 1997).
Functions	• CFTs relates to the use of integrating mechanisms in activities that require expertise from different functions (Maltz and Kohli, 2000).

Focused area	Definition of CFTs
	• A CFT is marked by a high degree of interdependence among team members. It is employed for its ability to bridge functions and thereby delivers better performance (Holland, et al. 2000). • A cross-functional project team is typically consisting of people from all functions who, at one time or another, are involved in the design, engineering, implementation/manufacturing, and marketing of the product (Bishop, 1999). • CFTs are defined as groups aimed at developing opportunities that require diverse expertise and induce/instigate people from different functions to work together (Pagell, 2004). CFTs need both time and resource investments to generate common commitment toward the achievement of both collective and individual goals. Members of CFTs must think and act jointly, in order to produce something beyond end products (Katzenbach and Smith, I993; Feng et al., 2010).
Departments, divisions, or disciplines	A CFT is more than a collection of individuals from different departments, divisions, or disciplines (Keller 2001; Bonner, et al. 2002). It is marked by a high degree of interdependence among team members and is employed for its ability to bridge functions and deliver better performance (Holland, et al. 2000).
Permanent/temporary groups	CFTs are permanent or temporary groups aimed at reducing conflicts in goals, language and processes that require cross-functional integration. These groups facilitate the interaction among members from different functions while performing temporary tasks, such as the development of new products (Turkulainen and Ketokivi, 2012),

Focused area	Definition of CFTs
Size	Ideally the CFT is a small group of key players from each affected functional area that have been carefully chosen for complementary skills and who are committed to a common goal and are mutually accountable for the team's success (Katzenbach and Smith, 1993).
Product development phase	A CFT is set up to manage product development, ensuring that the team has access to a diversity of information to aid decision-making. Generally, the involvement of the various functions in the team varies depending on (1) the type of products (new vs. variant); (2) the mode of development (in-house vs. outsourced); and (2) the phase of the project (e.g. idea generation vs. actual development) (Bunduchi, 2009).

Source: Compiled by author

3.2 Research Questions and Hypotheses

After reviewing the existing literature in Chapter 2, two research gaps are identified. Firstly, previous studies on CFTs focusing on the public sector are limited, and no empirical research objectively studied the effect of CFTs in the PRIs. Secondly, little empirical research has been conducted on managing employee diversity in the public sector. As a result, these research gaps can be transformed into research questions and hypotheses.

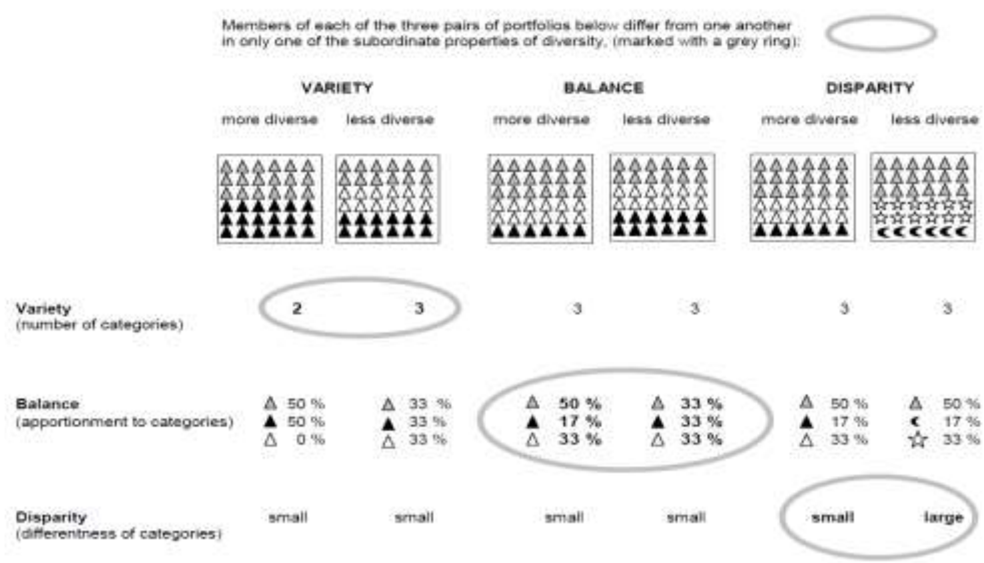
3.2.1 Effect of team diversity

Diversity concepts are employed across the full range of sciences called ‘variety’, ‘balance’ and ‘disparity’ (Stirling, 1994). Variety refers to the number of categories in a system. System A is more diverse than System B if System A consists of a larger number of distinguishable categories than System B. For example, it is natural to judge that a hypothetical market composed of films from ten different cultures is more culturally diverse than another hypothetical market with films from five different cultures given that films from each country can be a distinguishable category from others. The second dimension relates to the notion of balance, which is the extent of the apportionment between different categories. Given that System A and B have the same number of categories; i.e., the same degree of variety, System A is more diverse than System B if the categories in System A are more evenly proportioned, or balanced (Shin, 2015).

The third dimension of the diversity concept suggested by Stirling (1998) was disparity. More generally, given that System A and B have the same degrees of variety and balance, System A is more diverse than System B if the categories in System A are more dissimilar to each other than those in System B. Notions of disparity will vary depending on the particular frame of reference, which is adopted for any given purpose (Shin, 2015).

Figure 3-1 shows the example of variety', 'balance' and 'disparity'. Each individual symbol is a particular instance of a technology or product (or other 'option'). The instances are assigned to categories whose disparities are represented by the differences between the types of symbol (Stirling, 1998).

Figure 3-1: The separate contributions to diversity made by variety, balance and disparity



Source: Stirling, 1998

Although numerous studies have examined the relationship between demography and various outcomes, fewer have examined the processes through which demographic variables have their effect. Previous research investigated the effect of team diversity in various factors; such as, gender, age, ethnicity, experience, educational background, functional background, personality, values, attitudes, etc. on group performance. For product development teams, the most important diversity variable may be the functional mix. Teams may differ in terms of the proportion of individuals from each functional area. At one extreme, a team might comprise entirely of individuals from research and development. At the other extreme, one-third of a team's members might be from research and development, one-third from marketing, and one-third from manufacturing (Ancona and Caldwell, 1990). Team members must have varied skills and specific attitudes that are different and complimentary. For example, they may all be top-level scientists with similar values toward autonomy, yet differ in their disciplines and attitudes toward specific methods of data collection (Jain and Triandis, 1997). As a result, the use of CFTs has been proposed as a method of accelerating the product development process (c.f. Calantone and Cooper, 1981; Cooper, 1979; Voss, 1985). These teams offer two potential advantages. First, the team has direct access to expertise and information that would not be available if all team members were from the same area. Second, the team includes representatives from the manufacturing and marketing areas, so product transfer will be facilitated. Employing functional expertise as an indicator of cognitive diversity in teams is deemed efficient because organizations frequently structure functional groupings to carry out their operations. Consequently, functional diversity provides teams with direct access to a variety of expertise, information bases, and resources. This would not be readily available if all members came from the same functional areas (Horwitz, 2005).

Moreover, a person’s educational background can be a significant indicator of their knowledge, skills, and capability. Simons, Pelled and Smith (1999) observed that members’ diversity in education and company tenure influenced the quality of debates and, thus, positively impacted the decision-making process in a team of senior managers.

Diversity of experience is another important aspect. Heterogeneous organizational experience brings varied perspectives to develop more informed strategic alternatives (Horwitz, 2005). The findings of Taylor and Greve (2006) indicated that future research should focus on concrete measures of the career experiences of team members rather than on surface-level diversity; such as, the demographic variables of age, gender, and race (Harrison et al., 2002; Jehn, Northcraft, and Neale, 1999). In addition, studies of research and development teams have also documented the impact of task and product characteristics on performance (c.f. Charrabasti and O'Keefe, 1977; Katz and Tushman, 1979).

With effective diversity management, organizations can obtain the positive effects of diversity while at the same time minimizing the negative outcomes. As such, diversity can become a driver for innovation and help strengthen organizations. Furthermore, scientific institutions should recognize the value of the diversity of individual characters, skills, and positions, as well as value the potential for teamwork (Arlinghaus, 2014; Weingart, 2005). Yet, empirical data on how to get diversity in teams to work is still limited (Guillaume et al., 2013). Therefore, this research emphasizes four research questions as follows:

1. What degree does team diversity support CFTs to enhance successful research commercialization in a public research institute (PRI)?
    - Hypothesis 1a: High degree of difference in functions/departments.
    - Hypothesis 1b: High degree of difference in educational levels.
    - Hypothesis 1c: High degree of difference in educational fields/majors.
    - Hypothesis 1d: High degree of difference in years of work experience in each position.

2. What degree does team diversity influence the duration for achieving the first license agreement?
    - Hypothesis 2a: High degree of difference in functions/departments.

- Hypothesis 2b: High degree of difference in years of work experience in each position.

3. To what extent do the different technology contexts have an impact on CFTs in enhancing successful research commercialization in a PRI?

- Hypothesis 3: Different technology context has a significant impact on CFTs.

4. To what extent do the different technology contexts have an impact on the duration for achieving the first license agreement?

- Hypothesis 4: Different technology contexts have a significant impact on the duration for achieving the first license agreement.

3.2.2 Effect of top management support as an institutional factor supporting successful CFTs

Organizational capability is one of the factors for success in NPD projects. Bell et al. (2002, p.82) explained that "product development is a particularly salient area for organizational learning inquiry for a number of reasons: it is often a team-based pursuit, it requires a high degree of inter-functional coordination, and it is frequently project based."

In this study, the main institutional factor, which is explored in the context of a PRI, is top management because it is the key driver to support CFTs in order to maximize team performance. Existing private sector studies emphasize the importance of senior management support in promoting cross-functional integration (Harman et al., 2002; Maidique and Zirger, 1984; Parry et al., 2010). Senior management could increase the motivation and performance of the team members (Swink, 2003) and senior managers could provide a clear vision and agenda to inspire action (Harman et al., 2002). In the public sector, senior management support is seen as essential in overcoming cultural perceptions, particularly from employees expecting to follow traditional, vertical career pathways (Athanasaw, 2003). Kandemir et al. (2006) stated that the initiation of NPD was found to be influenced by the commitment of senior management, and the firm's resources were controlled by the senior management. This further confers with the research conducted by Ghorbani and Azamni (2014), which found that a senior management commitment was necessary for the initiation of a project. In addition, this plays a key strategic role in NPD in a typical Japanese company (Jacob and Herbig, 1998). A number of excellent reviews of upper echelon studies exist in the literature (Carpenter et al., 2004; Finkelstein and Hambrick, 1996). For example, Miller, Kets de Vries, and Toulouse (1982) investigated the question of whether a relationship exists between the personality of a CEO and his/her strategy making behavior. They found that firms led by confident and aggressive CEOs adopted riskier and more innovative strategies.

However, there was little difference between the private and public sector contexts. For example, although in the private sector the existence of senior management support is critical for the leadership to have the political strength to achieve membership within the teams, the seniority of the staff members can enable collaboration and team cohesion to reach the goals and reduce the need for senior management support (Oliveira, et al., 2015). In contrast, a top management commitment, encouragement and involvement, in terms of both financial and 'political' support is the most critical factor in the success of technology transfer/uptake in the public sector (Roupas, 2004). As a result, this research focuses on the following research question:

> How does top management contribute to CFTs in enhancing successful research commercialization in a PRI?

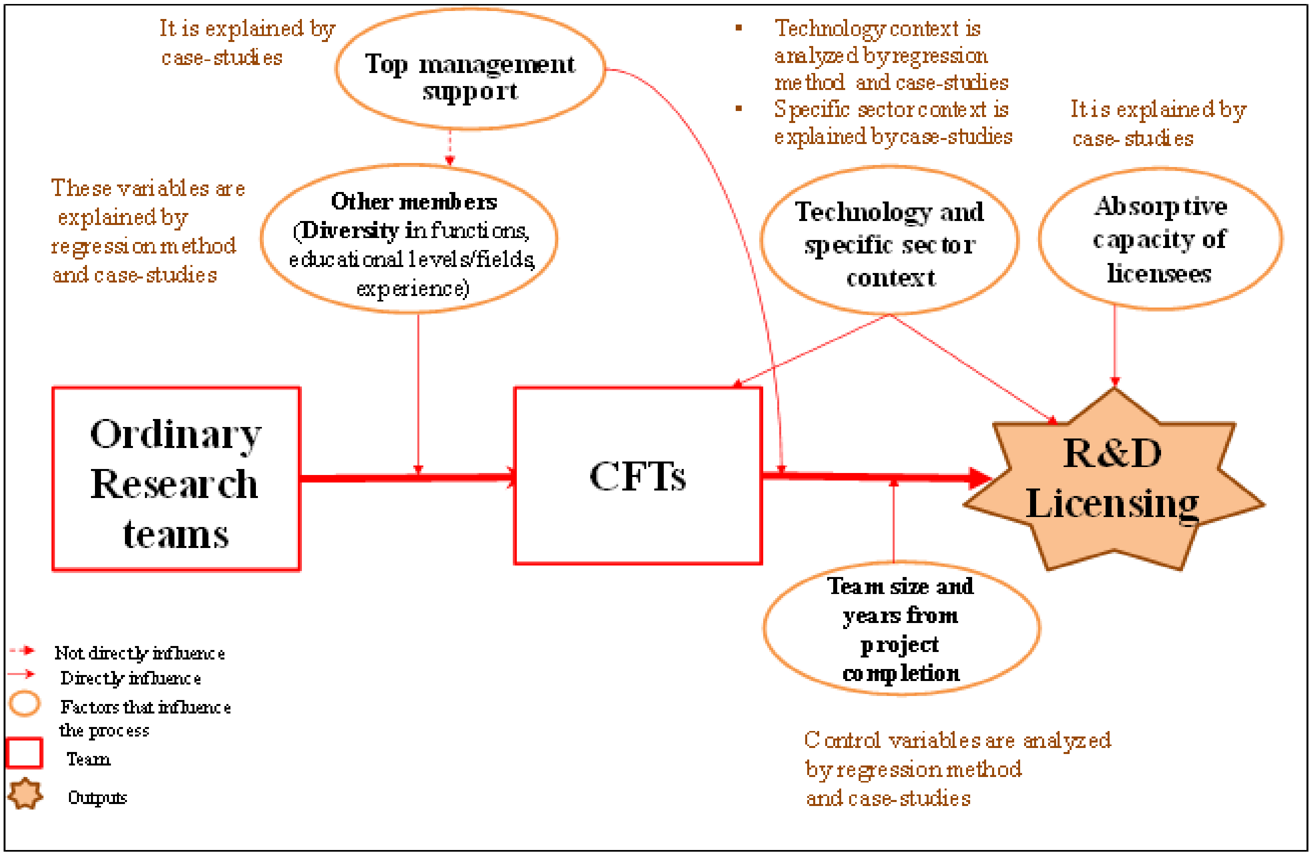
3.3 Research Framework

The use of CFTs is one of the key drivers for enhancing research commercialization in a PRI because the CFT approach is a means of overcoming these organizational silos and leveraging team members' diverse expertise as representatives of multiple governmental departments to improve organizational performance. Specifically, CFTs provide an opportunity to achieve transformative and sustainable change (Nanna, 2018).

Although the number of patents and licensing incomes are mostly considered as the key performance indicators of PRIs, they are not the indicators for research commercialization. A patent is the only exclusive right granted for an invention. It does not mean that if a research project has a patent it will be commercialized from the PRI to firms. Not all academic patents are licensed and not all patents earn income (OECD, 2004). On the other hand, high licensing revenue may come from one or two license agreements and the other license agreements may equally generate income. Therefore, it is not the suitable indicator for research commercialization. This information is confirmed by interviewing the President of the National Science and Technology Development Agency (NSTDA) of Thailand and a representative of the Institute of Physical and Chemical Research (RIKEN) of Japan. In contrast, R&D licensing is a statement of the firm's intention to invest a sum of money for developing an invention as a type of research utilization. In Thailand, when the PRIs submitted the expected R&D proposals including the expenditure per year and organization's performance in terms of research output; such as, the number of patents, publications, incomes, etc. to the government, the government informed that the research output did not show the capability of the PRIs for enhancing firms' efficacy. It requested the PRIs show the research utilization and research outcome from outstanding research projects before receiving approval of the government's budget. As a result, this present study uses licensed R&D projects as the unit of analysis because the lessons learned and best practices from licensed projects can show the government how public research delivers research outcomes for the beneficiaries.

In the research framework (Figure 3-2), there are five key groups of factors influencing the process for R&D licensing.

Figure 3-2: Research Framework



Source: The author

(1) Team diversity factors explained by the regression method and case studies

Ordinary research teams have other members that may have different levels of diversity in terms of functions/departments, educational levels, educational fields/majors and experience influencing the processes to form CFTs enhancing successful research commercialization. This research concentrates on the diversity in functions, educational background and experience because highly job-related attributes; such as, functional expertise and education background have a stronger impact on team performance than less job-related attributes like gender and ethnicity (Pelled, 1996). A person's educational background can be a significant indicator of their knowledge, skills, and capability. Furthermore, the choice of a specific educational major may reflect one's cognitive strength and personality (Holland, 1973). As in functional expertise, dissimilarity in educational background seems to have a positive impact on team performance because it fosters a broader range of cognitive skills (Cohen and Bailey, 1997). On the other hand, there is evidence that the heterogeneity of experience increases the chance that teams challenge past practices and are more open to change, thereby creating an impetus for organizational flexibility and strategic changes (Boeker, 1997; Dutton and Duncan, 1987; Katz, 1982).

(2) Technology and specific sector context

Different characteristics of technologies and different sectors affect both CFTs and licensing. In this study, the technology context is analyzed by the regression method and case studies, and the specific sector context is explained by case studies.

(3) Top management support factor explained by case studies

In terms of the institutional factor, senior management support, which means special support by executives, is the driving force for enhancing successful R&D licensing. For example, suggesting a team to have key members from different fields using their network to contact with key partners, prioritizing budgets for market trials, providing close advice about a market's needs, facilitating rapid processes involving licensing, etc. At the same time, senior management support may have an indirect influence on research teams by enhancing diversity.

(4) Control variables analyzed by the regression method and case studies
These are the size of the research teams and years from the project's completion.

(5) Absorptive capacity of licensees explained by case studies

Absorptive capacity is defined as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990). It is specific for every company and depends on the following elements: their current knowledge base, accumulated technological capability, and learning capability (Cohen and Levinthal, 1990; Kim, 1998). Based on the above theoretical perspectives and the available information from the interviews with researchers, the current study analyzes the level of the absorptive capacity from experience, key expertise, types of products, machinery and equipment.

3.4 Research Design

This research uses Thailand as a case study because it has been a recent arrival in trying to adopt and implement the innovation system approach (Bell, 2002; Intarakumnerd et al., 2002); furthermore, it is regarded as a typical developing country trying to upgrade its technical capability and reform the PRIs.

The Prayuth Chan-o-cha government, the current Thai government, has attempted to reform the Thai research and innovation management system. The government established the "National Research and Innovation Policy Council" on October 6, 2016, following the reform of the research and innovation system, as a single body to set the direction, policy and roadmap of research and innovation to facilitate national development. The National Council of Research and Innovation Policy comprises the Prime Minister (Council President), Deputy Prime Minister (Council Vice President No. 1), Deputy Prime Minister (Council Vice President No. 2), Minister of Interior, Minister of Finance, Minister of Foreign Affairs, Minister of Tourism and Sports, Minister of Social Development and Human Security, Minister of Agriculture and Cooperatives, Minister of Transport, Minister of Digital Economy and Society, Minister of Natural Resources and Environment, Minister of Energy, Minister of Commerce, Minister of Defence, Minister of Justice, Minister of Labor, Minister of Culture, Minister of Science and Technology, Minister of Education, Minister of Public Health, Minister of Industry, Director of the Bureau of the Budget, Secretary-General of the Council of State, Secretary-General of the National Economic and Social Development Board, Chairman of the Higher Education Commission, Chairman of the Council of University Presidents of Thailand, Chairman of the Council of Rajabhat University Presidents, Chairman of the Council of Rajamangala University of Technology Presidents, President of the Thai Academy of Science and Technology Foundation, Chairman of the Board of Trade of Thailand, Chairman of the Federation of Thai Industries, President of the Thailand Development Research Institute (TDRI), Secretary-General of the National Research Council of Thailand (NRCT), Secretary-General of the National Science Technology and Innovation Policy Office (STI Office), and not more than eight experts appointed by the

Prime Minister. Both the Secretary-Generals of the NRCT and the STI Office jointly share the secretariat role of the Council.

Moreover, the Prayuth Chan-o-cha government has formed the committee for reforming the integrative management of research and innovation chaired by the Deputy Prime Minister and is considering a 20-year research and innovation strategy (2017-2036). The plan will focus on the economic and social aspects, and consist of: 1) research and innovation for economic prosperity; 2) research and innovation for social and environmental development; 3) research and innovation for the building of the country's basic knowledge, and 4) the development of infrastructure, human resources, and national research and the innovation system (Thai government, 2018).

3.4.1 Organization level

To identify a Thai PRI, the National Science and Technology Development Agency (NSTDA), established in 1991, is represented as the largest public research institute in Thailand in terms of budget and researchers (Table 3-2). Furthermore, it is regarded as a typical PRI trying to increase research commercialization. Three specialized centers – Genetic Engineering and Biotechnology (BIOTEC), Metal and Materials Technology (MTEC), and Electronics and Computer Technology (NECTEC) – were integrated under the NSTDA's umbrella. These three centers were established in the 1980s in line with the global trend at the time and perceived the local needs for strong research capability in these areas. Later, the Nanotechnology Center (NANOTEC) was created in 2003. Moreover, the establishment of a new center, the Technology Management Center (TMC), in 2005 (Figure 3-3), can be seen as an example of an attempt to signal the change of the organizational vision toward a more open and service-oriented PRI with a high standard of research integrity. As a 'center', their importance has been substantially increased both in terms of budget received and visibility within the NSTDA and to external organizations (Intarakumnerd and Chairatana, 2008). To integrate all four national technology centers under the NSTDA together, the TMC has served as a linkage between scientists and the end users, and provides applicable technological services. Firstly, it has programs for upgrading the technological capability of Thai SMEs through the provision of technical experts (Industrial

Technology Assistance Program: ITAP) and commercialization of NSTDA's intellectual property. Secondly, it expands knowledge-based companies and entrepreneurs through the provision of financial assistance for technological development, R&D facilities in the Thailand Science Park, Software Park, and incubators for nurturing start-up entrepreneurs.

Figure 3-3: NSTDA’s Technology Management and Technology Centers

Source: The author

In addition to budget, the NSTDA has almost seven times more research staff than the total number of research staff of the Thailand Institute of Scientific and Technological Research (TISTR). In comparing the Thai PRIs, the NSTDA was the only PRI that had a research focus covering four technologies. That is the reason that the case studies of NSTDA can be generalized for other PRIs (Table 3-2).

Table 3-2: Comparison among Thai PRIs in Terms of Budget, Research Focus, Research Staffs

Issues	National Science and Technology Development Agency (NSTDA)	Thailand Institute of Scientific and Technological Research (TISTR)	Geo-Informatics and Space Technology Development Agency (GISTDA)	Synchrotron Light Research Institute	National Astronomical Research Institute of Thailand (NARIT)	Hydro and Agro Informatics Institute (HAII)
Budget (USD millions)	113	27	14	10	8	6
Research fields	4 fields: • Biotechnology • Electronics & Computer technology • Metal and materials technology • Nanotechnology	• Bio-industries • Sustainable Development	Geo-informatics and space technology	Synchrotron Light	Astronomy	Hydro and Agro Informatics
Number of employees	2,692	886	326	153	103	113
Research staffs	1,832	264	25	43	3	30

Source: NSTDA annual report, 2014, p.11. TISTR annual report, 2015, p.37, 78. GISTDA annual report, 2014. p15, 92. Synchrotron annual report, 2014, p.123, NARIT annual report, 2014, p11, 66. HAII website and HAII annual report, 2012, p. 106.

Moreover, during the period of 2011-2015, the NSTDA was regarded as a typical PRI trying to increase research commercialization (Figure 3-4).

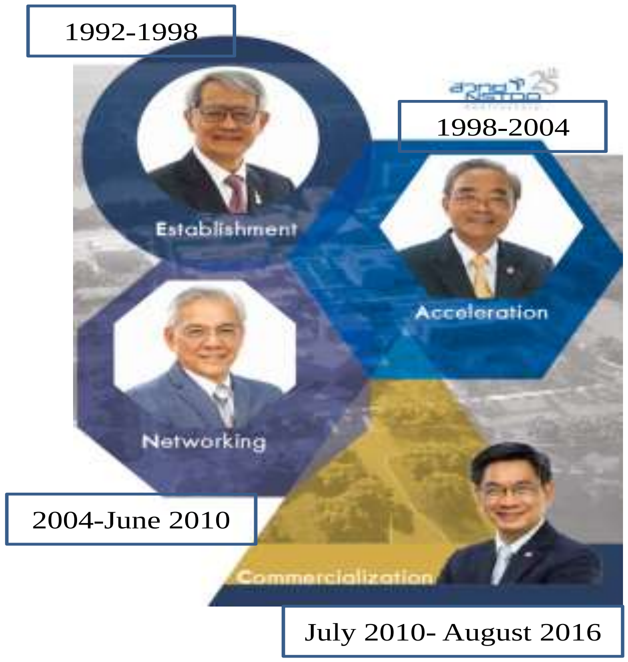


Figure 3-4: 25 years of NSTDA

Source: NSTDA, 2017

The experience and technological expertise of Dr. Thaweesak Koanantakool (NSTDA President between 2010 and 2016) was different from three former NSTDA Presidents because he had work experience in the private sector. He was co-founder of the Telbiz Company Limited, an innovative company in the Thai language system for computer and electronic mail, co-founder of the Advanced Research Group Company Limited (AR Group), and co-founder of the first Internet service provider, the Internet Thailand Company Limited. Moreover, he had expertise in electronics and information technology, computer hardware, software localization, e-commerce, IT law and computer security. Therefore, his past experience and key expertise was the important factor that influenced the decision-making about innovation and research management in the NSTDA. This was as follows:

- **NSTDA Investors' Day Exhibition**

From 2010 to 2016, the NSTDA held the NSTDA Investors' Day to exhibit research results to act as a bridge between "investors" and "inventors" with the idea to commercialize over 20 innovations and bring them to the marketplace every year. Dr. Thaweesak Koanantakool said:

> *"Technology-based businesses are a key force behind inventions, and new innovations and technology help to raise Thailand's competitiveness against other countries and drive the country's economic growth. These are the reasons why the NSTDA plans to organize the NSTDA Investors' Day fair to bridge the industrial, investment and financial sectors with the science sector, paving the way for investment in technology-based businesses that will contribute to economic growth and the social development of the country. This fair provides an opportunity for NSTDA researchers to showcase their inventions to investors and exchange ideas with their peers, as well as to stay informed of the demands of the industrial sector to further their research and development." Activities at the NSTDA Investors' Day included a keynote address entitled "The Future of Thailand's Science Sector in the Next 10 Years" and an exhibition of innovations, business negotiations and services offered by the NSTDA's partner firms. In addition to outstanding ready-for-market innovations, the fair also exhibited over 20 innovations by the four national research centers under the NSTDA, which can be rapidly further developed for commercialization" (NSTDA, 2010).*

An example of successful cases was a licensing agreement of a portable dissolved oxygen test kit called a 3-minute DO Test Kit, between BIOTEC-NSTDA and Eco Scientific Company Limited, which was signed on the NSTDA Investors' Day 2013 (Figure 3-5). The 3-minute DO Test Kit was developed by Dr. Srung Smanmoo, BIOTEC researcher of the Bioresources Technology Unit. The kit can give accurate quantitative results of dissolved oxygen concentration in water with a simple 3-minute procedure (NSTDA, 2013a).

Figure 3-5: 3 Minute DO Test Kit

Source: NSTDA, 2013a.

This invention is a result of the collaboration between BIOTEC-NSTDA and Eco Scientific Company Limited with an aim to develop a high-quality portable dissolved oxygen test kit for commercialization in response to customers' needs. The company explained that:

> *"There has never been a portable dissolved oxygen test kit produced in Thailand. The kit invented by BIOTEC is high quality, but less expensive compared to imported ones. Our company is proud to acquire this technology and make it available to Thai consumers. Production will commence next year, starting at 100-200 tests/month. Apart from the domestic market, Eco Scientific is looking into the export market in the near future (NSTDA, 2013a)."*

- **NSTDA Five-Year Strategic Plan (2010-2016)**

Dr. Thaweesak Koanantakool (NSTDA President) said:

> *"The NSTDA has made it explicit in its present five-year strategic plan that our research and development activities have to align with the national agenda, both the long-term direction and numerous short-term needs of the country. On a*

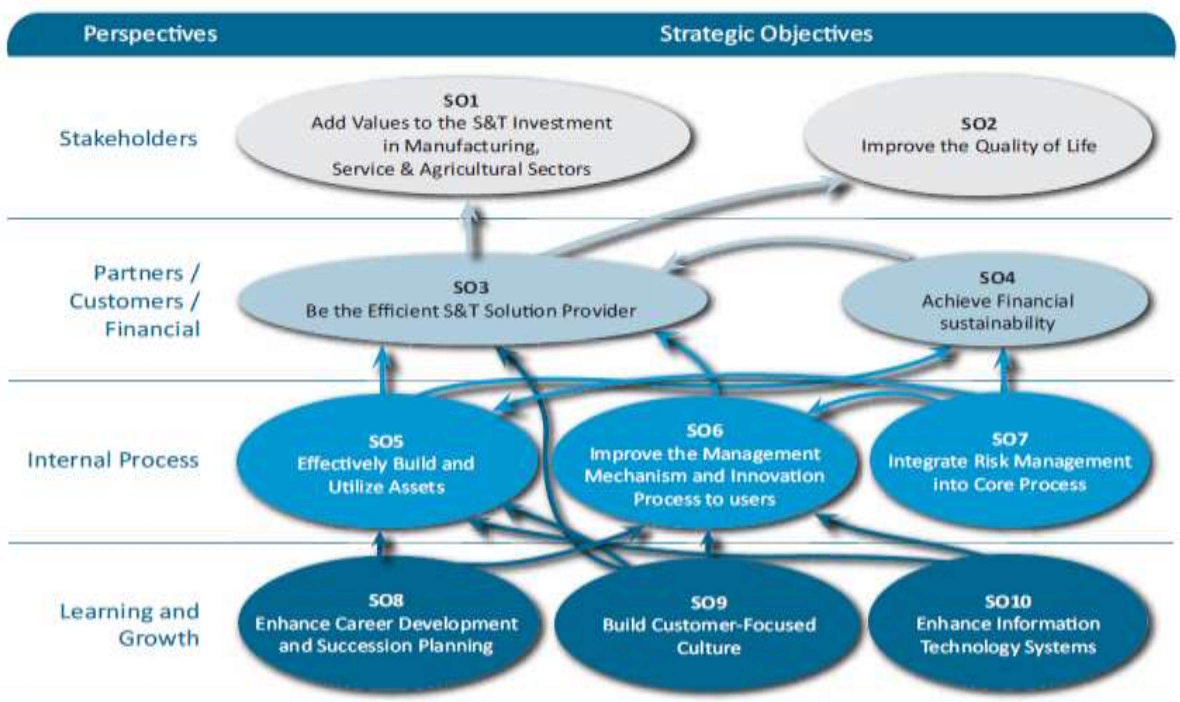
long-term prospect, the current strategic plan has focused on R&D activities in five key industrial and social clusters; namely, agriculture and food, energy and the environment, health and medicine, resources, communities and the underprivileged, and manufacturing and service industries. To do this, it is necessary to really align ourselves with the national agenda and work with the private sector on their industrial targets. We have to focus on the activities in the five clusters. Then, we have to make sure that our stakeholders within each cluster have access to and then apply our R&D to their activities. Without putting some good research into commercial use or social use, all research results will achieve nothing. If that is the case, it will be difficult to justify our contribution to the socio-economic development of the country. Thus, the people have actively engaged with potential users or manufacturers, sometimes even before the start of the project. The arts of transferring know-how and intellectual property licensing are critical success factors of a research institute (MEXT, 2013)."

- **Innovation and project management**

With regards to the NSTDA Five-Year Strategic Plan (2012-2016), the strategy map based on four perspectives consisting of stakeholders; partners; customers and finance; internal, and learning and growth of the balanced scorecard were determined. The NSTDA has set 10 objectives in its strategy map.

In the sixth strategic objective which was to improve the management mechanism and innovation process to users, one of the internal perspectives (Figure 3-6), the NSTDA had the aim of making the organization be the first in stakeholders' minds when they thought of science and technology. As a result, the agency had to improve the flexibility and speed of the processes in all systems to be appropriate for internal and external changes including rapidly changing technology. These included research management systems from innovation to users, research delivery, budgetary planning, and internal and external communications. For example, the NSTDA applied the Stage-Gate approach and Technology Readiness Levels (TRLs) assessment in the budgeting and planning processes for expanding investment and commercial utilization and focused on large multidisciplinary projects to deliver research output to users. In practice, the NSTDA used a modified Stage-Gate approach in the Giga Impact Initiative (GII) program and applied TRLs assessment in research project management. Furthermore, the NSTDA encouraged researchers to consider about the potential impacts from their research by writing a pre impact assessment before doing research.

Figure 3-6: NSTDA strategy map for the period 2012-2016



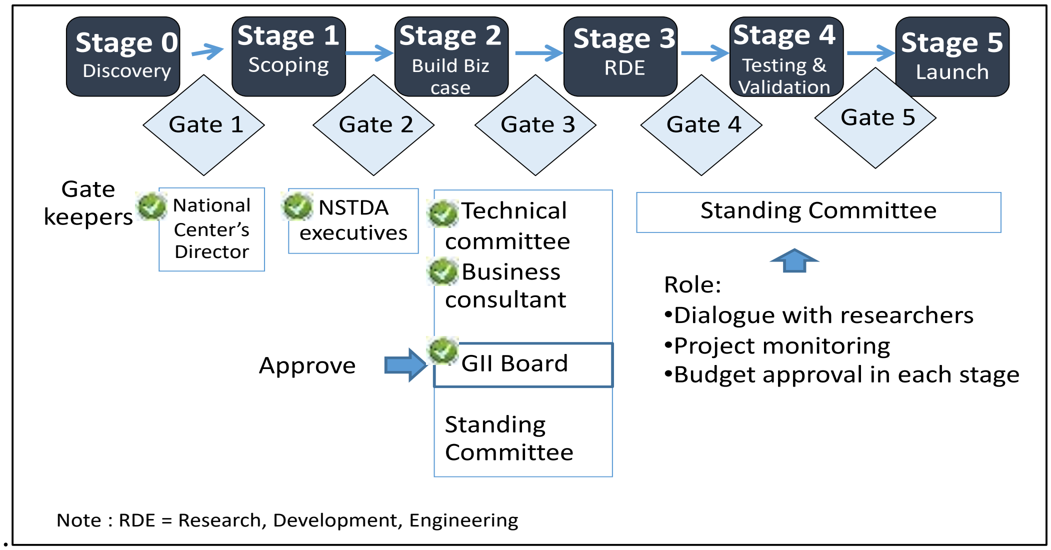
Source: NSTDA strategic plan, 2012.

❖ **Giga Impact Initiative (GII) and focusing on a cross-functional teams approach**

The Giga Impact Initiative (GII) covered the period between 2013 and 2016, which the research output could be transferred to real users and create an economic impact of one billion Baht or approximately 300 million USD after five years of the project's completion. The NSTDA offered support in all aspects: human resources, budget, equipment and infrastructure. From 2013-2016, the NSTDA used a modified Stage-Gate approach for five GII projects, which had four main gatekeepers. The first gatekeeper was the National Technology Center's Director, and the second gatekeeper was the NSTDA executives. The third gatekeeper was the GII Board whose members were the NSTDA President and external experts from both academia and industries. Before entering the GII Board, there were two committees that considered and provided technical and business recommendations for the researchers. The fourth gatekeeper was a standing committee. Each project had its own standing committee to dialogue with the researchers, monitor the project, and approve both the budget and research plan, as well as give technical and business suggestions to the researchers (Figure 3-7).

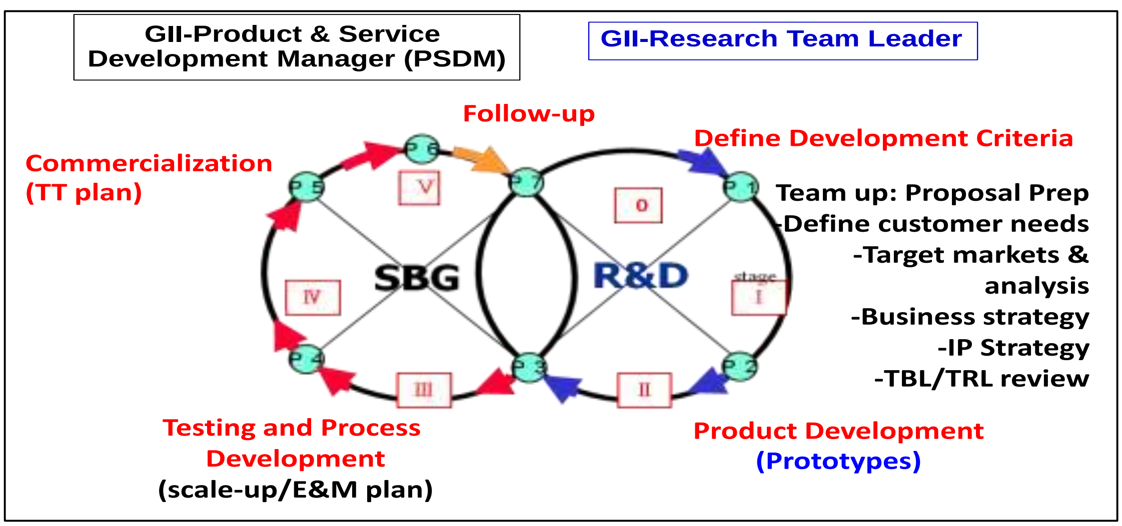
More importantly, the NSTDA tried to focus on a CFTs approach in the GII project management. The NSTDA executives appointed the NSTDA technology transfer officers (TTOs) as the Product and Service Development Managers (PSDM), a new position. The functions of the PSDM were to collaborate with the GII research team leader to prepare the proposal in terms of defining the customers' needs, market analysis, business strategy, intellectual property (IP) strategy and TRLs assessment. Moreover, the PSDM were responsible for obtaining feedback from potential customers and communicating with the GII research team leader in order to adjust the research plan and technology transfer plan, as well as develop prototypes related to the market's requirements (see Figure 3-8). The main concept behind this appointment was to stimulate cooperation between the research team and TTOs as a CFT approach to enhance successful research commercialization. If researchers know the market's needs before doing research and preparing for technology transfer, this will lead to successful research commercialization. This activity differed from the traditional technology transfer process in the PRIs, as TTOs usually did not get involved in the concept development, R&D, and prototype testing.

Figure 3-7: A modified Stage-Gate approach in the Giga Impact Initiative (GII) program



Source: NSTDA, 2014

Figure 3-8 Cross-functional team model in the GII program



Source: NSTDA, 2013

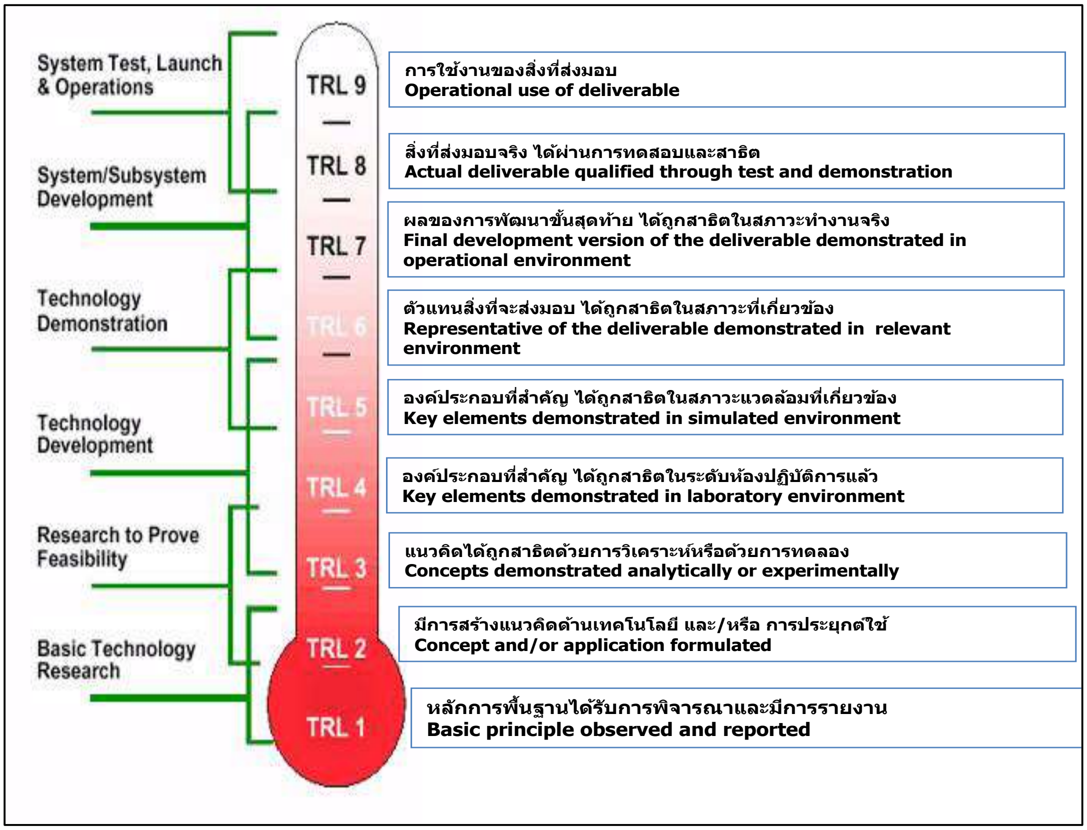
❖ **Pre Impact Assessment and Technology Readiness Levels (TRLs) Assessment**

Because of the limitation of the government budget for PRIs, the NSTDA has to stimulate researchers to deliver economic and societal impacts from their research in order to show the Thai people and Thai government that the NSTDA's research can solve national problems and enhance innovative capabilities of Thai firms. Therefore, the NSTDA executives requested the researchers who used a budget of more than one million Baht to complete a pre impact assessment form before submitting their proposal. The pre impact assessment form consists of three sections. The first section is about the beneficiaries, market needs, and objective of the research. The second section is about the types of research output. In case of prototypes, researchers have to identify the current TRL and the target TRL of their research. The TRL uses a nine-level metric scale for describing the maturity of the technology. Each level characterizes the progress in the development of the technology from the idea (level 1) to the full deployment of the product in the marketplace (level 9) (Figure 3-9)[3].

The TRL is used as a program management tool, a consistent comparison of maturity between different types of technology, and a communication tool between technologists and managers (Ikeda et al., 2010). Researchers have to think about the standards or regulations relating to their research results. As a result, this part is very important. If the prototype/research results are certified by recognized international standards/organizations, most companies will be confident about the efficiency of the prototypes or Thai products.

[3] http://www.innovationseeds.eu/virtual_library/knowledge/tlr_scale.kl

Figure 3-9: Technology Readiness Levels (TRLs)



Source: NSTDA, 2013

❖ Systematic criteria for the economic impact assessment of research

In addition to the pre impact assessment, the NSTDA has systematic criteria for the economic impact assessment of research as follows (NSTDA outcome and economic impact assessment guideline, 2014):

1) The assessment provides accurate and credible evidence-based results of the NSTDA's R&D investments. Impact assessment activities are necessary to ensure the NSTDA's accountability to the public and guarantee the value for the NSTDA's investments.
2) To consider the appropriate timing for the outcome and impact assessment, the evaluators study the expected adoption profile in different periods. In particular, four periods may be identified: (a) the period of R&D with no adoption, (b) the period of

early adoption, (c) the period of peak adoption, and (d) the period of the declining adoption rate due to replacement by other technologies.

3) To accurately identify a counterfactual, the evaluator chooses a situation similar to the current one except that it does not include the NSTDA's projects. The counterfactual is set to be as realistic as possible. For example, it may be a case with the latest technologies available in the market in the absence of the NSTDA's technologies.
4) To avoid double counting, the evaluators identify user groups from the beginning to the end period, and assess the economic impacts on each group clearly based on the concept of economic surplus.
5) To determine the NSTDA's attribution, the estimation is based on solid data; such as, the input cost shares of the project's R&D and implementation costs.

Moreover, the outcomes and impacts of the NSTDA projects are currently assessed for every project after its completion. However, such assessment provides at best rough estimates. In addition to the preliminary assessment, the NSTDA considers assessing the longer-term outcomes and impacts of some selected projects through "adoption studies" and "impact studies".

1) An adoption study is aimed at measuring the adoption of the project's outputs by users and assessing its outcomes and impacts in greater detail. In particular, it analyzes the adoption of the R&D outputs from the initial to the final user groups. In terms of timing, the adoption study is conducted within two-three years after the project's completion depending on the nature of the project. Due to the complexity of the study and to avoid a potential conflict of interest, the NSTDA has external consultants for evaluating the adoption study. Lead researchers and other specialists in the field (peers) are encouraged to provide basic information to set up the framework for the data collection and analysis.

As conducting an adoption study is quite costly, the NSTDA will only select some projects for the study. The projects chosen for the study may include:

- Research programs in the target clusters that address national problems; such as, the rice program. The target groups and outcomes should be explicitly identified.
- Projects that have relatively high R&D costs and should be evaluated to ensure accountability to the public.
- Research projects that are likely to have high impacts and are volunteered to be evaluated.

2) An impact assessment study is aimed at comprehensively assessing the impacts of the R&D outputs. As a result, detailed data on the benefits and costs need to be gathered and analyzed. Due to its high cost, an impact assessment study is limited to projects or programs with high initial impacts and/or a high adoption rate.

- Due to the complexity of the study and to avoid a potential conflict of interest, the NSTDA will consider tendering the study to external consultants. The impact assessment study is conducted approximately four-10 years after the project is completed depending on the nature of the project (NSTDA outcome and economic impact assessment guideline, 2014).

3.4.2 Project level

The unit of analysis used in this research is R&D project. Scope of the study is potentially licensable R&D projects between 2011 and 2015.

3.5 Research Method

This research applied both quantitative and qualitative methods as a mixed methods approach. The field of mixed methods research is relatively new with major work in developing it stemming from the middle to late 1980s. Early thoughts about the value of multiple methods, called mixed methods, resided in the idea that all methods had biases and weaknesses, and the collection of both quantitative and qualitative data neutralized the weaknesses of each form of data. Triangulating data sources, a means for seeking convergence across qualitative and quantitative methods, was born (Jick, 1979). By the early 1990s, mixed methods turned toward the systematic convergence of quantitative and qualitative databases, and the idea of integration in different types of research designs emerged (Creswell, 2014). With the mixed methods approach to research, researchers incorporate methods of collecting or analyzing data from the quantitative and qualitative research approaches in a single research study (Creswell, 2003; Johnson and Onwuegbuzie, 2004; Tashakkori and Teddlie, 2003). That is, researchers collect or analyze not only numerical data, which is customary for quantitative research, but also narrative data, which is the norm for qualitative research in order to address the research question(s) defined for a particular research study. As an example, in order to collect a mixture of data, researchers might distribute a survey that contains closed-ended questions to collect the numerical, or quantitative, data and conduct an interview using open-ended questions to collect the narrative, or qualitative, data (Williams, 2007).

3.5.1 Quantitative approach

Quantitative research begins with a problem statement and involves the formation of a hypothesis, a literature review and a quantitative data analysis. It employs strategies of inquiry; such as, experiments and surveys, and collects data on predetermined instruments that yield statistical data" (Creswell, 2003). It also involves data collection that is typically numeric, and the researcher tends to use mathematical models as the methodology of data analysis. There are three broad classifications of quantitative research: descriptive, experimental and causal comparative (Leedy and Ormrod, 2001). The descriptive research approach is a basic research method that examines the situation, as it exists in its current state. This involves identification of the attributes of a particular phenomenon based on an observational basis, or the exploration of a correlation between two or more phenomena.

During the experimental research, the researcher investigates the treatment of an intervention into the study group and then measures the outcomes of the treatment. In causal comparative research, the researcher examines how the independent variables are affected by the dependent variables and involves cause and effect relationships between the variables. The factorial design focuses on two or more categories with the independent variables as compared to the dependent variables. The causal comparative research design provides the researcher the opportunity to examine the interaction between independent variables and their influence on dependent variables (Vogt, 1999).

To answer two research questions, the study relies on Poisson regression analysis because the number of license agreements as a dependent variable is asymmetric and has left-skewed distribution. Poisson regression is similar to regular multiple regression except that the dependent (Y) variable is an observed count that follows the Poisson distribution. Thus, the possible values of Y are the nonnegative integers: 0, 1, 2, 3, and so on. It is assumed that large counts are rare (NCSS, 2007). Poisson distribution is commonly used to describe the pattern of random point-like events in 1-, 2- and 3-dimensions or, more typically, to provide the model for randomness against which an observed event's pattern in time or space may be compared. If events occur randomly and independently, *at a constant rate* (in time) or with a *constant density* (in space), then the *count* of these events per unit time or per unit area will conform to a Poisson distribution and the pattern of occurrence is described as a *Poisson process* (de Smith, 2015).

In practical applications, Poisson distribution should only be used where the number of events observed is reasonably large (typically >25, and preferably >100) and the probability of an individual event occurring at any particular time or place is small (typically <0.10). Events are assumed to occur entirely independently and do not occur simultaneously, or at the same location. In many applications of the Poisson distribution, the mean, λ, is not large, but there is no requirement for λ to be small (ibid). In the Poisson regression model, the Poisson incidence rate μ is determined by a set of k regressor variables (the X's). The expression relating to these quantities is:

$$\mu = t\exp(\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k)$$

Note that often, $X_1 \equiv 1$ and β_1 is called the intercept. The regression coefficients $\beta_1, \beta_2, \ldots, \beta_k$ are unknown parameters that are estimated from a set of data. Their estimates are labeled $b_1, b_2, \ldots, b_k$. Using this notation, the fundamental Poisson regression model for an observation *i* is written as:

$$\Pr(Y_i = y_i \mid \mu_i, t_i) = \frac{e^{-\mu_i t_i} (\mu_i t_i)^{y_i}}{y_i!}$$

Where

$$\begin{aligned} \mu_i &= t_i \mu(\mathbf{x}_i' \boldsymbol{\beta}) \\ &= t_i \exp(\beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}) \end{aligned}$$

That is, for a given set of values of the regressor variables, the outcome follows the Poisson distribution (NCSS, 2007).

This study adopted a quantitative research approach. The variables are summarized in Figure 3-3. Poisson regression analysis was used to estimate the number of license agreements. The dependent variable was the number of license agreements, and there were 13 independent variables in seven groups: type of technology, degree of difference in functions/departments, degree of difference in educational levels, degree of difference in educational fields, degree of difference in experience, team size, and timing of the project's completion. Most independent variables were dummy variables except the team size. Jaccard (2001) clearly explained the concept about how to create and interpret dummy variables. A dummy variable is created by the analyst to represent the group membership on a variable. For example, in the case of gender, a dummy variable can be created and assign a 1 to all males and a 0 to all females. This method of scoring is called "dummy coding" or "indicator coding" and involves assigning a 1 to all members of one group and a 0 to everyone else. When a qualitative variable has more than two levels, it is necessary to specify more than one dummy variable to capture the membership in the different groups. In general, one needs m – 1 dummy variables, where m is the number of levels of the variable. For instance, a predictor variable could be a person's political party affiliation that could take on three values: Democrat, Republican, or Independent. In this case, 3 −1 = 2 dummy variables that would be needed to represent the party affiliation. For the first dummy variable, DD, all Democrats would be assigned a 1 and everyone else a 0. For the second dummy variable, DR, all Republicans would be assigned a 1 and everyone else a 0. Although a third dummy variable for Independents would be created and assigned a 1 and everyone else a 0, such a variable would be completely redundant with the other two dummy variables. Once it is known whether someone is a Republican by means of the first two dummy variables, he or she would be an Independent. The reasoning behind this is more evident if one considers a dummy variable for gender. A single dummy variable would be created to discriminate the two groups whereby males are assigned a score of 1 and females a score of 0. If a second dummy variable that assigns a score of 1 to females and a score of 0 to males was created, it would be negatively correlated with the first dummy variable and, hence, redundant. With dummy coding, the group that does not receive a 1 on any of the dummy variables is called the reference group for that variable. In the examples above, the reference group for gender is females and for party affiliation the reference group is Independents (Jaccard, 2001).

Table 3-3: Variables used Poisson Regression Analysis

Variables name	Definition	Type of variables
1. Dependent variable		
1.1 License ($\hat{Y}$)	Number of license agreements	Numerical variable
2.Independent variables		
2.1 Type of technology	Nanotechnology is a reference group	
2.1.1 ICT (x_1)	Information and communications technology	Dummy variable (1 = ICT; 0 =Biotec; 0=Mtec;0 =Nanotec)
2.1.2 Biotec (x_2)	Biotechnology	Dummy variable (0 = ICT; 0 =Biotec; 1=Mtec; 0 =Nanotec)
2.1.3 Mtec (x_3)	Materials technology	Dummy variable

Variables name	Definition	Type of variables
		(0 = ICT; 0 =Biotec; 0=Mtec; 1 =Nanotec)
2.2 Degree of difference in functions/departments	Low degree is a reference group (All members work in same laboratory in the PRI)	
2.2.1 Mfunc (x_4)	Medium degree (Members include different laboratories/divisions and technology transfer office in the PRI)	Dummy variable (1=Medium; 0 =High; 0=Low)
2.2.2 Hfunc (x_5)	High degree (Having external partners outside the PRI)	Dummy variable (0=Medium; 1 =High; 0=Low)
2.3 Degree of difference in educational levels	Low degree is a reference group (Same educational level) For example, all members educated from master degree.	
2.3.1 Medulevel (x_6)	Medium degree (Combination of researchers having two different educational levels; doctoral degree, master degree and bachelor degree) For example, the project has members educated from both doctoral degree and master degree.	Dummy variable (1=Medium; 0 =High; 0=Low)
2.3.2 Hedulevel (x_7)	High degree (Combination of researchers having more than two different educational levels) For example, the project has	Dummy variable (0=Medium; 1 =High; 0=Low)

Variables name	Definition	Type of variables
	members educated from doctoral degree, master degree and bachelor degree.	
2.4 Degree of difference in educational fields/majors	Low degree is a reference group (Less than 50% of the team having different educational fields)	
2.4.1 Medufields (x_8)	Medium degree (Between 50 and 75% of the team having different educational fields)	Dummy variable (1=Medium; 0 =High; 0=Low)
2.4.2 Hedufields (x_9)	High degree (More than 75% of the team having different educational fields)	Dummy variable (0=Medium; 1 =High; 0=Low)
2.5 Degree of difference in experience	Low degree is a reference group (Same range of working experience)	
2.5.1 Mexperience (x_{10})	Medium degree (Two different ranges of working experience)	Dummy variable (1=Medium; 0 =High; 0=Low)
2.5.2 Hexperience (x_{11})	High degree (More than two different ranges of working experience)	Dummy variable (0=Medium; 1 =High; 0=Low)
2.6 Team size (x_{12})	The number of members in each project	Numerical and control variable
2.7 Years from project completion (x_{13}**)**	The number of years between the completed years of Potentially Licensable Projects (PLPs) and counting as the number of licensed project in 2017 (The number of	Numerical and control variable

Variables name	Definition	Type of variables
	licensed projects is as of the end of 2017)	

Source: The author

- **The purpose and contribution of the statistical (Poisson regression) analysis**

  Although the sample is not representative of the entire projects conducted by the NSTDA, the Potentially Licensable Projects (PLPs) can represent the specific characteristic of team diversity and the best practices of CFTs in different technologies. It is very useful for PRIs to form CFTs for achieving license agreements. Therefore, the purpose of Poisson regression analysis is to find significant factors in terms of team diversity and different technologies for achieving license agreements.

- **Scope of the study**

  This focused on potentially licensable R&D projects between 2011 and 2015. “Potentially Licensable Projects (PLPs) had been chosen out of all the projects that had been completed within a given year. Therefore, there were a total of 173 projects. When the PLP was licensed between a completed year and 2017, it was counted as the number of the licensed project for each project. For example, among 40 PLPs in 2011, there were 27 PLPs licensed in 2011; three PLPs licensed in 2012 and two PLPs licensed in 2013 (see Table 3-4).

  However, the number of licensed projects ends at 2017. As a result, each PLP may have different timing between the project’s completion and 2017. For example, the PLPs in 2011 had longer time (seven years) between 2011 and 2017 for achieving license agreements compared to the PLPs in 2015 which only had a duration of three years between 2015 and 2017. Therefore, this was analyzed as a control variable in the Poisson regression analysis (see Chapter 4).

Table 3-4: Number of licensed projects compared with the number of completed projects between 2011 and 2015

	2011	2012	2013	2014	2015	Total
Total No. of research projects	1,609	1,678	1,629	1,770	1,619	8,305
• No. of ongoing projects	662	634	562	603	573	3,034
• No. of new projects	565	563	574	580	592	2,874
• No. of completed projects	382	481	493	587	454	2,397
No. of Potentially Licensable Projects (PLPs) chosen out of all completed projects within a given year	**40**	**39**	**32**	**32**	**30**	**173**
• No of the licensed PLPs between a given year and 2017	32	31	23	30	28	144
• The exact number of licenses counted for each project	2011: 27 projects 2012: 3 projects 2013: 2 projects	2012: 22 projects 2013: 7 projects 2014: 3 projects	2013: 17 projects 2015: 3 projects 2016: 3 projects	2014: 27 projects 2015: 2 projects 2016: 1 project	2015: 23 projects 2016: 2 projects 2017: 3 projects	

	2011	2012	2013	2014	2015	Total
• Percentage of No. of the licensed projects compared with No. of finished research projects	8.4	6.4	4.7	5.1	6.2	6.0
• Percentage of No. of the licensed projects compared with No. of potentially licensable projects	80	79	72	94	93	83
• No. of the unlicensed PLPs between a given year and 2017	8	8	9	2	2	29
• No. of responses	37	34	30	32	30	163

Source: The author

Note: The number of licensed projects is as the end of 2017.

In terms of the selection procedure for the PLPs, the NSTDA had three steps as follows:

(1) Laboratory heads, researchers and the Research Support Division discussed among each other and selected the R&D projects that were expected to be completed by a given year. After selecting them, the Research Support Division sent the list of the completed projects to the Business Development Division.

(2) According to the list of completed projects, the Business Development Division chose only the projects that had received registered patents or were filing patents and

sent them to the Technology Licensing Office (TLO). Nevertheless, it did not only choose the successful projects because not all academic patents were licensed and not all patents earned income (OECD, 2004).

(3) With regards to the lists of the projects from the Business Development Division, the TLO matched the list from Item 2 and the initial requirements of the expected firms that were sent to the TLO. As a result, between 30 and 40 potentially licensable R&D projects (PLPs) were concluded, which related to the maximum capacity of the TLO in each year.

After finalizing the PLPs, the TLO contacted the customers and informed them about the list of the expected research outputs. However, this did not mean that all PLPs were licensed to companies because of many conditions. Some projects signed license agreements after finishing the projects. On the other hand, some projects could not achieve license agreements (unlicensed projects) in a given year because of several reasons. For example, the customers wanted to have new collaborative projects for developing complex prototypes more than the current project or after discussing the details of the expected research outputs, they found that these outputs could not match the real needs of firms.

Since 2014, the TRL assessment had added as one of the TLO's criteria. NSTDA executives intended to use TRL assessment as a tool to identify technology maturity. The selecting PLPs process was not biased because TLO chose PLPs from both low TRLs and high TRLs depending on the characteristic of each technology. For example, drug projects had been chosen as PLPs since the low TRLs and they were finally licensed by customers, whereas the software projects which had high TRLs were selected to be PLPs. Some software projects were not licensed by the beneficiaries. As a result, it did not refer that the PLPs including the high and low TRL projects were successful projects because most PLPs based on the technology push model and they were neither utilized for commercial purpose nor licensed by any customers.

After selecting PLPs in 2014 and 2015, NSTDA executives set a new policy to stimulate the market officers and the business development officers in order to increase the number of the licensed projects out of PLPs. The main responsibility of them was to actively find the expected licensees after the projects completed and were selected as the PLPs. As a result, the percentage of the licensed projects compared with the number of PLPs increased from 80% in 2011 to more than 90% in 2014 and 2015.

Although the good research management was considered as the important factor, the key success factor for achieving research commercialization was to have the CFT in terms of educational fields/expertise and functions in order to resolve the research problems. For example, some projects had the good project managers and high TRLs but the research team did not have the high diversity of functions and medium/high diversity of educational fields/expertise for resolving the specific problems of customers. As a result, these projects were not successful in terms of research commercialization.

- **Data collection**

  Data collection was conducted by sending questionnaires (see the Appendix) to one member either a head of a project or a member of a project as the representative.

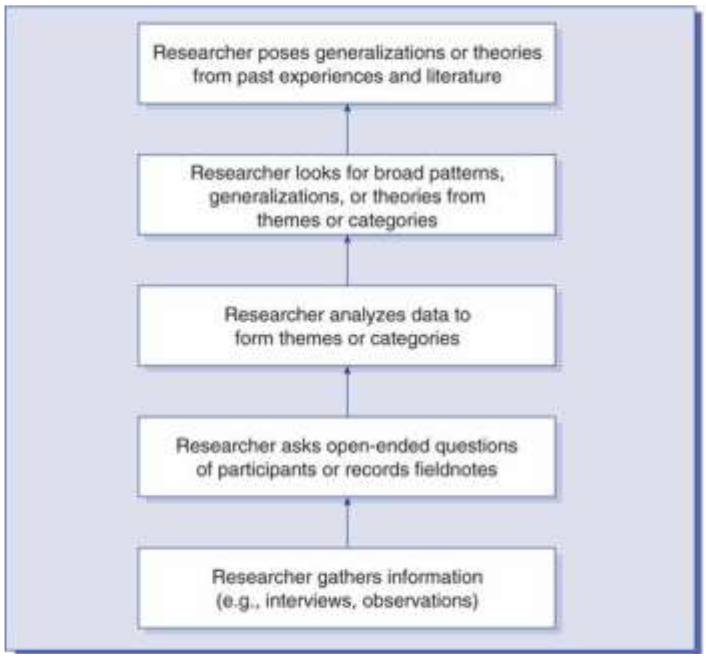
- **Limitation of this study**

  Compared with the total research projects, this research had a small number of licensed projects. A total of 173 projects were selected by licensing staff as potentially licensable projects out of 2,397 completed research projects (Table 3-4). As a result, the sample selection may be biased because it mostly focused on the licensed projects.

3.5.2 Qualitative approach

Qualitative research is a holistic approach that involves discovery. It is also described as an unfolding model that enables the researcher to develop a level of detail from high involvement in the actual experiences (Creswell, 1994).

Figure 3-10: The inductive logic of research in a qualitative study



Source: Creswell (2014)

The logic of this inductive approach is shown in Figure 3-10. The researcher begins by gathering detailed information from participants and then forms this information into categories or themes. These themes are developed into broad patterns, theories, or generalizations that are then compared with personal experiences or with existing literature on the topic (Creswell, 2014). As a result, this research is conducted by applying a case study analysis in order to confirm and explain the regression results and evaluate the impact of senior management on CFTs in delivering successful licensing. The projects selected for the case studies are either an outstanding project in terms of achievement evaluated by the NSTDA or has a high number of license agreements.

The following interview issues consist of two main topics:

1) Background information and team diversity factors:

- Research problems.
- Key milestones.
- Degree of diversity in functions/departments, educational levels, educational fields/majors and experience.
- Cooperation between the researcher and technology transfer officer.
- Major changes of the project in terms of the objectives and management practices.
- Comparison between the commercialization result before and after adopting a CFT.

2) Technological system and innovation model.

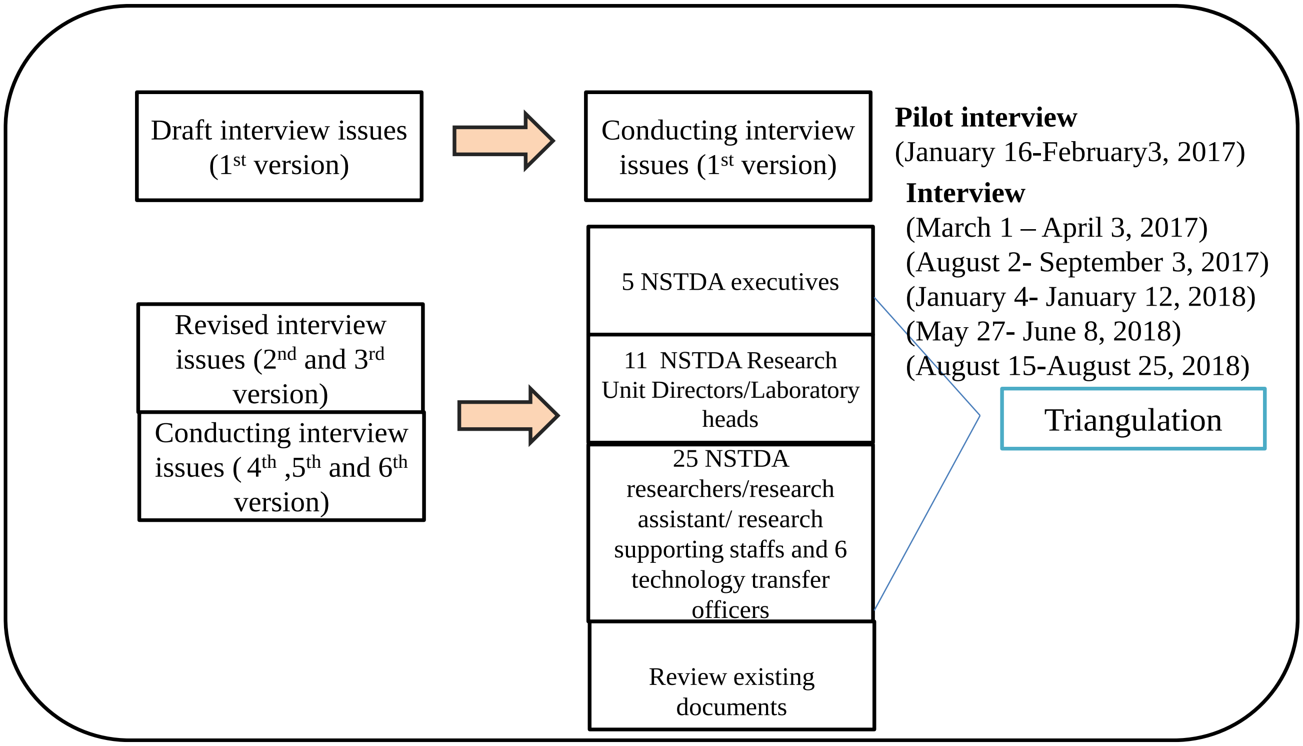
3) Technology Readiness Level (TRL) and the absorptive capacity of customers.

4) Institutional factors for supporting research commercialization:

- Type of top management support.
- Types of incentives stimulating researchers for involving research commercialization.
- Problems about other management procedures.

Data collection was conducted by interviewing three groups: NSTDA executives (five persons), Research Unit Directors/Laboratory Heads/researchers (36 persons) and technology transfer officers (six persons). There was a total of 47 interviewees and a total of 11 case studies. The information gathered from all interviewees was cross-checked against each other including existing documents as secondary data relating to each project and the management procedures (see Figure 3-11).

Figure 3-11: Pilot Interview and Interview by Qualitative Method



Source: Author

3.6 Concluding Remarks

This chapter presents research questions, research framework and research methods in order to describe the relationship between the main variables identified in the study. The next chapter will explain the quantitative analysis by using Poisson regression analyzed by SPSS software.

Chapter 4

Results and Discussion

(Quantitative Analysis)

This chapter aims to analyze the data regarding the influence of the types of technologies, team diversity, team size and the number of years from the project's completion to accounting as the licensed projects on enhancing the number of license agreements in the Thai PRI. It also investigates key factors supporting CFTs to achieve the first license agreement. It consists of six sections and is analyzed by Poisson regression analysis. Section 4.1 summarizes general information about the survey results. Key findings of regression analysis are discussed in Section 4.2. Section 4.3 analyzes significant factors supporting CFTs in each technological field, and Section 4.4 investigates the significant factors influencing the duration for achieving the first license agreement. Section 4.5 presents the discussion of the Poisson regression results. Finally, Section 4.6 provides the conclusion regarding these issues.

4.1 General Information about the Survey Results

After selecting the projects by the licensing staff, there are a total of 173 potentially licensable projects (PLPs) between 2011 and 2015. Sending questionnaires to the head of the project or one researcher as a representative of each project results in a total of 163 projects, accounting for 94% of the PLPs. These consist of 58 information and communications technology (ICT) projects, 39 biotechnology projects, 37 materials technology projects, and 29 nanotechnology projects (Table 4-1). However, the 163 PLPs consist of 134 licensed projects and 29 unlicensed projects.

Table 4-1: Number of Sample Breaking Down in Technology Fields

Type of technology	Number of Sample	Percent (%)
1. Information and communications technology (ICT)	58	35%
2. Biotechnology	39	24%
3. Materials technology	37	23%
4. Nanotechnology	29	18%
Total	**163**	**100%**

Source: The author

4.2 Result of the Poisson Regression Analysis

Table 4-2 shows the descriptive statistics. This provides the means, standard deviations (SD), minimum (Min) and maximum values (Max). Although the value in the "Value/df" column for the "Pearson Chi-Square" row in Table 4-3 is 0.523, the test of the model effects as shown in Table 4-4 indicates that the model is a proper fit for the variables considered in the sig column; the p-value is 0.001.

Table 4-2: Descriptive Statistics

	Number of Obs.	Mean	SD	Min.	Max.
Dependent variable					
Number of license agreements	163	1.17	0.91	0	5
Independent variables					
ICT	163	0.36	0.48	0	1
Biotec	163	0.24	0.43	0	1
Mtec	163	0.23	0.42	0	1

	Number of Obs.	Mean	SD	Min.	Max.
Mfunc	163	0.17	0.37	0	1
Hfunc	163	0.37	0.48	0	1
Medulevels	163	0.28	0.45	0	1
Hedulevels	163	0.32	0.47	0	1
Medufields	163	0.31	0.46	0	1
Hedufields	163	0.50	0.50	0	1
Mexperience	163	0.52	0.50	0	1
Hexperience	163	0.33	0.47	0	1
Team size	163	4.63	1.85	2	12
Years from completion	163	4.15	4.94	3	7

Source: The author

Table 4-3: Goodness of Fit

	Deviance	Pearson Chi-Square	Log Likelihood	Akaike's Information Criterion (AIC)	Bayesian Information Criterion (BIC)
Value	85.759	77.955	-191.673	411.346	454.658
df	149	149			
Value/df	0.576	0.523			

Source: The author

Table 4-4: Omnibus Test Model Effects for Poisson Regression Model

Likelihood Ratio Chi-Square	df	Sig.
34.959	13	0.001

Source: The author

On the other hand, Table 4-5 shows that the four variables are statistically significant predictors of the number of license agreements at the 95% confidence level (($p < 0.05$). That is to interpret a high diversity of functions/departments, high diversity of educational fields/majors, team size and years from the project's completion strongly influence the number of license agreements. Contrastingly, the high degree of difference in educational levels will in turn lead to a decrease in the number of license agreements. On the other hand, it can be explained that a change in the high degree of difference in functions/departments and the high degree of difference in educational fields/majors will lead to an increase in the number of license agreements by 78.9% (from Exp(B) -1 =1.789 -1 =78.9%) and 55.4%, respectively.

Table 4-5: Parameter Estimates of 163 projects

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
(Intercept)	-1.912	0.7439	-3.370	-0.454	6.606	1	0.010	0.148
ICT	-0.291	0.2490	-0.780	0.197	1.370	1	0.242	0.747
Biotec	-0.194	0.2464	-0.677	0.289	0.620	1	0.431	0.824
Mtec	-0.213	0.2566	-0.716	0.290	0.690	1	0.406	0.808
Mfunc	0.386	0.2196	-0.044	0.817	3.097	1	0.078	1.472
Hfunc	**0.582**	**0.1874**	**0.214**	**0.949**	**9.637**	**1**	**0.002**	**1.789**
Medulevels	0.272	0.1882	-0.097	0.640	2.082	1	0.149	1.312
Hedulevels	0.126	0.1809	-0.229	0.481	0.484	1	0.486	1.134
Medufields	-0.063	0.2106	-0.476	0.350	0.090	1	0.764	0.939
Hedufields	**0.441**	**0.2074**	**0.035**	**0.848**	**4.524**	**1**	**0.033**	**1.554**
Mexperience	0.025	0.2211	-0.408	0.459	0.013	1	0.909	1.026
Hexperience	-0.065	0.2286	-0.513	0.383	0.082	1	0.775	0.937

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
Team size	**0.185**	**0.0415**	**0.104**	**0.267**	**20.017**	**1**	**0.000**	**1.204**
Years from project completion	**0.102**	**0.0513**	**0.001**	**0.202**	**3.931**	**1**	**0.047**	**1.107**

Source: The author

The estimated regression coefficients for the fixed effects in this model imply that differences between the technological fields are fixed. As a result, no differences are found between the technological fields. After dividing these data into the four technological fields: information and communications technology (ICT), biotechnology, material technology and nanotechnology, and performing a Poisson regression analysis in each technological field, it is found that there are differences about the important factors supporting CFTs in each field.

4.3 Significant factors Supporting CFTs in Each Technological Field

Considering the important factors in each technological field for supporting CFTs, it is found that a high degree of difference in educational fields/majors and team size strongly influenced the number of license agreements of the ICT projects (Table 4-7) whereas the high degree of difference in functions/departments is positively related to the number of license agreements in biotechnology projects (Table 4-9). On the other hand, the high diversity of educational fields, team size and the number of years from the project's completion in a given year to accounting as the licensed project in 2017 as the control variables are significant factors for materials technology projects (Table 4-11), but there are no significant factors at the 95% confidence level (($p < 0.05$) influencing the number of license agreements in nanotechnology projects (Table 4-13).

Table 4-6: Descriptive Statistics of ICT Projects (58 projects)

	N	Minimum	Maximum	Mean	Std. Deviation
Dependent variable					
Number of license agreements	58	0	5	1.21	0.913
Independent variables					
Mfunc	58	0	1	0.21	0.409
Hfunc	58	0	1	0.33	0.473
Medulevels	58	0	1	0.36	0.485
Hedulevels	58	0	1	0.28	0.451
Medufields	58	0	1	0.10	0.307
Hedufields	58	0	1	0.72	0.451
Mexperience	58	0	1	0.53	0.503
Hexperience	58	0	1	0.34	0.479
Team size	58	2	10	5.00	2.052
Years from project completion	58	3	7	4.79	1.472

Source: The author

Table 4-7: Parameter Estimates of ICT Projects (58 projects)

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
(Intercept)	-3.955	1.2151	-6.336	-1.573	10.593	1	0.001	0.019

Parameter	**B**	**Std. Error**	**95% Wald Confidence Interval**		**Hypothesis Test**			**Exp(B)**
			Lower	**Upper**	**Wald Chi-Square**	**df**	**Sig.**	
Mfunc	0.539	0.3753	-0.197	1.274	2.062	1	0.151	1.714
Hfunc	0.749	0.4522	-0.138	1.635	2.741	1	0.098	2.114
Medulevels	0.239	0.3011	-0.351	0.829	0.631	1	0.427	1.270
Hedulevels	0.017	0.3666	-0.702	0.735	0.002	1	0.964	1.017
Medufields	0.452	0.4659	-0.461	1.365	0.940	1	0.332	1.571
Hedufields	**0.914**	**0.2945**	**0.337**	**1.492**	**9.640**	**1**	**0.002**	**2.495**
Mexperience	0.319	0.4560	-0.574	1.213	0.491	1	0.484	1.376
Hexperience	-0.161	0.4137	-0.972	0.650	0.151	1	0.697	0.851
Team size	**0.270**	**0.0891**	**0.095**	**0.445**	**9.172**	**1**	**0.002**	**1.310**
Years from project completion	0.166	0.0893	-0.009	0.341	3.473	1	0.062	1.181

Source: The author

Table 4-8: Descriptive Statistics of Biotechnology Projects (39 projects)

	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Dependent variable					
Number of license agreements	39	0	3	1.10	0.718
Independent variables					

	N	Minimum	Maximum	Mean	Std. Deviation
Mfunc	39	0	1	0.13	0.339
Hfunc	39	0	1	0.41	0.498
Medulevels	39	0	1	0.10	0.307
Hedulevels	39	0	1	0.38	0.493
Medufields	39	0	1	0.41	0.498
Hedufields	39	0	1	0.28	0.456
Mexperience	39	0	1	0.62	0.493
Hexperience	39	0	1	0.26	0.442
Team Size	39	3	7	3.79	1.056
Years from project completion	39	3	7	4.90	1.619

Source: The author

Table 4-9: Parameter Estimates of Biotechnology Projects (39 projects)

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
(Intercept)	-0.568	1.5746	-3.654	2.518	0.130	1	0.718	0.566
Mfunc	0.416	0.5214	-0.606	1.437	0.635	1	0.425	1.515
Hfunc	**0.849**	**0.3868**	**0.091**	**1.608**	**4.822**	**1**	**0.028**	**2.338**
Medulevels	0.076	0.6004	-1.100	1.253	.016	1	0.899	1.079
Hedulevels	0.200	0.3523	-0.491	0.891	0.322	1	0.570	1.221

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
Medufields	-0.322	0.3959	-1.098	0.454	0.662	1	0.416	0.725
Hedufields	-0.276	0.4219	-1.103	0.551	0.429	1	0.513	0.759
Mexperience	-0.428	0.5765	-1.557	0.702	0.550	1	0.458	0.652
Hexperience	-0.329	0.6243	-1.553	0.894	0.278	1	0.598	0.720
Team size	0.137	0.1690	-0.194	0.468	0.657	1	0.418	1.147
Years from project completion	-0.039	0.1036	-0.242	0.164	0.140	1	0.708	0.962

Source: The author

Table 4-10: Descriptive Statistics of Materials Technology Projects (37 projects)

	N	Minimum	Maximum	Mean	Std. Deviation
Dependent variable					
Number of license agreements	37	0	5	1.24	1.211
Independent variables					
Mfunc	37	0	1	0.19	0.397
Hfunc	37	0	1	0.32	0.475
Medulevels	37	0	1	0.35	0.484
Hedulevels	37	0	1	0.30	0.463
Medufields	37	0	1	0.24	0.435
Hedufields	37	0	1	0.68	0.475

	N	Minimum	Maximum	Mean	Std. Deviation
Mexperience	37	0	1	0.38	0.492
Hexperience	37	0	1	0.49	0.507
Team size	37	3	12	5.08	2.100
Years from project completion	37	3	7	5.11	1.125

Source: The author

Table 4-11: Parameter Estimates of Materials Technology Projects (37 projects)

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
(Intercept)	-4.697	1.5988	-7.831	-1.563	8.631	1	0.003	0.009
Mfunc	0.469	0.4615	-0.436	1.373	1.032	1	0.310	1.598
Hfunc	0.601	0.3765	-0.137	1.339	2.552	1	0.110	1.825
Medulevels	-0.413	0.4384	-1.272	0.447	0.886	1	0.347	0.662
Hedulevels	-0.107	0.4697	-1.028	0.813	0.052	1	0.820	0.898
Medufields	0.555	0.5928	-0.607	1.717	0.876	1	0.349	1.742
Hedufields	**1.326**	**0.6047**	**0.141**	**2.511**	**4.807**	**1**	**0.028**	**3.765**
Mexperience	0.494	0.4249	-0.338	1.327	1.353	1	0.245	1.639
Hexperience	0.664	0.4360	-0.191	1.518	2.318	1	0.128	1.942
Team size	**0.179**	**0.0775**	**0.027**	**0.331**	**5.355**	**1**	**0.021**	**1.197**

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
Years from project completion	**0.364**	**0.1696**	**0.032**	**0.697**	**4.611**	**1**	**0.032**	**1.439**

Source: The author

Table 4-12: Descriptive Statistics of Nanotechnology Projects (29 projects)

	N	Minimum	Maximum	Mean	Std. Deviation
Dependent variable					
Number of license agreements	29	0	2	1.07	0.704
Independent variables					
Mfunc	29	0	1	0.10	0.310
Hfunc	29	0	1	0.48	0.509
Medulevels	29	0	1	0.28	0.455
Hedulevels	29	0	1	0.34	0.484
Medufields	29	0	1	0.69	0.471
Hedufields	29	0	1	0.10	0.310
Mexperience	29	0	1	0.52	0.509
Hexperience	29	0	1	0.17	0.384
Team size	29	2	7	4.41	1.547
Years from project completion	29	3	7	5.07	1.580

Source: The author

Table 4-13: Parameter Estimates of Nanotechnology Projects (29 projects)

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
(Intercept)	-0.844	2.1874	-5.131	3.443	0.149	1	0.700	0.430
Mfunc	0.743	0.7388	-0.706	2.191	1.010	1	0.315	2.101
Hfunc	0.249	0.5309	-0.791	1.290	0.221	1	0.639	1.283
Medulevels	0.579	0.6797	-0.753	1.912	0.726	1	0.394	1.785
Hedulevels	0.340	0.6031	-0.842	1.522	0.318	1	0.573	1.405
Medufields	-1.405	0.8370	-3.045	0.236	2.817	1	0.093	0.245
Hedufields	-0.413	0.9684	-2.311	1.485	0.182	1	0.670	0.662
Mexperience	0.066	0.6275	-1.164	1.296	0.011	1	0.916	1.068
Hexperience	-1.052	0.8702	-2.758	0.653	1.462	1	0.227	0.349
Team size	0.218	0.1602	-0.096	0.532	1.857	1	0.173	1.244
Years from project completion	-0.007	0.1523	-0.305	0.292	0.002	1	0.965	0.993

Source: The author

4.4 Significant Factors Influencing the Duration for Achieving the First License Agreement

It is found that 134 projects out of the total number of PLPs licensed between 2011 and 2017 were collected because 29 PLPs could not be licensed. The duration for achieving the first license agreement is a dependent variable and the independent variables are different technologies, degree of difference in functions/departments and degree of difference in experience. The results from the Poisson regression analysis show that ICT and the high diversity of functions are significant factors influencing the duration for achieving the first license agreement (see Table 4-14). However, this analysis is just for reference purpose because the sample selection mostly focuses on the licensed projects.

Table 4-14: Parameter Estimates of Significant factors influencing on duration for achieving the first license agreement (134 projects)

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)
			Lower	Upper	Wald Chi-Square	df	Sig.	
(Intercept)	-0.999	0.6973	-2.365	0.368	2.051	1	0.152	0.368
ICT	**0.451**	**0.2273**	**0.005**	**0.896**	**3.933**	**1**	**0.047**	**1.570**
Biotec	0.131	0.2338	-0.327	0.589	0.313	1	0.576	1.140
Mtec	0.122	0.2392	-0.346	0.591	0.262	1	0.609	1.130
Mfunc	0.225	0.2017	-0.170	0.620	1.244	1	0.265	1.252
Hfunc	**0.467**	**0.2293**	**0.017**	**0.916**	**4.141**	**1**	**0.042**	**1.595**
Mexperience	-0.218	0.2246	-0.658	0.223	0.940	1	0.332	.804
Hexperience	0.006	0.2666	-0.516	0.529	0.001	1	0.982	1.006
Team size	0.063	0.0487	-0.033	0.158	1.648	1	0.199	1.065

Source: The author

4.5 Discussion of the Poisson Regression Results

The results of the current study contribute to the literature about the cognitive resource theory, which posits that diverse values among teammates will contribute to better team performance.

Members will share information from a greater variety of perspectives, a practice that leads to higher quality analysis of tasks, which in turn fosters higher quality results (Woehr et al., 2013). Moreover, this reinforces the suggestions by Wiersema and Bantel (1992) and Schwenk (1984) that low diversity teams are usually more prone to have a declining performance unlike teams with a high diversity, as the team members will be challenging each other's perceptions, which usually allows them to reach better justified decisions. Although there are several studies that have examined the relationship between education levels and team performance (Jackson et al., 1995; Jehn, Chatwick, and Thatcher, 1997; Knight et al., 1999), the present study investigated the effects of both the education levels and educational fields on potentially licensable R&D projects. The choice of a specific educational major may reflect one's cognitive strength and personality (Holland, 1973). For instance, an individual educated in computer science can be expected to have a somewhat different cognitive disposition than an individual educated in marketing or advertising (Hambrick and Mason, 1984). Moreover, different technological projects require different educational fields to support effective CFTs. For example, a high diversity of educational fields is an important factor contributing to CFTs in ICT projects and material technology projects. In contrast, a high diversity of functions/departments is the critical factor for biotechnology projects. This implies that the key success factor of successful biotechnology projects is cooperation among members from different departments in the PRI and external partners outside the PRI consisting of university researchers, related government agencies, agriculturalists, etc.

When Poisson regression analyzes factors affecting the duration for achieving the first license agreement, it was found that the effects of ICT and a high diversity of functions were statistically significant. It is implied that the characteristics of ICT and cooperation among different departments in the PRI and external partners supported CFTs in achieving the first license agreement.

On the other hand, cross tabulation is used to compare the relationship between the two variables (functions and educational fields of members working together according to the definition of CFTs in this study) because cross tabulation can examine relationships within the data that might not be readily apparent when analyzing the total survey responses (De Franzo, 2012). The results show that there are different types of relationships in each technological field. In ICT projects, 48.3% of projects consisting of a low diversity in functions have high diversity of educational fields because the research results are software development whereas 85% of projects having a high diversity in functions have high diversity of educational fields in order to develop hardware innovations. Moreover, 56.5% of the H functions in biotechnology projects have medium diversity of educational fields because the contribution of the universities is indispensable. On the other hand, 60% of the L functions in materials technology projects have high diversity of educational fields whereas 58.3% of the H functions have high diversity of educational fields because they need to cooperate with the expected licensees for testing the prototypes. In contrast, most nanotechnology projects that achieved only one license agreement have low diversity of functions and medium diversity of educational fields. Some nanotechnology projects, which have high diversity of functions and medium diversity of educational fields, could achieve two license agreements.

Table 4-15: Functions * Edufields Cross-tabulation in ICT Projects

			Edufields			**Total**
			Ledufields	**Medufields**	**Hedufields**	
Functions	**Lfunctions**	Count	8	7	**14**	29
		% within Lfunctions	27.6%	24.1%	**48.3%**	100.0%
		% within Ledufields	88.9%	58.3%	**37.8%**	50.0%
		% of Total	13.8%	12.1%	24.1%	50.0%
	Mfunctions	Count	1	2	6	9
		% within Mfunctions	11.1%	22.2%	66.7%	100.0%
		% within Medufields	11.1%	16.7%	16.2%	15.5%
		% of Total	1.7%	3.4%	10.3%	15.5%
	Hfunctions	Count	0	3	**17**	20
		% within Hfunctions	0.0%	15.0%	**85.0%**	100.0%

			Edufields			Total
			Ledufields	Medufields	Hedufields	
		% within Hedufields	0.0%	25.0%	**45.9%**	34.5%
		% of Total	0.0%	5.2%	29.3%	34.5%
Total		Count	9	12	37	58
		% within functions	15.5%	20.7%	63.8%	100.0%
		% within edufields	100.0%	100.0%	100.0%	100.0%
		% of Total	15.5%	20.7%	63.8%	100.0%

Source: The author

Table 4-16: Functions * Edufields Cross-tabulation in Biotechnology projects

			Edufields			Total
			Ledufield	Medufields	Hedufields	
Functions	**Lfunctions**	Count	5	7	2	14
		% within Lfunctions	35.7%	50.0%	14.3%	100.0%
		% within Ledufields	71.4%	31.8%	20.0%	35.9%
		% of Total	12.8%	17.9%	5.1%	35.9%
	Mfunctions	Count	0	2	0	2
		% within Mfunctions	0.0%	100.0%	0.0%	100.0%
		% within Medufields	0.0%	9.1%	0.0%	5.1%
		% of Total	0.0%	5.1%	0.0%	5.1%
	Hfunctions	Count	2	**13**	8	23
		% within Hfunctions	8.7%	**56.5%**	34.8%	100.0%
		% within Hedufields	28.6%	**59.1%**	80.0%	59.0%
		% of Total	5.1%	**33.3%**	20.5%	59.0%
Total		Count	7	22	10	39
		% within functions	17.9%	56.4%	25.6%	100.0%
		% within edufields	100.0%	100.0%	100.0%	100.0%
		% of Total	17.9%	56.4%	25.6%	100.0%

Source: The author

Table 4-17: Functions * Edufields Cross-tabulation in Materials technology projects

			Edufields			Total
			Ledufield	Medufields	Hedufields	
Functions	**Lfunctions**	Count	3	5	12	20
		% within Lfunctions	15.0%	25.0%	60.0%	100.0%
		% within Ledufields	100.0%	41.7%	54.5%	54.1%
		% of Total	8.1%	13.5%	32.4%	54.1%
	Mfunctions	Count	0	2	3	5
		% within Mfunctions	0.0%	40.0%	60.0%	100.0%
		% within Medufields	0.0%	16.7%	13.6%	13.5%
		% of Total	0.0%	5.4%	8.1%	13.5%
	Hfunctions	Count	0	5	7	12
		% within Hfunctions	0.0%	41.7%	58.3%	100.0%
		% within Hedufields	0.0%	41.7%	31.8%	32.4%
		% of Total	0.0%	13.5%	18.9%	32.4%
Total		Count	3	12	22	37
		% within functions	8.1%	32.4%	59.5%	100.0%
		% within edufields	100.0%	100.0%	100.0%	100.0%
		% of Total	8.1%	32.4%	59.5%	100.0%

Source: The author

Table 4-18: Functions * Edufields Cross-tabulation in Nanotechnology projects

			Edufields			Total
			Ledufield	Medufields	Hedufields	
Functions	**Lfunctions**	Count	1	19	3	23
		% within Lfunctions	4.3%	82.6%	13.0%	100.0%
		% within Ledufields	100.0%	76.0%	100.0%	79.3%

			Edufields			Total
			Ledufield	Medufields	Hedufields	
		% of Total	3.4%	65.5%	10.3%	79.3%
	Mfunctions	Count	0	1	0	1
		% within Mfunctions	0.0%	100.0%	0.0%	100.0%
		% within Medufields	0.0%	4.0%	0.0%	3.4%
		% of Total	0.0%	3.4%	0.0%	3.4%
	Hfunctions	Count	0	5	0	5
		% within Hfunctions	0.0%	100.0%	0.0%	100.0%
		% within Hedufields	0.0%	20.0%	0.0%	17.2%
		% of Total	0.0%	17.2%	0.0%	17.2%
Total		Count	1	25	3	29
		% within functions	3.4%	86.2%	10.3%	100.0%
		% within edufields	100.0%	100.0%	100.0%	100.0%
		% of Total	3.4%	86.2%	10.3%	100.0%

Source: The author

4.6 Concluding Remarks

This chapter investigates the influence of team diversity, types of technologies, team size, and years from the project's completion on the number of license agreements. Based on the results of a hypothesis test by Poisson regression analysis, the findings indicate that the high degree of difference in functions/departments and the high degree of difference in educational fields are statistically significant for supporting CFTs in enhancing the number of license agreements. On the other hand, there are differences about the significant factors affecting the number of license agreements in each technological field.

In addition, this study it uses Poisson regression to explore the key factors supporting CFTs to achieve the first license agreement. The results indicate that ICT and a high diversity of functions/departments are significant factors.

The next chapter will apply case studies to explain and confirm why some factors are important in one form of technology more than other technologies.

Chapter 5

Results and Discussion
(Qualitative Analysis by Using a Case Studies Approach)

According to Poisson regression and the cross tabulation results discussed in Chapter 4, this chapter presents case studies in order to describe the reasons why some types of team diversity factors are key success factors for supporting CFTs in one technological field more than other fields. The four sections (Sections 5.1-5.4) consist of fifteen NSTDA case studies covering the four types of different technological contexts: information and communications technology (ICT), biotechnology, materials technology, and nanotechnology. The criteria for selecting effective case studies are to have outstanding projects in terms of achievement evaluated by the NSTDA or have a high number of license agreements. In addition, a non-effective case study, which has a medium/high diversified team in terms of educational fields/functions but does not commercialize the research result to the companies was selected as a final case study in each technological field. Finally, Section 5.5 analyzes the cross case analysis, and the conclusion regarding these issues is provided in Section 5.6.

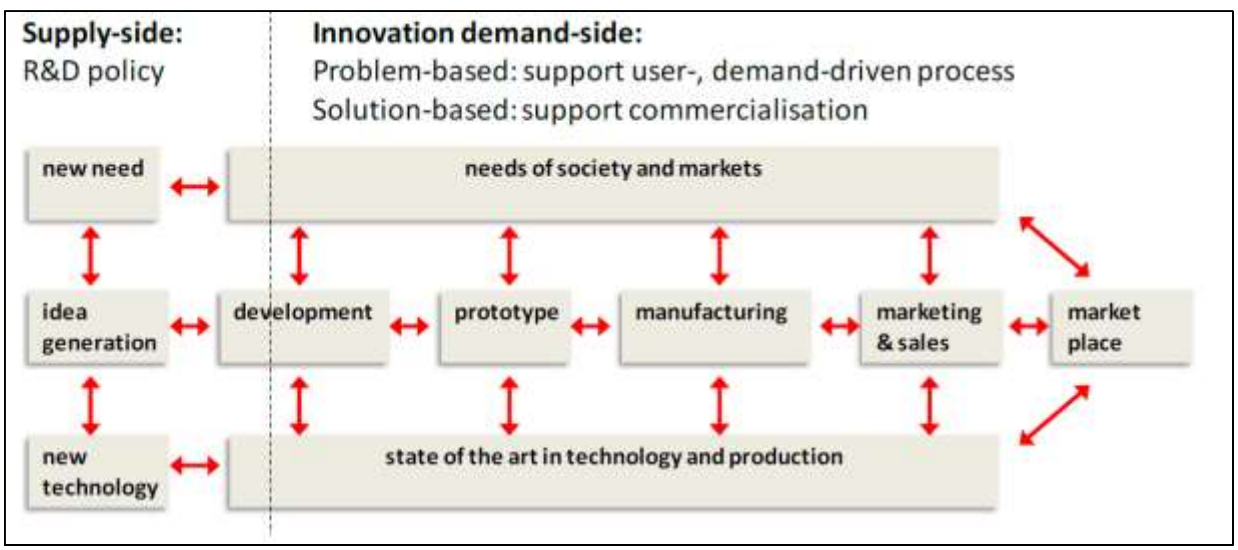
5.1 ICT Case Studies

5.1.1) Characteristics of ICT

The rising pace of technological change in information and communications technology (ICT) has provoked technological convergence by providing a new mode of diversification (Kim, 2013). Technological convergence has been regarded as an emerging trend and has received particular attention in the ICT industry (Hacklin et al., 2009). Furthermore, convergence between heterogeneous types of technologies has created a combination of technologies aimed at resolving issues existing in the different technological fields. Bioinformatics, a human interface, and nanobiosensors are pertinent examples of convergence of this type, which have combined ICT with biotechnology or nanotechnology (Kim, 2013). In addition, convergence between homogeneous technologies, occurring in the same field, generally implies a combination of several technologies to handle multiple functions (ibid). Telecommunications products and services; such as, camera phones, portable PCs, and IPTVs, are good examples of homogeneous converging technologies in which different technological subsystems interact and function as a technically integrated end to end system that provides the user with a range of voice, data, and imaging services (Davies, 1996).

The coupling model of innovation is helpful in showing the important role of ICT as a pervasive and general purpose technology. ICT can affect both the way in which the different elements interact, but can also impact the elements of the framework (see Figure 5-1). New ICT applications; such as, big data, web-based platforms and the Internet of Things (IoT) are affecting the red arrows in the graph, and the communicative interactions which these arrows represent. Such new ICT applications result in new combinations and new business models. For instance, the trend of crowdsourced manufacturing, or the 'maker economy' shows how ICT platforms can actively involve customers in a demand-driven process of prototyping and manufacturing. New ideas for innovations may also originate from introducing new ways to communicate with the market place and new analytical tools to make predictions based on big data (Wintjes, 2016).

Figure 5-1: The 'coupling model' of innovation



Source: Rothwell and Zegveld, 1985.

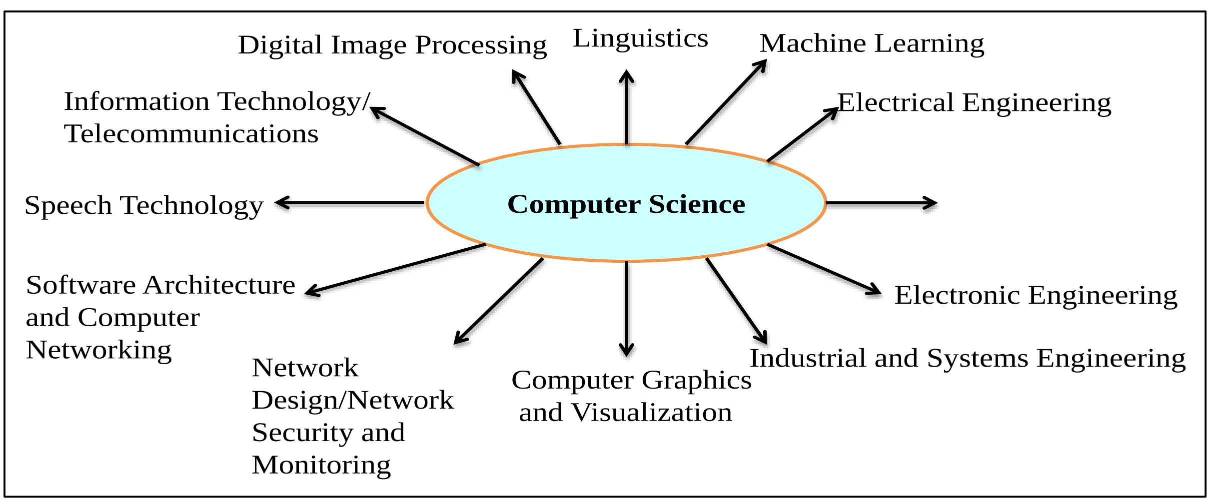
5.1.2) Relationship between low/high diversity of functions and high diversity of educational fields

According to the results of the regression analysis and cross tabulation, a high diversity of educational fields is the significant factor supporting CFTs to enhance the number of license agreements in ICT projects. Forty-eight percent of projects consisting of a low diversity in functions have a high diversity of educational fields because the research results are software development whereas 85% of projects comprising a high diversity in functions have a high diversity of educational fields in order to develop hardware innovations.

1) Software

Achieving the first license agreement of software and computer program development occurs between six months and one year from the project's completion because it can be applied in many sectors. The core discipline for developing software is Computer Science. Relevant fields in Computer Science for developing software are Linguistics, Machine Learning, Electrical Engineering, Computer/Software Engineering, Digital Image Processing, Electronic Engineering, Software Architecture and Computer Networking, Information Technology, etc. (see Figure 5-2).

Figure 5-2: Relevant fields in Computer Science for developing software



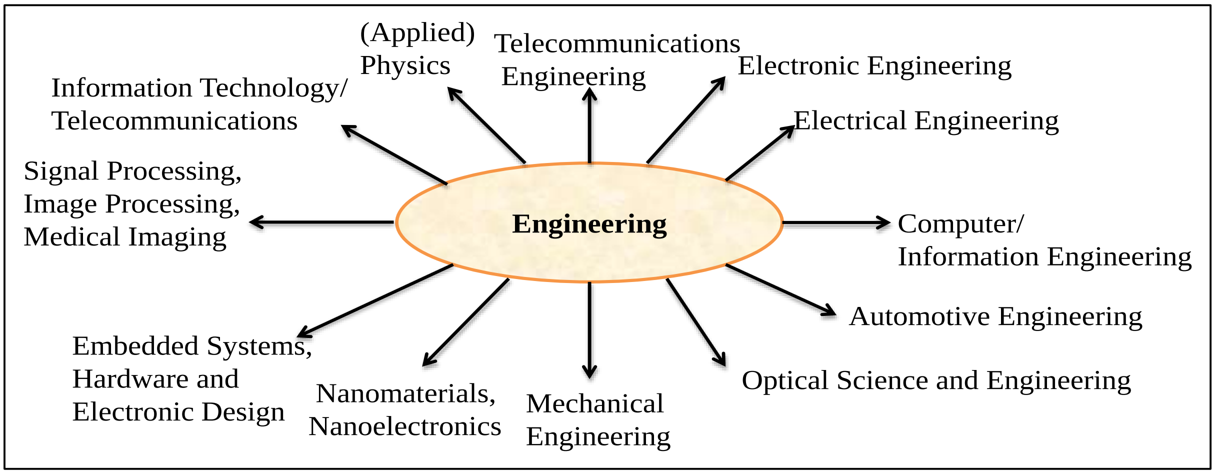
Source: The author

In addition to educational fields, CFTs for developing software and computer programs should have important knowledge and skills complementing each other; such as, Text Mining, Sentiment Analysis and Opinion Mining, Information Retrieval and Search Engine, Information Filtering and Recommender System, Natural Language Processing, Big Data Analytics and Visualization, Speech Synthesis, Text-to-Speech Synthesis, Speech Coding, Ontology and Semantic Web, Syntax, Semantics, Corpus Linguistics, Sociolinguistics, Machine Translation, Automatic Speech Recognition, HMM-based Speech Synthesis, Corpus Linguistics, Database Management System, Web Programming, Mobile Application, Web Programming and Design, etc.

2) ICT hardware innovations

Most ICT projects focusing on hardware innovations have achieved the first license agreement by the first year. This serves the needs of a specific sector. The core discipline is Electrical Engineering with relevant fields including Physics, Telecommunications Engineering, Electronic Engineering, Materials Science, Quantum Science and Engineering, Mechanical Engineering, Signal Processing, Image Processing, Medical Imaging, Nanomaterials, Nanoelectronics, etc. (see Figure 5-3).

Figure 5-3: Relevant fields in Electrical Engineering for developing hardware innovations



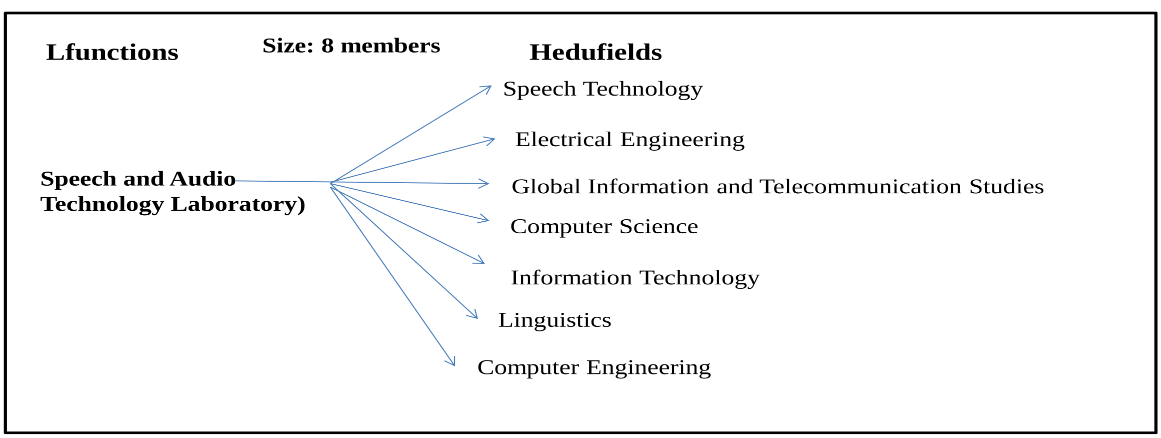
Source: The author

In addition, supplementary knowledge and skills for developing hardware innovations in ICT projects consist of Optoelectronics Materials, Bioelectronics, Micro/Nano Optical Devices, Interference Lithography, Electromagnetic Computation, Optical Sensor, Biosensor, Optical Design, Holography, Optical Mechanical Systems, Mechanical Design, Systems Design, CAD Design and Mechanics, Embedded Software, Low-energy Embedded Systems, Real-time Systems, Robotics, Computer Visions, Control Systems, Signal Processing Systems for Medical Applications, Digital Signal Processing, etc.

5.1.3) Software: VAJA version 7.0

An example of Thai speech synthesis software is the VAJA version 7.0 project. It had a low diversity of functions and high diversity of educational fields. Based on a Speech and Audio Technology Laboratory, the CFT had eight members educated in Speech Technology, Electrical Engineering, Global Information and Telecommunication Studies, Computer Science, Information Technology, Linguistics, and Computer Engineering (Figure 5-4). Considering the members' educational fields, it was found that the percentage of different disciplines compared with the team size was 87.5%, which was due to the high degree of difference in educational fields. Additional skills included Text Mining, Sentiment Analysis and Opinion Mining, Information Retrieval and Search Engine, Natural Language Processing, Big Data Analytics and Visualization, Automatic Speech Recognition, and HMM-based Speech Synthesis.

Figure 5-4: Relationship between function and educational fields in VAJA project



Source: The author

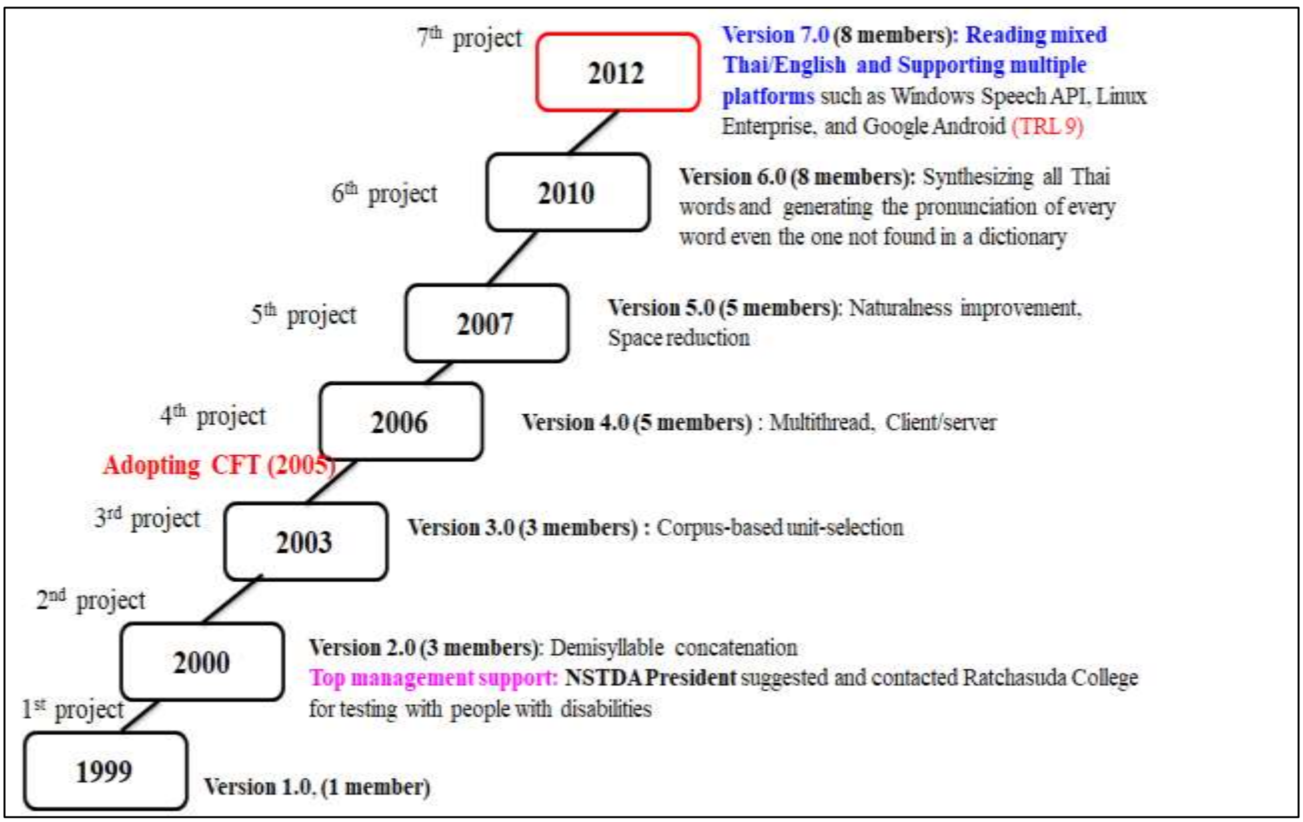
- **Key milestones (see Figure 5.5)**

VAJA had been extensively researched and developed since 1997. Version 1.0 conducted by one researcher was released in 1999. In 2000, the NSTDA President as the senior management support suggested and contacted Ratchasuda College, Mahidol University, Nakhon Pathom province, Thailand to test the VAJA version 2.0 with people with disabilities (Figure 5-5). Adopting a CFT occurred during the period of developing the VAJA version 4.0 in 2005 because two Thai government scholarship students educated in Speech Technology and Assistive Technology for the Deaf returned to work as the head of the project and a member of the project. In this period, the percentage of different disciplines compared with the team size was 80%, as a result of the high degree of difference in educational fields: Computer Science, Information and Telecommunication Studies, Speech Technology and Assistive Technology for the Deaf.

The project leader studied the best practices of foreign countries, a licensed local Thai language module from a doctoral student, and trained a research specialist working as the marketing engineer or technology transfer officer of this laboratory. Moreover, the research specialist had the responsibility to contact potential customers. Between 2005 (version 4.0) and 2007 (version 5.0), the VAJA engines produced a much higher sound quality than the former unit-concatenation based engine, as the synthetic speech sometimes sounded unnatural, especially when synthesizing non-Thai words written with Thai characters. Improvement of the quality in both the text processing and speech synthesis was required before state-of-the-art engines of the same level of quality as those which had been successfully developed for other languages; such as, English and Japanese, could be achieved (Wutiwiwatchai and Furui, 2007a). Most of the improvements were conducted by introducing prosody prediction modules (Rugchatjaroen et al., 2007) and better unit-selection algorithms (Saychum et al., 2008) while the core speech database remained. It was known that major improvement of a Text-to-Speech Synthesis Engine (TTS) could be obtained by enhancing the speech database (NECTEC, 2008).

In 2008, the project leader increased the number of members of the CFT to three, who were educated in Linguistics, Electrical Engineering and Computer Engineering, in order to develop versions 6.0 and 7.0. The percentage of the number of different disciplines compared with the team size was 87.5%, as a result of the high degree of difference in educational fields. The member who had expertise in Linguistics helped the team to develop linguistic/prosodic processing as one subsystem of the VAJA. In the period of testing the software, members who had expertise in Electrical Engineering and Computer Engineering were the key members to undertake the alpha and beta testing in order to evaluate the quality of the software. These tests focused on finding faults. After passing the two tests, the engineering teams had to get feedback from a selected group of end-users and resolve any problems. When releasing a new version, the engineering team would continue to check the performance and resolve any faults in the software including conducting continuous development with the researchers.

Figure 5-5: Key milestones of VAJA version 7.0



Source: The author

- **Major changes of the project in terms of the objectives and management practices**

A team achieved the first objective in assisting disabled people in VAJA version 6 because it had an interface for people with a visual disability to access information in online newspapers. However, the scope of the project was extended to develop the VAJA version 7.0 to support multiple platforms. A CFT had achieved the goal in 2012 when VAJA version 7.0 could read mixed Thai/English and support several platforms; such as, Windows Speech API, Linux Enterprise, and Google Android.

Furthermore, this project was a top-down policy for initiating this project by enhancing a member of a CFT that was and closely recommended by two former NSTDA Presidents. The second NSTDA President assigned the team to develop the VAJA software as an option for people with disabilities and suggested the team invite a member educated in Assistive Technology for the Deaf into the CFT, and the fourth NSTDA President recommended the team to develop software based on portable devices.

- **Comparison between the commercialization result before and after adopting a CFT**

Although this project had adopted a CFT in terms of the high diversity of educational fields since 2005, the new project leader and team had to learn from many problems. For example, a major problem of the corpus-based unit selection text-to-speech (TTS) was the large size of the speech corpus required to obtain high-quality, natural synthetic speech. The scalability and adaptability of such huge database became a critical issue (Wutiwiwatchai et al., 2007b).

Nevertheless, a CFT successfully developed VAJA version 6.0 by utilizing the HMM-based speech synthesis system (HTS). This technique eliminated the problem of uneven sound that occurred in the previous versions. The new synthesis technique together with a prosody prediction module, which predicted the phrase boundaries and the duration of each phone, made the synthesized speech sound more natural and increased users' satisfaction. Furthermore, version 6.0 was able to synthesize all the Thai words since it had a text analysis module, which could generate the pronunciation of every word including those not found in a dictionary[4]. Later, version 7.0 was capable of reading mixed Thai/English text at no less than 92% of reading correctness. It supported multiple platforms; such as, Windows Speech API, Linux Enterprise, and Google Android. In particular for the Android application, complicated machine learning modules had to be optimized to operate on low-resource mobile devices.

Before adopting a CFT, there were no license agreements. A CFT developed several projects in order to improve the capability of the VAJA software. The important change occurred in 2008 before VAJA versions 6.0 and 7.0 were developed. The project leader described that:

"To achieve licensing and commercialization, a CFT had to divide the team into two sub teams. The first sub team consisted of researchers and assistant researchers that had expertise in theory, Speech Technology, Computer Science, language and software architecture whereas the second sub team comprised engineers to test the reliability, maintainability, extensibility, scalability, and security issues. During the alpha and beta tests, the second sub team were able to receive feedback and resolve any problems/faults."

The first license agreement of VAJA version 7.0 appeared one year after the project was completed in 2012. There were five license agreements from version 7.0.

- **Technological system and innovation model**

The coupling model of innovation emphasizes the fact that both the supply and demand side of interactions matter for innovation. Although generating new ideas and technologies by performing R&D; e.g., by scientists, is part of the process and a valuable source, also learning-by-doing from experiments, lessons and new ideas from interacting with clients and suppliers are important sources of innovation (Rothwell and Zegveld, 1985).

In the case of VAJA version 7.0, a CFT tried to resolve many problems that it received from the licensees in previous versions and individual users who downloaded the program free of charge

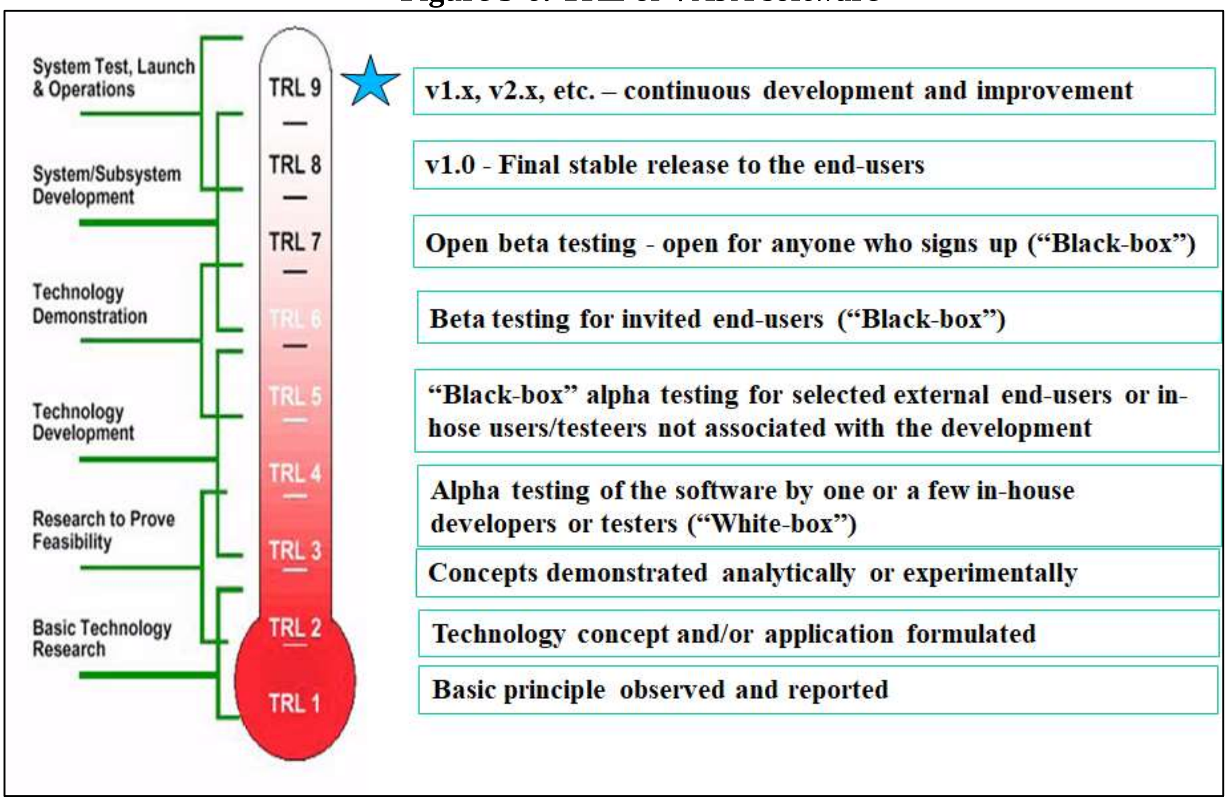
[4] http://vaja.nectec.or.th/

for personal use. In addition, new demands in terms of using on many platforms were included in version 7.0.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

Most NSTDA software programs were transferred to the licensees at TRL 8 because only version 1.0 was released to the end-users. However, some projects that had v1.x, v2.x, etc. before licensing to customers were evaluated at TRL 9. As a result, the VAJA version 7.0 was evaluated at TRL 9 (Figure 5-6).

Figure 5-6: TRL of VAJA software



Source: Adapted from Notander (2015)

Regarding the absorptive capacity of customers, the software's design was user-friendly; such as, had a speech synthesizer with a natural female voice, Thai/English support, adjustable speed and tone, did not require an Internet connection, had the ability to assist the communication for disabled people, etc. Therefore, the users of VAJA versions 6.0 and 7.0 had several levels; such as, individual user, SMEs, large firms, universities, and hospitals. General users, however, could download the program free of charge for personal use with limited features. On the other hand, advanced users or developers who would like to use enhanced features; such as, VAJA API, editable dictionary for new words and pronunciation, and other platforms had to obtain a license from the NSTDA.

Since 2011, VAJA has been widely deployed for social and commercial purposes. For example, VAJA has been integrated with software for teaching students with learning disabilities, used in a traffic information application, hospital queue calling systems (more than 70 hospitals), and in interactive voice response systems or call centers. The cumulative economic impact made by VAJA was over USD$ 600,000 estimated from the technological investment and the reduction of foreign technological imports.

5.1.4) DentiiScan 1.1

- **Key milestones of DentiiScan 1.1**

The first project was initiated in 2007. The research team had only ICT members for developing DentiiScan version 1.0 as the laboratory prototype in 2008. The former NSTDA President and senior adviser of the NSTDA President considered that the team needed a materials technology team to improve the rotation accuracy of the X-ray tube relating to the software's operation, so it was invited into a CFT. As a result, the CFT had a high diversity of educational fields compared with the team's size. It was a combination of members educated from Electrical Engineering, Information and Image Processing, Software Development, Cone Beam Computed Tomography (CT), Manufacturing Systems Engineering, Material Selection for Engineering Design, Biomedical Engineering and Mechanical Engineering. On the other hand, it had a high diversity of functions/departments because the team was the cooperation between the X-Ray CT and Medical Imaging Laboratory, Medical Rapid Prototyping Laboratory, and Business Development Division. Moreover, it had external partners; such as, the SDC Dental Center, Thammasat University Hospital, and Faculty of Dentistry, Chiang Mai University.

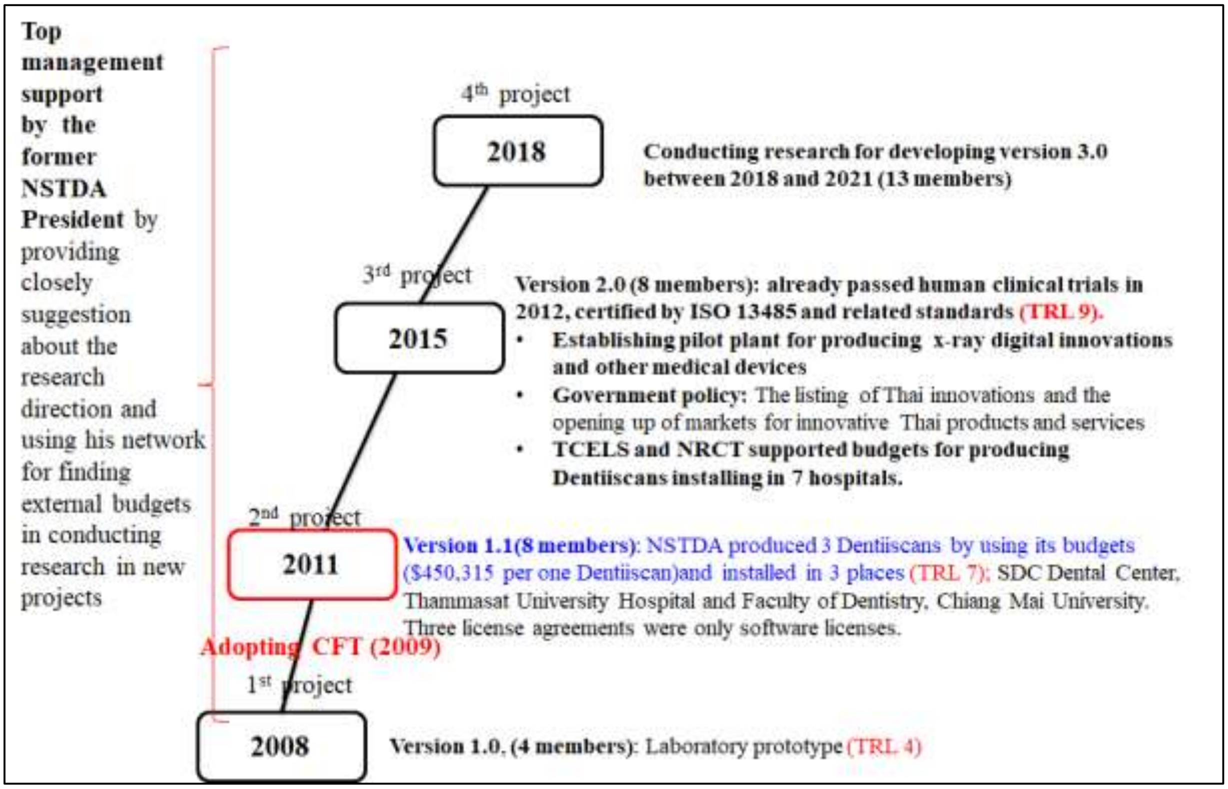
After adopting a CFT in 2009, it had successfully developed DentiiScan 1.1 in 2011. It was the first dental cone beam CT scanner that had been researched in Thailand. The machine went through clinical trials in mid-2011. DentiiScan 1.1 was then installed in three hospitals/dental clinics (more than 4,000 scans); Faculty of Dentistry, Chiang Mai University (since 2011), Suthasinee Dental Clinic (SDC) (since 2011), and Thammasat University Hospital (since 2013).

In 2015, a CFT achieved the goal for developing DentiiScan 2.0 that had a smaller machine than the previous version (Figure 5-7). DentiiScan could be applied with other applications; such as, implant-supported auricular prosthesis and acute sinusitis. It provided less radiation doses to a patient than typical medical CT scanners. DentiiScan 2.0 had already passed the radiation safety test from the Department of Medical Sciences, Ministry of Public Health, and the machine safety test from the Electrical and Electronic Product Testing Center (PTEC). It also received ethical approval from the National Ethics Committee by the Institution of the Development of Human Research Protections (IHRP), Ministry of Public Health. Moreover, it passed human clinical trials in 2012 and received ISO 13485 certification in 2016 (Figure 5-8).

Figure 5-7: DentiiScan version 1.1 (Left) and DentiiScan version 2.0 (Right)

Source: NSTDA website, 2017

Figure 5-8: Key milestones of DentiiScan versions



Source: The author

In 2018, NSTDA researchers were developing product innovations in order to serve digital dentistry by combining ICT and materials technology. Firstly, software for a dental digital platform was being developed by using the ICT field. Secondly, DentiiScan version 3.0 will be produced between 2018 and 2021 by integrating ICT and materials technology. Thirdly, the materials technology field will be used for developing “Designing and producing system for implant, crown, bridge and removable partial denture” and “Synthetic calcium phosphate ceramic for dentistry” between 2018 and 2021 (see Figure 5-8).

- **Major changes of the project in terms of the objectives and management practices**

A CFT achieved the objective in developing DentiiScan version 1.1 in 2011 and version 2.0 in 2015. Major changes of the DentiiScan 2.0 project were a result of government policy. The listing of Thai innovations and improving the regulations of the Office of the Prime Minister on the procurement of goods in 1992 to purchase goods or services relating to the list of Thai innovations through special cases were among the government's measures to promote Thai innovation development. Government agencies were allowed to buy products and services on the innovation list with at least 10% of their budget allocations each year, but not exceeding 30%. However, the products and services must be certified by the relevant agencies to ensure their accepted standards. They must also be creative and applicable on a commercial basis (BOI, 2015).

In May 2017, Air Chief Marshal Dr. Prajin Juntong, Deputy Prime Minister of Thailand, presided over the signing ceremony for an agreement between the Ministry of Public Health, Ministry of Science and Technology, and the National Research Council of Thailand to promote the use of Thai innovations in the Ministry of Public Health (Figure 5-9).

Figure 5-9: The signing ceremony for an agreement between the Ministry of Public Health, Ministry of Science and Technology, and the National Research Council of Thailand to promote the use of Thai innovations

Source: The Government Public Relations Department, Office of the Prime Minister, Thailand

In addition to the above government policy, DentiiScan version 2.0 was certified by ISO 13485 and the related standards. The NSTDA established the new pilot plant for producing DentiiScan in 2016. With the readiness of a CFT and infrastructure, the Thailand Center of Excellence for Life Sciences (TCELS) and National Research Council of Thailand (NRCT) supported the budget for producing version 2.0 and installing it in seven hospitals.

On the other hand, this project was the top-down policy by the former NSTDA President. In the beginning of the project, one software team was formed from ICT researchers. After considering the key components of creating a DentiiScan prototype, materials technology members were invited in order to improve the rotation accuracy of the X-ray tube relating to the software's operation. The former NSTDA President also worked as a main researcher and adviser of this project because he developed the first CT scan in Thailand and was educated in Electronic and Computer Engineering. Moreover, he used his network for finding the external budget in conducting research of new projects.

- **Comparison between the commercialization result before and after adopting a CFT**

Before adopting a CFT, a research team developed only a laboratory prototype. As a result, there were no license agreements. The first license agreement of DentiiScan 1.1 appeared in 2011 after the project adopted a CFT in 2009, and it was completed in 2011. In addition, DentiiScan 2.0 was installed in seven hospitals between 2016 and 2017.

Dr. Pairat Thajayapong, Director of the Computer X-ray Development Project for Dentistry explained that:

> *"This project was initiated by the former NSTDA President and the adviser of the NSTDA President. He formed a CFT before developing DentiiScan versions 1.1 and 2.0. He considered that this project needed to have a CFT that consisted of members who had the skills and knowledge from the ICT, materials technology and mechanical engineering fields. ICT researchers can simulate a cross-cutting 3D image using image translation software whereas materials technology researchers can create, modify, and*

rotate the computer's X-ray machine relating to the software's operation. Executive management support led to both successful licensing and diversification of the team because the adviser of the NSTDA President suggested that the team should cooperate with the veterinarian for animal testing by following ethical research on humans and radiation safety. Moreover, he used his network to find the expected licensees and external budget for conducting research in new projects."

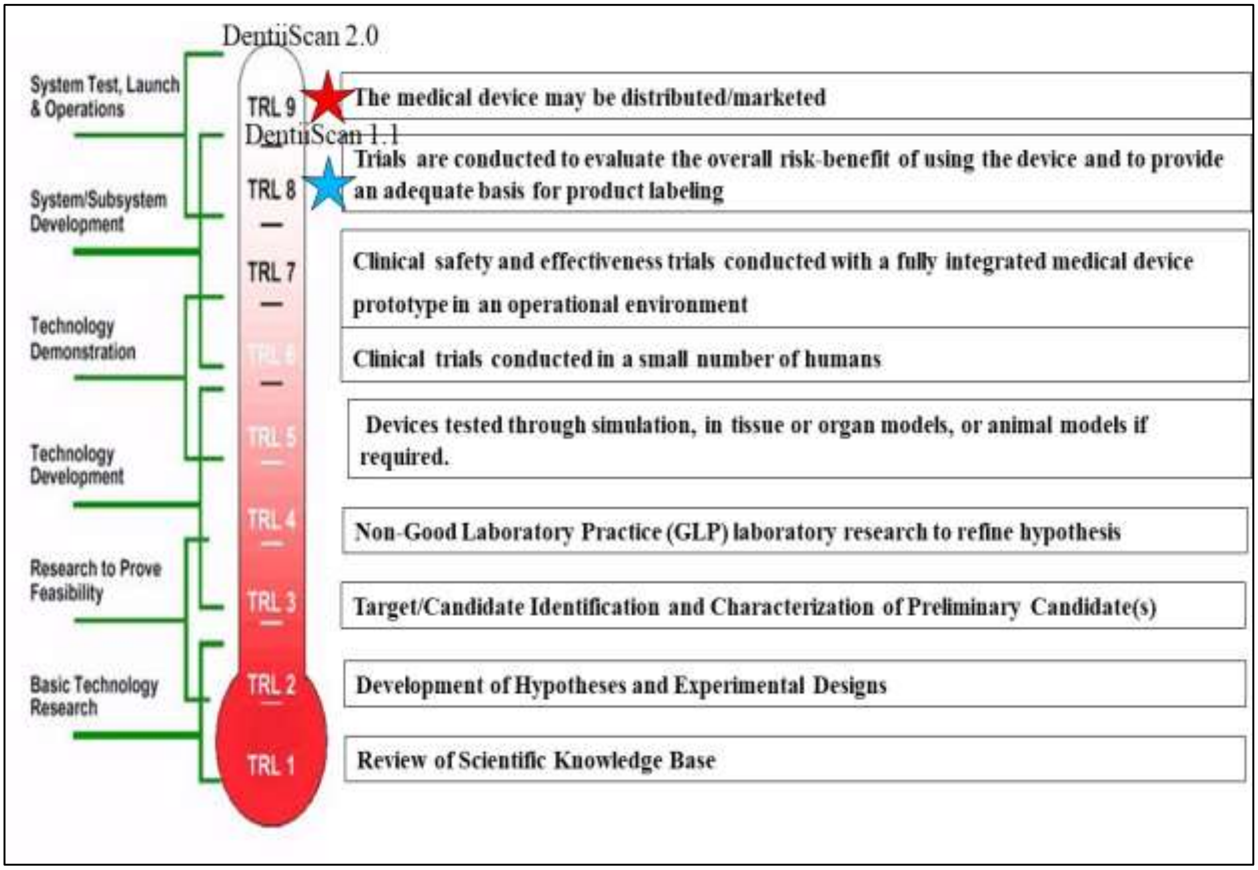
- **Technological system and innovation model**

Based on the coupling model of innovation, DentiiScan development involved customers in a demand-driven process of prototyping. DentiiScan 1.1 had been installed in three clinical sites. After receiving the feedback from the three hospitals, a CFT solved the problems and developed a new version of DentiiScan (version 2.0) in 2015. With the characteristics of ICT as a pervasive and general purpose technology, DentiiScan was widely used for diagnosis and treatment planning in dental and maxillofacial applications; such as, dental implant placement, maxillofacial surgery, impacted tooth extraction, orthodontics and jaw cysts.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

DentiiScan 1.1 was transferred to hospitals at TRL 8 because it had passed the clinical trials in 2011 with more than 170 volunteers and was installed in three hospitals. On the other hand, DentiiScan 2.0 was transferred at TRL 9 because it had already passed the related standards; such as, the radiation safety test from the Ministry of Public Health and the ethical approval from the National Ethics Committee, and had been installed in seven hospitals since 2016. Moreover, the pilot plant for producing DentiiScan 2.0 was certified by ISO 13485.

Figure 5-10: TRL of DentiiScan versions 1.1 and 2.0



Source: Adapted from NASA and the US Army Medical Research Department

In terms of the absorptive capacity of the licensees, they did not have the capability to produce DentiiScan by themselves because they were government agencies. As a result, the NSTDA produced and installed DentiiScan 1.1 in two hospitals and the Faculty of Dentistry whereas government agencies licensed the software copyright.

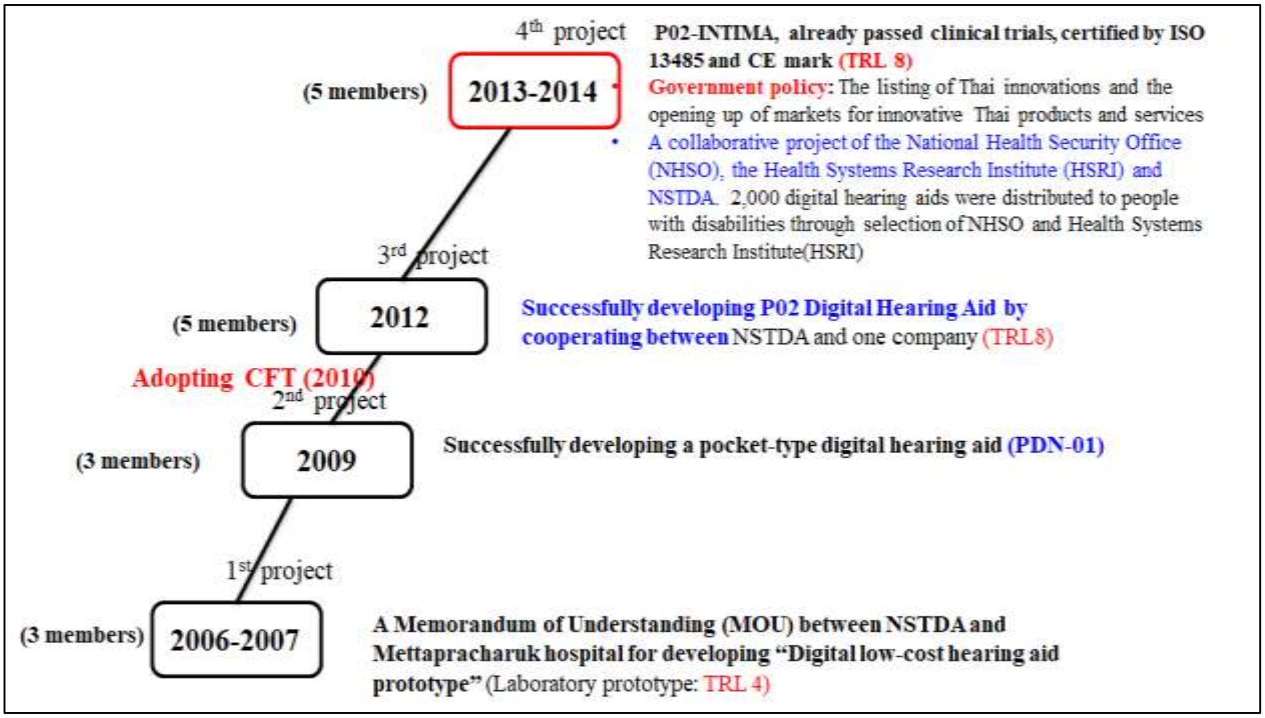
5.1.5) Digital hearing aid P02-INTIMA

- **Key milestones (see Figure 5-11)**

This first project conducted between 2006 and 2007 was a Memorandum of Understanding (MOU) between the NSTDA and Mettapracharuk Hospital for developing a "digital low-cost hearing aid prototype." The output of the research team was a laboratory prototype. The second project was initiated in 2008 and completed by 2009. It successfully developed a pocket type digital hearing aid (PDN-01). The key components were the microphone, receiver, and the baseband processor (DSP). The hearing aid specific DSP was a low-voltage chip (1 volt), which would offer superior current consumption over general DSP baseband counterparts (usually run on a 3.5 volt supply). Additionally, being a system on a chip (meaning that all functions were included in a one chip package); such as, the hearing aid specific DSP, usually implied lower power consumption (Israsena et al., 2013).

The third project implemented by using a CFT was the cooperative research project between the NSTDA and one company, which was a medical device manufacturer. It was completed in two years. The research team had the main functions in conducting research and developing an electronic device whereas the company had the responsibility of the market research, package design, and manufacturing procedure following the related standards. In this period, the CFT had a high diversity of functions by working with the Rehabilitation and Assistive Technology Laboratory, Electrical and Electronic Products Testing Center (PTEC), Business Development Division, and external partners (one company, the Rural ENT Foundation of the Royal College of Otolaryngologists-Head and Neck Surgeons of Thailand, and Department of Otorhinolaryngology, Khon Kaen University). On the other hand, this project had a high diversity of educational fields. It was a combination of Signal Processing Systems for Medical Applications, Embedded Systems, Electrical Engineering, Rehabilitation and Assistive Technology, and Electronics Hardware. Two new members who had expertise in Rehabilitation and Assistive Technology and Electronics Hardware helped the CFT enhance the digital processing quality and produced some parts following the electronic standards. Finally, in 2012, the CFT successfully developed the digital hearing aid (version P02) following the international standards; such as, IEC 60118-7 and EC 60118-13. P02 was a portable digital hearing aid that could be connected to a mobile phone by means of Bluetooth.

Figure 5-11: Key milestones of the digital hearing aid P02-INTIMA



Source: The author

Following the success of the P02 digital hearing aid, it was certified by CE Mark and ISO 13485 in 2012 as the new model, P02-INTIMA. Moreover, the outstanding characteristic of P02-INTIMA was a rechargeable battery. Later, in 2013, there was a collaborative project between the National Health Security Office (NHSO), Health Systems Research Institute (HSRI), and the NSTDA. Two thousand digital hearing aids were distributed to people with disabilities through the selection of the NHSO and HSRI (Figure 5-11).

- **Major changes of the project in terms of the objectives and management practices**

A CFT achieved the objective in developing digital hearing aids not only for Thai users in rural areas, but also for needy users in the urban areas.

A CFT and the Department of Otolaryngology, Faculty of Medicine, Khon Kaen University conducted a clinical trial to test the effectiveness of the P02-INTIMA digital hearing aids. The results indicated that they helped the elderly have a better quality of life. The equipment's quality was no different than that of an imported version, and the price was also lower than in the market (HSRI, 2015). According to the above results of the clinical trial, the NSTDA President consulted with the HSRI about the dissemination of the research results. As a result, the HSRI proposed the policy recommendation to the NHSO in order to adopt INTIMA hearing aids. Finally, the NHSO accepted it and launched a pilot program that was offered to 13 standardized hospitals that had follow-up services. The target group was the elderly with moderate hearing loss.

- **Comparison between the commercialization result before and after adopting a CFT**

Before adopting a CFT, the research team had only developed a laboratory prototype. As a result, there were no license agreements. The first license agreement of the P02 digital hearing aid emerged in 2012 after the project was completed in the same year and led to a collaborative project between the NHSO, HSRI and the NSTDA.

- **Technological system and innovation model**

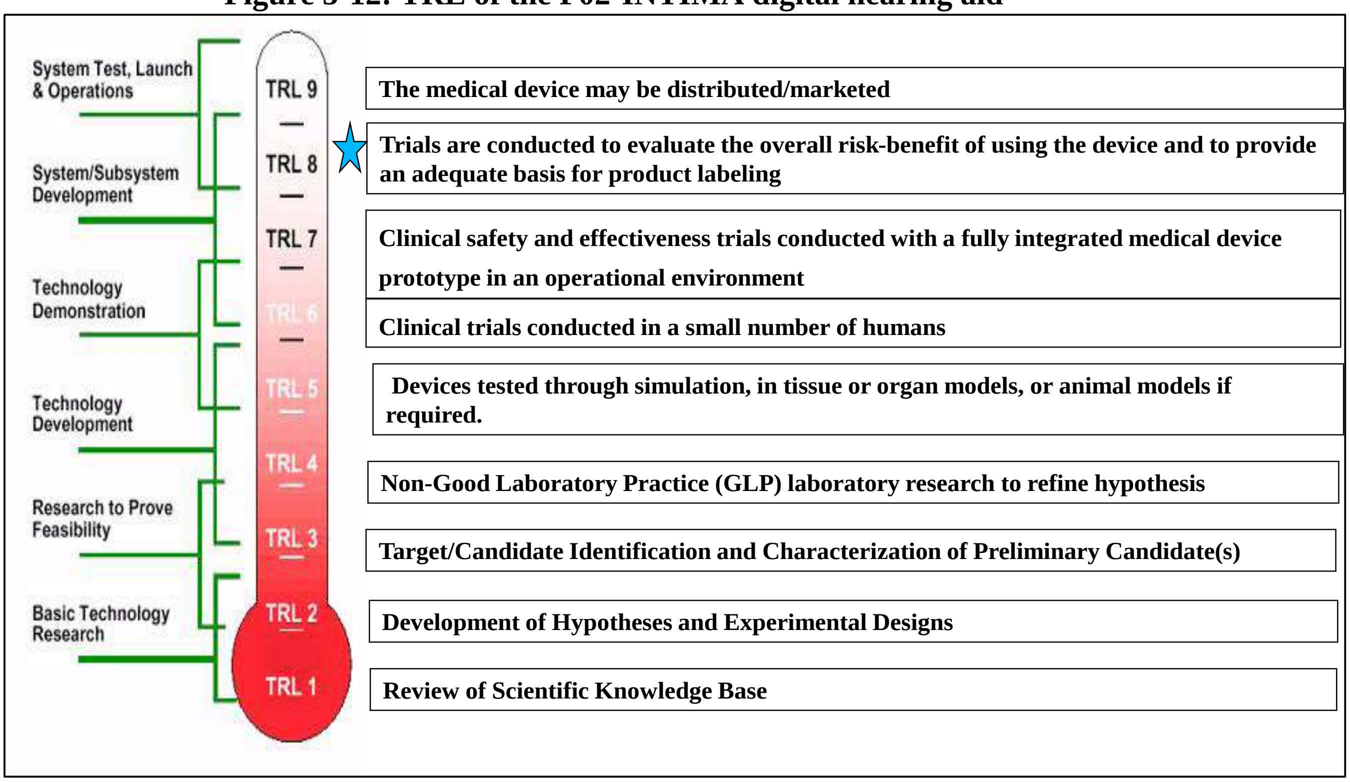
In relation to the coupling model of innovation, a CFT gathered the feedback from users, especially those in the rural areas. The users suggested that there were still demands for a pocket type device, which was considered more robust to extreme conditions and easier to operate. The team collaborated with a team of physicians and specialists from the Department of Otorhinolaryngology, Khon Kaen University in the clinical trials. The test was based on the Abbreviated Profit of Hearing Aid Benefit (APHAB) and was tested for consistency in quality from continuous use. From the results of the test amplification, the machine was still capable of being reprogrammed. In addition, volunteers were also pleased to use it, and the user group was highly satisfied. The hardware capabilities were stable, and the sound quality was equivalent to hearing aids imported from Europe.

After receiving much feedback, the CFT designed the P02-INTIMA as a pocket type with minimal use of peripherals; such as, sockets and buttons. The number of buttons was also reduced further by the fact that the hearing aid was designed to be fitted to a computer rather than needed built-in trimmers. The Thai language fitting software was also provided in the new model (Israsena et al., 2013).

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

The P02-INTIMA digital hearing aids were transferred to companies at TRL 8 (Figure 5-12) because they had passed the clinical trials, the test of the acoustic performance IEC 60118-7, IEC 60601-1 (a collateral standard for "medical equipment/medical electrical equipment), and EC 60118-13 (Hearing aids - Part 13: Electromagnetic compatibility (EMC)). Furthermore, the P02-INTIMA digital hearing aids were certified by ISO 13485 and received the CE mark certification that met the European Union (EU)'s health, safety, and environmental requirements.

Figure 5-12: TRL of the P02-INTIMA digital hearing aid



Source: Adapted from NASA and the US Army Medical Research Department

Considering the absorptive capacity of the licensee, the company was a manufacturer of medical devices and had certified quality management systems from ISO 13485/AC2009. Therefore, it had the capability to produce digital hearing aids and distribute them to the markets.

5.1.6) Case study A

- **Key milestones**

ICT researchers had continuously emphasized on the Thai agricultural sector by supporting new technologies of farming or a smart farm, especially on managing and using ICT technologies for the improving of agricultural products.

In 2015, a CFT tried to build a working prototype of a smart sensor to enable agriculturalists to monitor their products in real time and adjust the input accordingly. The sensor could control and create the environment that was suitable for plants; such as, temperature, humidity, moisture and light. The system automatically worked in the greenhouse. When the parameter showed high/low, the notifications were sent to the agriculturists through their mobile phones. Moreover, they could increase the types of plants and enter more information into the system.

In spite of successfully developing the field prototypes by 2015, the CFT could not commercialize these prototypes to the expected companies.

- **Major changes of the project in terms of the objectives and management practices**

There were no major changes in the objectives and management practices.

- **Comparison between the commercialization result before and after adopting a CFT**

A CFT which comprised nine members had both the high diversity of educational fields and the high diversity of functions as follows:

1) It integrated the ICT fields; such as, Microelectronics, Electrical Engineering, Technology Management, Electronics and Computer Science, System Engineering, Sensor Technology and Microelectromechanical Systems (MEMS).
2) In order to receive feedback from the users, the agriculturalists as the expected users were involved to test the field prototypes in the relevant environments.

A main researcher and the technology transfer officer explained that:

"Although the CFT received good testing results in some areas, it had to resolve technical problems in some areas. These results implied that different types of plants, weather/temperature and other conditions of different areas affected the system's stability and reliability. They were the main obstacles for transferring products to the beneficiaries."

- **Technological system and innovation model**

This case study was related to the coupling model of innovation.

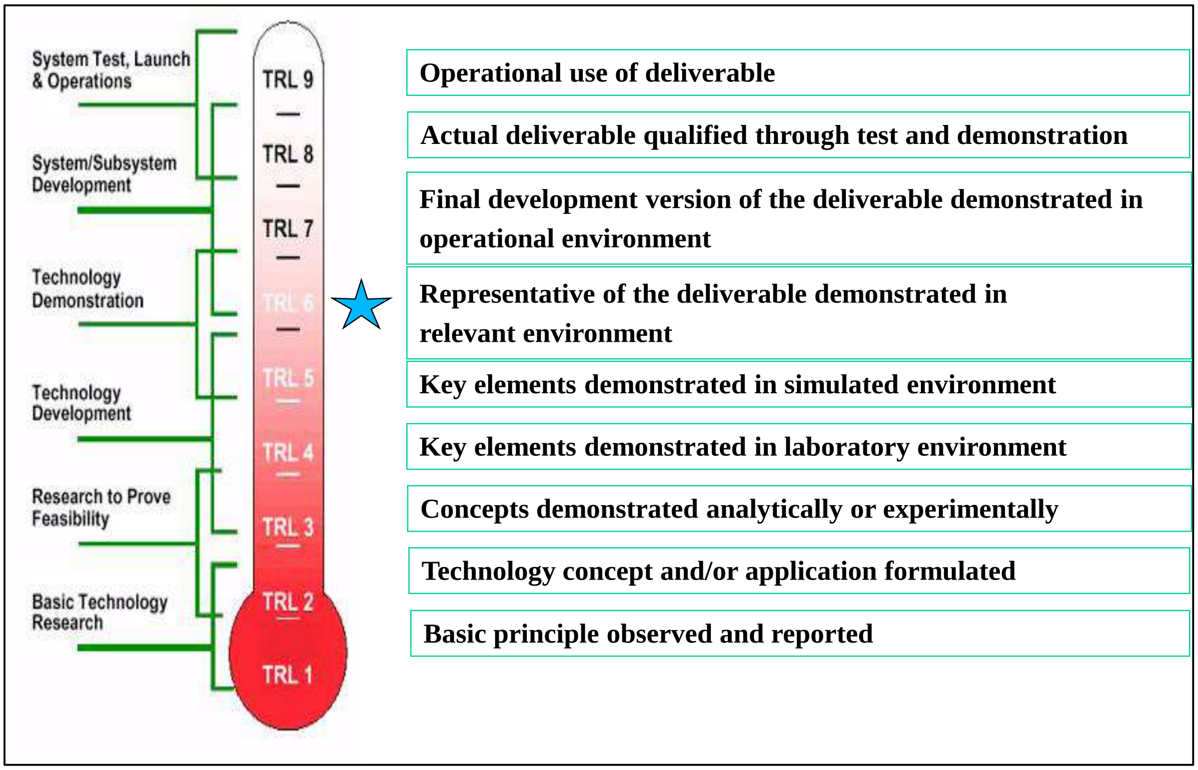
A main researcher described that:

"*The use of smart sensors on a smart farm is widespread. However, nowadays, sensors are imported from foreign countries. They are designed for applying in stable environments, especially industrial plants. Therefore, the research problem is to develop the sensor technology, which is suitable for the agricultural sector in Thailand, which had climate fluctuation. In order to test and receive feedback from the expected users, the CFT tested the prototypes with the greenhouses of some agriculturists."*

- **Technology Readiness Level (TRL)**

A CFT successfully developed the smart sensors at TRL 6 (Figure 5-13). This referred to the prototypes performing effectively in some areas. In order to enhance the stability and reliability of the smart sensors, the CFT had to understand the numerous conditions of the different types of plants in various areas/provinces in Thailand. In addition, most Thai agriculturists were not accustomed to the use of the Internet and complex features of mobile phones. Thus, these problems could be a barrier to commercialize smart sensors.

Figure 5-13: TRL of case study A



Source: Adapted from Sandia National Laboratories, 2007

5.1.7 Top management support enhancing team diversity

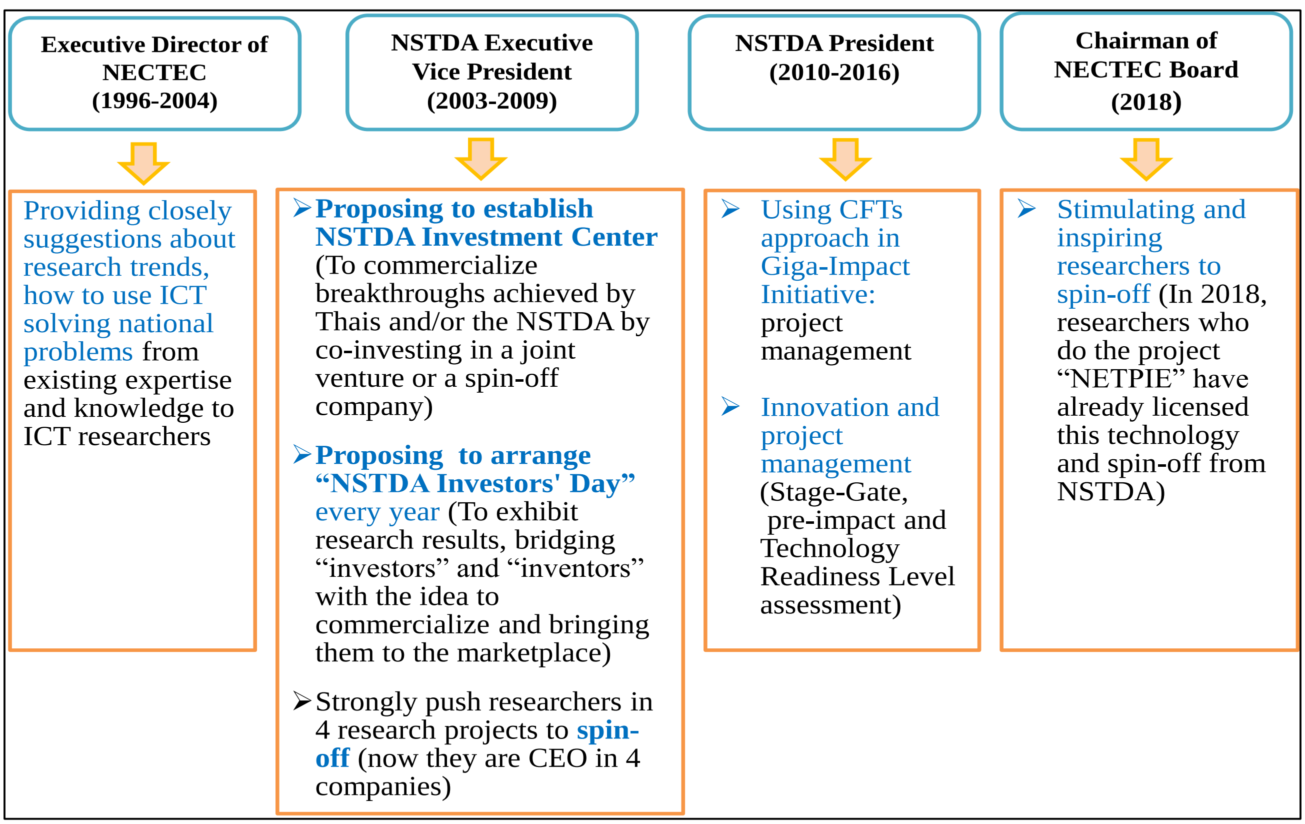
In addition to top management support in each project, senior management support by Dr. Thaweesak Koanantakool, NSTDA President, was one of the key factors for enhancing the NSTDA's research commercialization, especially for ICT projects.

From the interview, he stated that:

> *"When I was the Executive Director of NECTEC between 1996 and 2004, I had a close relationship with ICT researchers by providing suggestions about how to develop ICT innovations solving national problems. After I was the NSTDA Executive*

Vice President between 2005 and 2009, I considered that new technology always had a high risk for a new entrepreneur or a company in investing money for creating new business. As a result, I proposed to set up the "NSTDA Investment Center (NIC)", which was responsible for promoting investment in science and technology by co-investing with the ultimate goal of benefiting Thailand's economy and society. The NIC commercialized breakthrough technologies achieved by Thais and/or the NSTDA by co-investing in a joint venture or a spin-off company. Between 2006 and 2008, I guided researchers in three research projects to become a spin-off. Moreover, in this year, as the Chairman of the NECTEC Board, I inspired researchers to conduct the "NETPIE" project in order to license and spin-off this technology from the NSTDA" (see Figure 5-14).

Figure 5-14: Top management support by Dr. Thaweesak Koanantakool



Source: The author.

"When I was NSTDA President between 2010 and 2016, I created many mechanisms for enhancing research commercialization. For example, I set and chaired the NSTDA Commercialization Group (NCG) as the working group consisting of business development officers and technology transfer officers (TTOs) in order to facilitate the NSTDA's commercialization process smoothly. I considered that there was a gap between the researchers and TTOs. The researchers required the TTOs to help them find the market's needs/do a market survey. They did not want the TTOs involving the CFTs only for the final stage of licensing. As a result, I tried to fill this gap by initiating the Giga Impact Initiatives (GII) projects. In the GII projects, the TTOs participated in an active role in the CFTs since the beginning of the project by offering information about the market's needs and patent mapping. Moreover, the TTOs were strongly involved in the field trial/scale-up stage and commercialization stage because some companies could license only the laboratory prototype for testing in their companies, or some companies could license pilot scale prototypes in the fifth stage of innovation management.

Another example was assigning the working group to develop the "NSTDA's Guideline for the Technology Readiness Levels (TRLs) Assessment" because the TRL was a communication tool between the technologist and the TTOs and was a consistent comparison of maturity between the different types of technology. Many government agencies including PRIs used TRLs; such as, the National Aeronautics and Space Administration (NASA), United States; Department of Defense (DOD), United States; Department of Energy (DOE), United States; Department of Homeland Security (DHS), United States; North Atlantic Treaty Organization (NATO), United States; European Space Agency (ESA); Japan Aerospace Exploration Agency (JAXA), etc. Moreover, the National Research Foundation, Singapore and Horizon 2020 program of Europe employed TRLs as the criteria for calling a research proposal. On the other hand, I strongly pushed the TTOs to actively perform by using the TRLs of finished research projects to help researchers find *licensees because R&D licensing can occur at any TRL depending on the readiness of the customers/companies."*

"In terms of R&D licensing, although there are a small number of licensing projects compared to the total research projects, it is necessary for forming CFTs. However, the team diversity factors of CFTs in each technology are different depending on the characteristics of each technology. For example, ICT has a high diversity of educational fields because there is convergence between ICT and other technological fields; such as, "materials informatics" and "bioinformatics." In addition, I used a "Consortium" for enhancing the NSTDA's research commercialization; such as, the "Biomedical Consortium", "CCTV Consortium", "Thailand's National e-Science Infrastructure Consortium, etc." On the other hand, after visiting many NSTDA laboratories, I listened to the progress of many research projects and suggested that some projects need to have members in some educational fields to solve the key problems of the projects. Moreover, I helped researchers contact government agencies or companies for achieving collaborative research projects."

"For your research framework, in addition to team diversity and senior management support as the key factors supporting CFTs in enhancing research commercialization, I propose that researchers need to have "growth mindset" for achieving research commercialization success. Growth mindset means that individuals who believe their talents can be developed (through hard work, good strategies, and input from others) (Dweck, 2016)."

5.2 Biotechnology Case Studies

5.2.1) Characteristics of biotechnology

Biotechnology involves the manipulation of biological molecules, viruses, and living microorganisms for applications in the fields of pharmacology, medicine, and agriculture; for example, using advanced laboratory techniques for culturing cells, manipulating genes, separating and purifying biomolecules, and computational modeling. Biotechnologists have achieved remarkable scientific breakthroughs; such as, sequencing the human genome, innovating gene therapies, and advancing agricultural products. Moreover, biotechnologists engineer viruses (10s-100s of nm), bacteria (1-3 μm), animal and human cells (10-25 μm), and plant cells (10-100 μm) (Omninano, 2016). In addition, the biotechnology industry is dependent on academic research and, therefore, there is an increasing number of technology transfer and entrepreneurial activities within PRIs and universities (Branstetter and Ogura, 2005; Gross, 2009; Kim and Marschke, 2005). Decter et al. (2007) explained that "*biotechnology companies have a closer relationship between university research for inventing and developing new products, compared to other fields*."

Some authors refer to biotechnology products as "technology push" innovations (Krimsky and Wrubel, 1996; Hackings, 1986; Russell, 1991). Biotechnology companies put great effort into developing novel technologies and rely on intellectual property protection to protect their markets. An exacerbating factor is that while development costs in biotechnology are difficult to predict – a challenge also shared by traditional technological development – the feasibility of technological development is also uncertain. This means that an emerging product developing biotechnology firm may have uncertainty in the feasibility of its product, the cost to develop and produce the product, the market for its product, the path to consumers, and the price consumers will pay (Friedman, 2009). For example, the dominant big pharma model is predicated on a relatively simple linear, technology push model of the innovation process: a capability to perform increasingly high levels of internal R&D in an efficient, 'machine like' manner, and coupling this with an even more expensive global marketing and sales capability (Tidd, 2005).

5.2.2) Relationship between the high diversity of functions and medium diversity of educational fields

Regarding the results of the regression analysis, a high diversity of functions is the significant factor supporting CFTs to enhance the number of license agreements in biotechnology projects.

In order to clarify the details of CFTs in these projects, this study analyzed the relationship between the functions and educational fields by using cross tabulation. It was found that most biotechnology licensed projects consisting of a high diversity of functions had a medium diversity of educational fields.

After considering the educational fields of the total CFTs in the biotechnology licensed projects, the key common fields for developing biotechnology products were found to be microbiology and biotechnology.

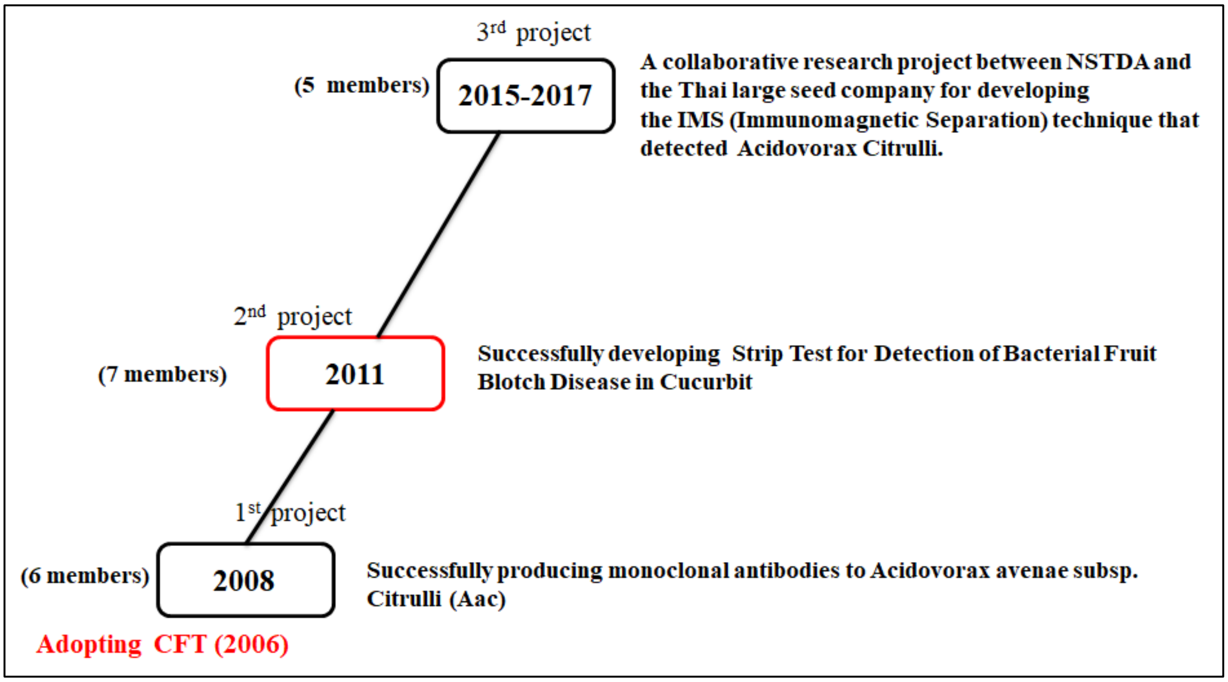
5.2.3) Strip test for the detection of bacterial fruit blotch disease in cucurbit

- **Key milestones (see Figure 5-15)**

As part of the collaboration between the NSTDA's Monoclonal Antibody Production Laboratory, NSTDA's Microbial Cell Factory Laboratory, Kasetsart University and Khon Kaen University as the high diversity of functions/departments between 2006 and 2008, a CFT had successfully produced a catalog of mouse monoclonal antibodies and rabbit polyclonal antibodies for detection of plant pathogens that caused serious plant diseases; such as, tomato yellow leaf curl virus, whitefly-transmitted geminiviruses, capsicum chlorosis virus, watermelon silver mottle virus, tomato necrotic ringspot virus, melon yellow spot virus, watermelon mosaic virus-2, potyviruses and Acidovorax avenae subsp. citrulli. These antibodies were used to develop enzyme-linked immunosorbent assays for an efficient detection of the plant diseases. On the other hand, it was found that the percentage of a number of different disciplines compared with the team size (six members) was 66.7% as the medium degree of difference in educational fields. This was a combination of Biology, Agricultural Biotechnology, Plant Pathology and Microbiology.

The second project emerged between 2009 and 2011, which paid attention to developing the IC strip test for the detection of bacterial fruit blotch disease in cucurbit. A CFT and a new member from the Department of Agriculture, Ministry of Agriculture and Cooperatives successfully developed an immunochromatographic strip test for the rapid detection of seedborne bacterium Acidovorax avenae subsp. citrulli.

Figure 5-15: Key milestones of the strip test for the detection of bacterial fruit blotch disease in cucurbit



Source: The author

After completing the second project, the CFT waited for four years. The third project was a collaborative research project between the NSTDA and a large Thai seed company for developing the immunomagnetic separation (IMS) technique that detected Acidovorax Citrulli. This new innovation made it possible to quickly detect the contamination of the bacteria in the seed. It took only six-10 days to isolate Acidovorax Citrulli from the seed. This project was the cooperation between the NSTDA's Monoclonal Antibody Production Laboratory, NSTDA's Microbial Cell Factory Laboratory, Department of Agriculture, Ministry of Agriculture and Cooperatives, and a large company as the high diversity of functions/departments.

- **Major changes of the project in terms of the objectives and management practices**

A CFT achieved the objective in producing monoclonal antibodies for the governmental and private sectors. After sending the survey to many Thai seed companies, the head of the project found that the current market's need was the strip tests, which were easy to use for detecting plant pathogenic bacteria. As a result, the objectives of the CFT were changed from only monoclonal antibody production to strip test development.

- **Comparison between the commercialization result before and after adopting a CFT**

This project had applied the CFTs approach since the first project. The NSTDA researchers produced a monoclonal antibody whereas university researchers prepared plant pathogenic bacteria for testing. On the other hand, a member from the Department of Agriculture, Ministry of Agriculture and Cooperatives had the main responsibility for developing the strip test.

The main researcher explained that:

> *"I formed a CFT by relying on my close relationship with one NSTDA researcher from a different laboratory and inviting the university researchers and the representative of the Department of Agriculture, who had a close collaboration with the NSTDA and my main researcher. I considered that if a CFT had complimentary skills and knowledge among members, it would lead to achieve the license agreements and the goal for research commercialization.*
>
> *Coordinating between the Monoclonal Antibody Production Laboratory and Microbial Cell Factory Laboratory, monoclonal antibodies (MAbs) were raised against sonicated cell suspension of Aac. MAb, designated 11E5, specifically reacting with only Acidovorax avenae subsp. citrulli (Aac) but did not cross-react with other phytopathogenic and saprophytic bacteria.*
>
> *In collaboration with Kasetsart University, Khon Kaen University and the Department of Agriculture, the immunochromatographic strip test successfully developed antibodies and various immunological assays for detecting plant pathogens that caused serious diseases in crops; such as, whitefly-transmitted Gemini viruses, tomato yellow leaf curl virus (TYLCV), tospovirus serogroup IV, melon yellow spot virus (MYSV), potyviruses, and watermelon mosaic virus-2 (WMV-2)".*

After adding one member into a CFT in the second project, this helped the CFT to expand from the existing customer base that licensed only antibodies to the new customers that licensed strip tests. However, the first license agreement of the strip test appeared two years after the project was completed because most Thai seed companies had a low capability to produce the strip tests.

- **Technological system and innovation model**

Before successfully developing the monoclonal antibodies for Acidovorax avenae subsp. Citrulli (Aac) in 2008 and the strip test for the detection of bacterial fruit blotch disease in 2011, a research team had to do basic research to study the relationship among the types of thrips, host plants and tospovirus infection in tomato, pepper and cucurbit production fields. The goal of the project was to identify the thrips species that were responsible for the transmission of the four tospoviruses (watermelon silver mottle virus, capsicum chlorosis virus, melon yellow spot virus and tomato necrotic ringspot virus) found in Thailand. A survey to identify the thrips species and plant infecting tospoviruses in the tomato, pepper and cucurbit production fields was conducted in seven provinces of Thailand. In addition to the basic knowledge, this project provided several useful methods for tospovirus resistance screening in a breeding program.

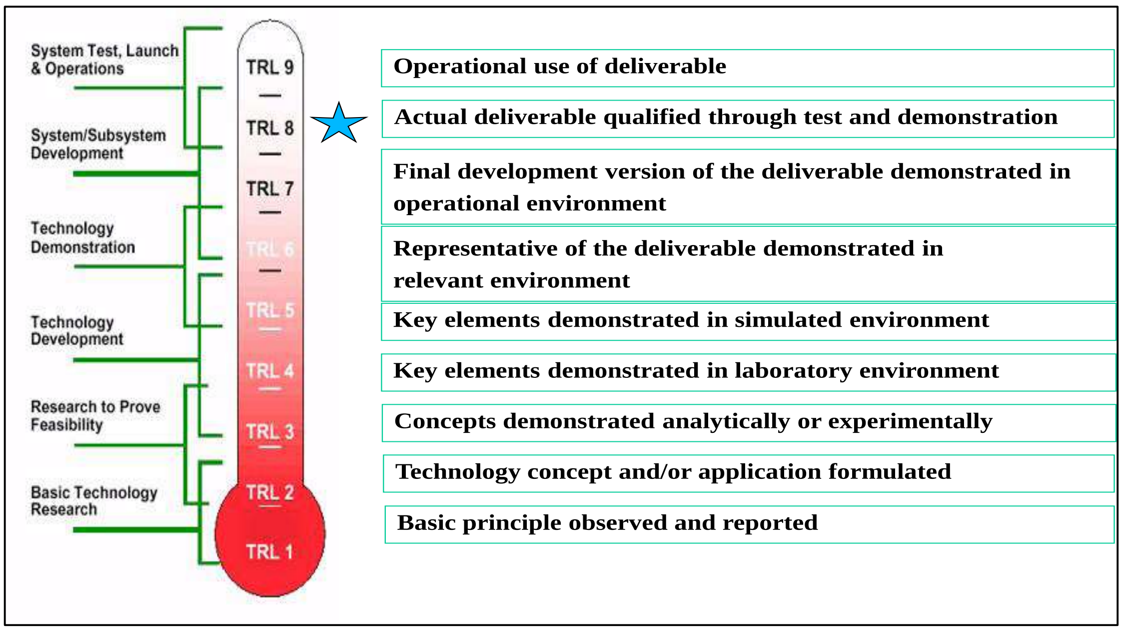
With regards to the technology push model of innovation and characteristics of biotechnology, the Monoclonal Antibody Production Laboratory provided services in increasing and purifying the monoclonal antibodies for the governmental and private sectors. Moreover, the Laboratory established the systematic hybridoma collection program with an effective database management system. More than 400 hybridoma clones were stored at this laboratory. These hybridoma clones were the results of the research projects involved in monoclonal antibody production both from this laboratory and other institutes whose research funds were supported by the NSTDA. The specification of the secreted antibodies covered a wide range of antigens including plant viruses and bacteria, bovine progesterone, food pathogens, aflatoxin and avian flu virus. The candidate hybridoma clones were annually tested for their viability and ability to produce the specific antibodies to their corresponding antigens.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

Strip tests for the detection of bacterial fruit blotch disease in cucurbit were transferred to the companies at TRL 8 (Figure 5-16). The company needed to buy antibodies as raw materials from the NSTDA and the Department of Agriculture to help it develop strip tests for commercial purposes.

In terms of the absorptive capacity of the licensee, the company engaged in the import, distribution, and distribution of chemicals for many industries did not have the capability to produce strip tests. Therefore, the NSTDA and the Department of Agriculture provided assistance in this aspect.

Figure 5-16: TRL of the strip test



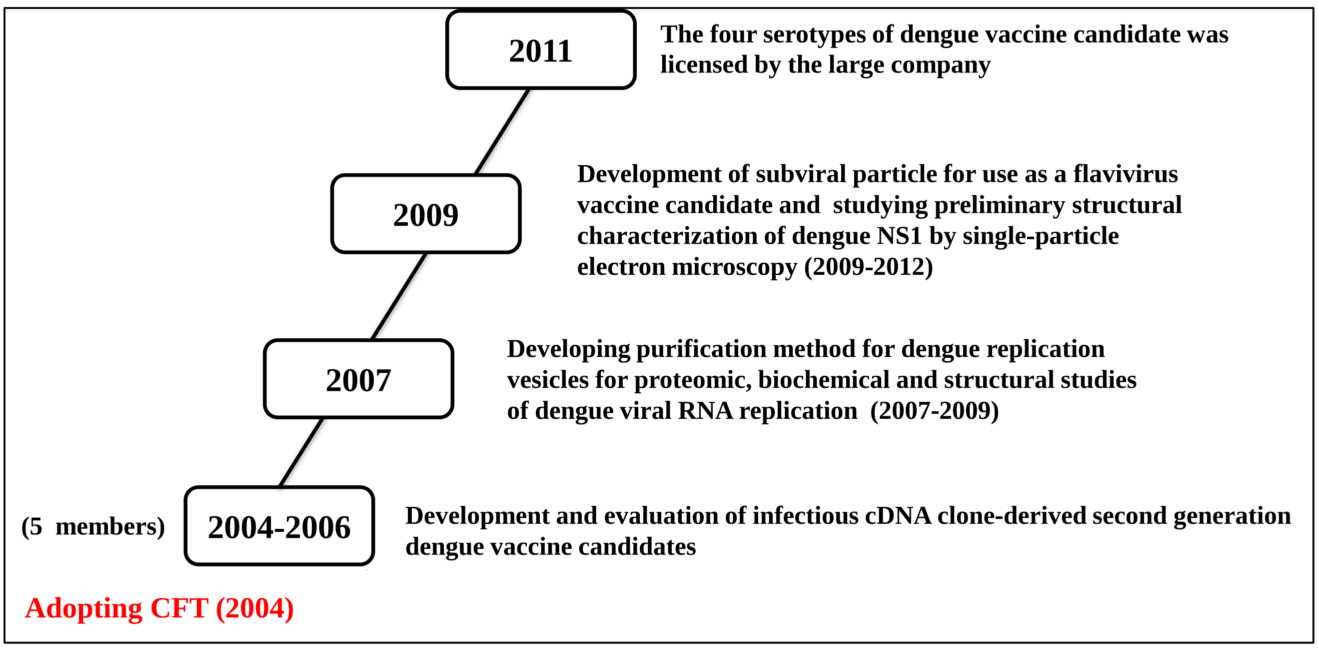
Source: Adapted from NASA and the Sandia National Laboratory, USA.

5.2.4) Dengue vaccine candidate

- **Key milestones (Figure 5-17)**

Before licensing the four serotypes of chimeric live-attenuated vaccine to a large company in 2011, a CFT had conducted many research projects since 2004; such as, "Development and evaluation of infectious cDNA clone-derived second generation dengue vaccine candidates," "Developing a purification method for dengue replication vesicles for proteomic, biochemical and structural studies of dengue viral RNA replication", and "Development of a subviral particle for use as a flavivirus vaccine candidate and studying preliminary structural characterization of dengue NS1 by single-particle electron microscopy" (see Figure 5-17).

Figure 5-17: Key milestones of the four serotypes of the chimeric live-attenuated vaccine candidate



Source: The author

Due to the high diversity of the functions/departments, the NSTDA's Medical Biotechnology Research Laboratory, NSTDA's Business Development Division, Chiang Mai University and Mahidol University successfully engineered the chimeric live-attenuated dengue viruses, which had good potential to be developed further as a vaccine candidate for safety and efficacy studies in a non-human primate model in 2011. The large company licensed the four serotypes of the dengue vaccine candidate from the NSTDA in the same year. The Mahidol University researcher was the key person because he developed the first live-attenuated virus (LAV) vaccine, one type of dengue vaccine (Bhamarapravati and Sutee, 2000). This project had the medium diversity of educational fields by combining Microbiology, Pathobiology and Medical Technology. The main researcher explained that:

> *"Dengue is caused by four closely related viruses, dengue serotypes 1-4, which single-stranded RNA viruses are spreading primarily through the A. aegypti mosquito. A set of tetravalent, live-attenuated dengue vaccine was previously developed by serial passages of dengue viruses in appropriate mammalian cells. From the study, a number of modifications of genetic material in different regions of the genome of dengue serotype 2 was found to result in the attenuation of virus virulence. This discovery led to the construction and testing of the chimeric viruses, which comprised the prM-E coding region from recent dengue clinical isolates on the genetic background of the attenuated virus. Based on the promising results from the neurovirulence and immunogenicity testing in mice, the chimeric viruses were considered to have good potential to be developed further as a vaccine candidate for safety and efficacy studies in a non-human primate model" (NSTDA, 2011).*

- **Major changes of the project in terms of the objectives and management practices**

There were no major changes in the objectives and management practices. Although the four serotypes of the chimeric live-attenuated vaccine candidate were licensed to the company, researchers had to continue developing dengue vaccine candidates in preclinical and clinical scales and conduct bio-medical and translational research in the immunopathogenesis of dengue hemorrhagic fever (DHF).

- **Comparison between the commercialization result before and after adopting a CFT**

A CFT could not achieve the first license agreement in the first project because the development of the vaccine took several years for producing good results for transferring the necessary technology. The project leader explained that *"The NSTDA researchers had expertise in subunit* *vaccine whereas Chiang Mai University researchers helped the team study the response of the virus and a Mahidol University researcher had expertise in DNA vaccine. Complementary expertise could help a CFT achieve successful licensing."* When receiving positive results from the animal testing and the dengue vaccine candidate had good potential to be developed in preclinical and clinical studies, it was immediately licensed by the large company.

- **Technological system and innovation model**

Based on the technology push model of innovation and the characteristics of biotechnology, the NSTDA researchers undertook almost 10 years of laboratory research in order to collect knowledge to develop dengue vaccine candidates. The vaccine efficacy test was done in animals; such as rats and monkeys, and had satisfactory results. The animals were free of disease and could also be immunized. If this vaccine candidate had to be tested in preclinical research and clinical trials, it would have to be done in factories, research institutes and hospitals that had been certified by international standards; such as, Good Laboratory Practice (GLP), Good Manufacturing Practice (GMP), Good Clinical Practice (GCP), etc. Therefore, licensing this technology by the company before conducting preclinical studies could help PRIs reduce the technology risks.

One member of a CFT said that:

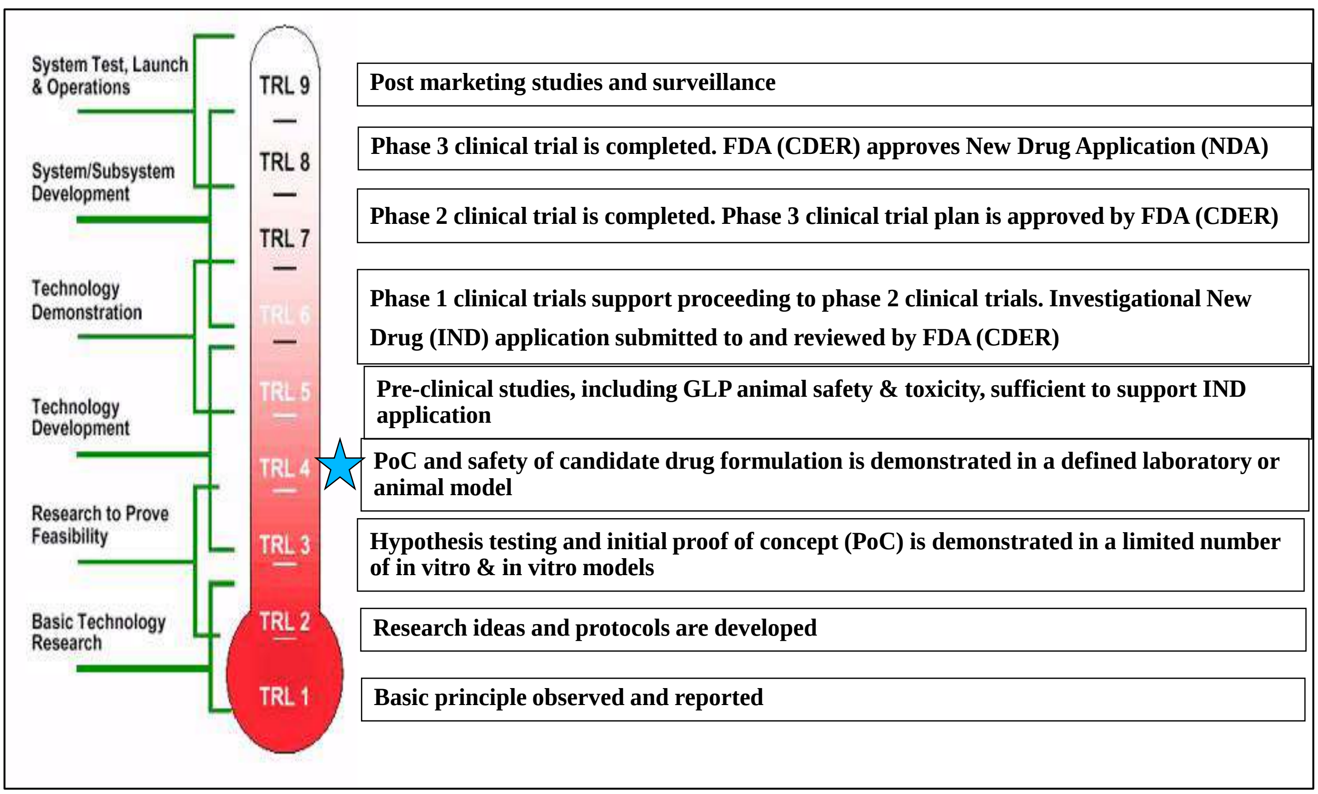
> *"The main problem of vaccine research in Thailand was that the Government Pharmaceutical Organization (GPO) did not have either the technology or qualifications to produce vaccine. Another obstruction was the lack of personnel involved in the vaccine research and production field. Despite the thousands of new pharmaceutical graduates every year, almost none of them want to work in vaccine research" (Rujivanarom, 2016).*

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

In 2011, the NSTDA, Chiang Mai University, Mahidol University and BioNet-Asia Co., Ltd. signed a licensing agreement for a dengue vaccine candidate at TRL 4 (Figure 5-18). The agreement enabled the company to further develop and produce the vaccine for testing in the preclinical and clinical stages. This collaboration was expected to commercialize the dengue vaccine in Thailand.

Although the NSTDA transferred this technology at the low TRL (TRL 4) to the company, BioNet-Asia Co., Ltd. had the capability in both scientists and infrastructure to undertake preclinical and clinical research. The company is based in Thailand with its core business in the development and marketing of vaccines in emerging market countries. It started vaccine development activities in 2007 with the first project on the recombinant a cellular pertussis vaccine and has been actively working on different vaccine R&D programs using the most recent technologies available in its state-of-the-art vaccine research and development center in Ayutthaya.

Figure 5-18: TRL of the four serotypes of the chimeric live-attenuated vaccine candidate



Source: Adapted from the US Army Medical Department.

The company representative said that:

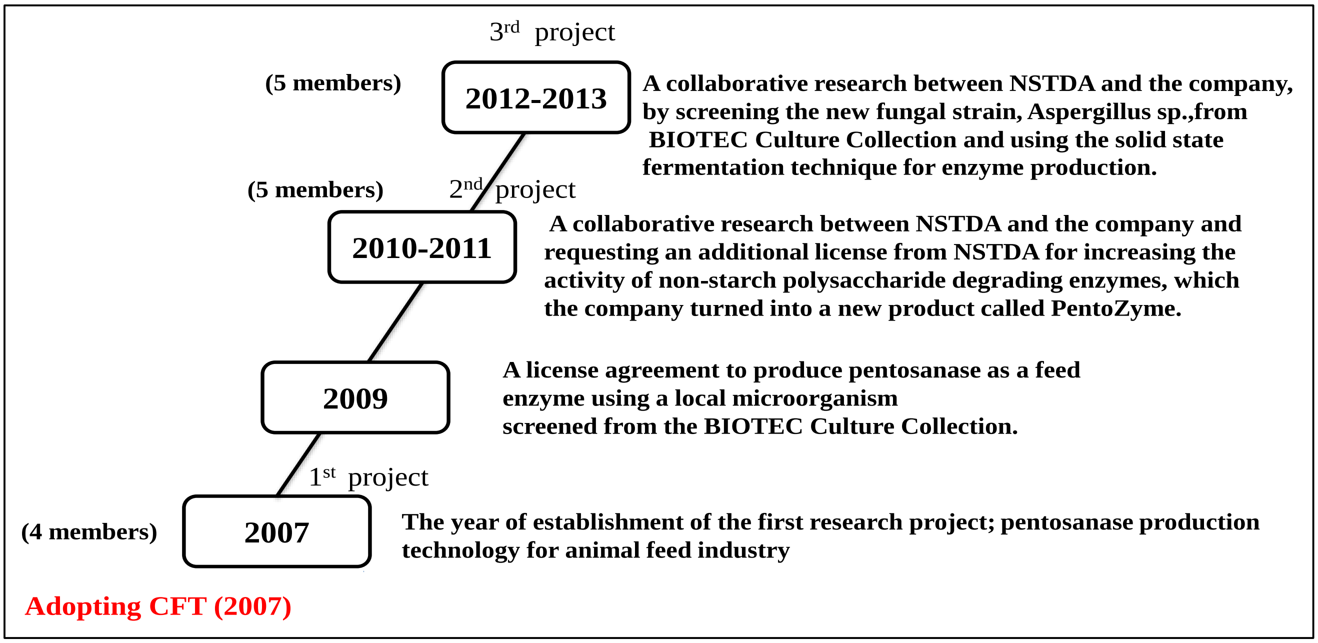
> *"We had evaluated different development strategies for a dengue vaccine and have eventually selected the dengue-dengue chimeric constructs because this vaccine would induce more complete immunity. We had also acquired advanced cell culture technology and were assembling a group of researchers to participate in this exciting vaccine project. We were confident that with the licensed strains, our technology and talented team of scientists, we could bring an innovative chimeric dengue vaccine within a reasonable time frame" (Press release, 2011).*

5.2.5) Pentosanase production technology for the animal feed industry

- **Key milestones (see Figure 5-19)**

The research problem was pig farmers importing expensive enzyme products, which resulted in increased costs. After conducting research between 2007 and 2009, a CFT consisting of the Food Biotechnology Laboratory, Bioprocess Technology Laboratory, and Chiang Mai University as the high diversity of functions/departments and the medium diversity of educational fields (Food Science Technology, Biotechnology and Zoology) found that pentosanase could be used to digest non-starch polysaccharides in the raw materials of animal feed, so that animals could absorb and utilize more nutrients. Pentosanase produced from Aspergillus spp. was tested at a pig farm and outperformed the imported enzymes when used as a feed additive. As a result, in 2009, one company signed a license agreement to produce pentosanase as a feed enzyme using a local microorganism screened from the BIOTEC Culture Collection. The company had been releasing feed enzyme products under the trade name A-Zyme.

Figure 5-19: Key milestones of pentosanase production technology for animal feed industry



Source: The author

The success of A-Zyme led to cooperative research between the NSTDA and the company between 2010 and 2011. In this second project, a new member as the representative of the company was included in a new CFT. He gave information about the conditions and enzyme production processes in his factory to the team. Finally, in 2011, the company requested an additional license for increasing the activity of non-starch polysaccharide degrading enzymes, which the company turned into a new product called PentoZyme.

After signing two license agreements from the NSTDA, the products gained market acceptance. The company had increased the production capacity along with created new products based on fermentation. Therefore, between 2012 and 2013, there was collaborative research between the NSTDA and the same company by screening the new fungal strain, Aspergillus sp, from the BIOTEC Culture Collection and using the solid state fermentation technique for enzyme production. In 2013, the same company acquired a technology license from the NSTDA again. This technology optimized a solid state fermentation process for pentosanase production. The desirable enzyme should be stable and active under the appropriate conditions (temperation, pH, etc.) inside the animal's digestive system, as well as be able to digest carbohydrate in feed to enhance the overall digestion efficiency of animals.

- **Major changes of the project in terms of the objectives and management practices**

There were no major changes in the objectives and management practices.

- **Comparison between the commercialization result before and after adopting a CFT**

This project had applied a CFTs approach since the first project. Three license agreements from the same company proved that it trusted the research outputs from the CFT. This achieved the objective for developing an enzyme for increasing the digestion capability making nutrients more accessible than traditional feed formulas. Moreover, it helped the pig farmers reduce their costs for importing enzyme products. The research problems of the three projects were different. The first license agreement of the second project and the third project appeared immediately after the project was completed in 2011 and 2013, respectively.

In order to produce low-cost enzyme products for the pig farmers, the NSTDA researchers developed the first project as the technology push model by using team diversity in terms of educational fields and functions. They did not know whether the project would have license agreements or not. When the company licensed the product from the first project, achieving the license agreements was set as the goals for the second and the third projects. The expected licensing in the second and the third projects, as collaborative projects, led to the team diversity of the CFT through the cooperation between the NSTDA researchers, the university researcher and the company's staff.

- **Technological system and innovation model**

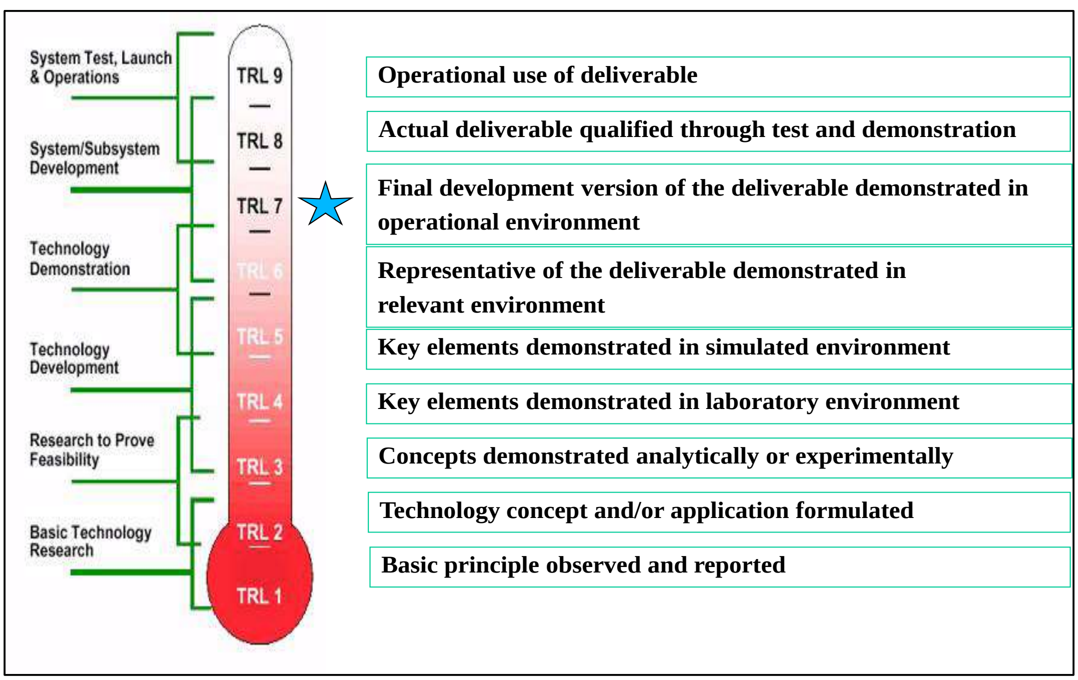
Based on the technology push model of innovation, the NSTDA provided the microbial bank (the Microbe Bank of BIOTEC), which was a source of microorganisms providing more than 20,000 samples for the private sector. Furthermore, the microorganisms were kept in accordance with international standards (ISO 9001) by being frozen in a liquid nitrogen tank or in a dry vacuum tube. Microbial experts would set the storage methods for receiving the surviving microbes. For example, the Company said that:

> *"Acquiring the license of technology developed by BIOTEC, access to a competent research team, and the availability of the Microbe Bank were the key successes for our business. It accelerated the R&D process in our company, and helped us save the cost, too" (NSTDA, 2016).*

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

After testing different research outputs from the pentosanase production technology in the company and receiving positive results, the company licensed them in 2009, 2011 and 2013, respectively at TRL 7 (Figure 5-20). The company considered that it was a chance and had the capability to produce these products in large quantities of standardized products because the company was a trading firm of feed products and raw feed materials. The company's factory was certified by international standards: GMP, ISO 9001:2000, and ISO 14001:2004.

Figure 5-20: TRL of pentosanase production technology



Source: Adapted from NASA and the Sandia National Laboratory, USA.

Since these feed products were based on research conducted locally, they performed well in the tropical environment, local breeds and conditions. Feeds supplemented with enzyme were well accepted by farmers shortly after the product launch because of its excellent performance. Competitors started to emerge with similar products. The strong point of the company was its constant improvement made on its products by employing new technologies; such as, nanotechnology and the encapsulation technique, as well as monitoring and controlling the enzyme activities (NSTDA, 2016).

Moreover, in 2014, the company obtained partial funding from the NSTDA Company Directed Technology Development Program (CD) to build an enzyme production plant.

5.2.6) Case study B

- **Key milestones**

This case study was one example of a biotechnology project. The outbreak of counterfeit drugs contained artermisinin as an active ingredient. Each year, over one million people died from consuming them. Artermisinin also required advanced analytical chemistry. As such, development of an artemisinin test kit in a drug was based on fluorescence technology.

The method of measurement was not complicated, and it was fast and easy. The color change reaction occurred within 30 seconds; therefore, it could be used to analyze artermisinin and any derivatives that mixed both antimicrobial and fake antibiotics.

After conducting research between 2011 and 2012, a CFT successfully developed this prototype at the laboratory scale. Although the research result was presented in the NSTDA Annual Conference (NAC) 2012, the CFT could not deliver the research result to customers/licensees.

- **Major changes of the project in terms of the objectives and management practices**

There were no major changes in the objectives and management practices.

- **Comparison between the commercialization result before and after adopting a CFT**

Although this project had a diversified team among the three members by combining knowledge between Clinical Chemistry and Pharmacology, Industrial Chemistry, Organic Chemistry and had cooperation with the NSTDA laboratory and external partners, the university researcher, and a hospital, the CFT could not move from the laboratory testing to the preclinical phase and clinical testing.

The project leader explained that *"It was very difficult to acquire counterfeit drugs legally for preclinical testing because they are controlled drugs. The Food and Drug Administration is the organization that has these controlled drugs, but I do not have the close collaboration. Therefore, in drug development, there needs to be a strong linkage between the NSTDA researchers, Food and Drug Administration and the hospitals as the expected users."*

- **Technological system and innovation model**

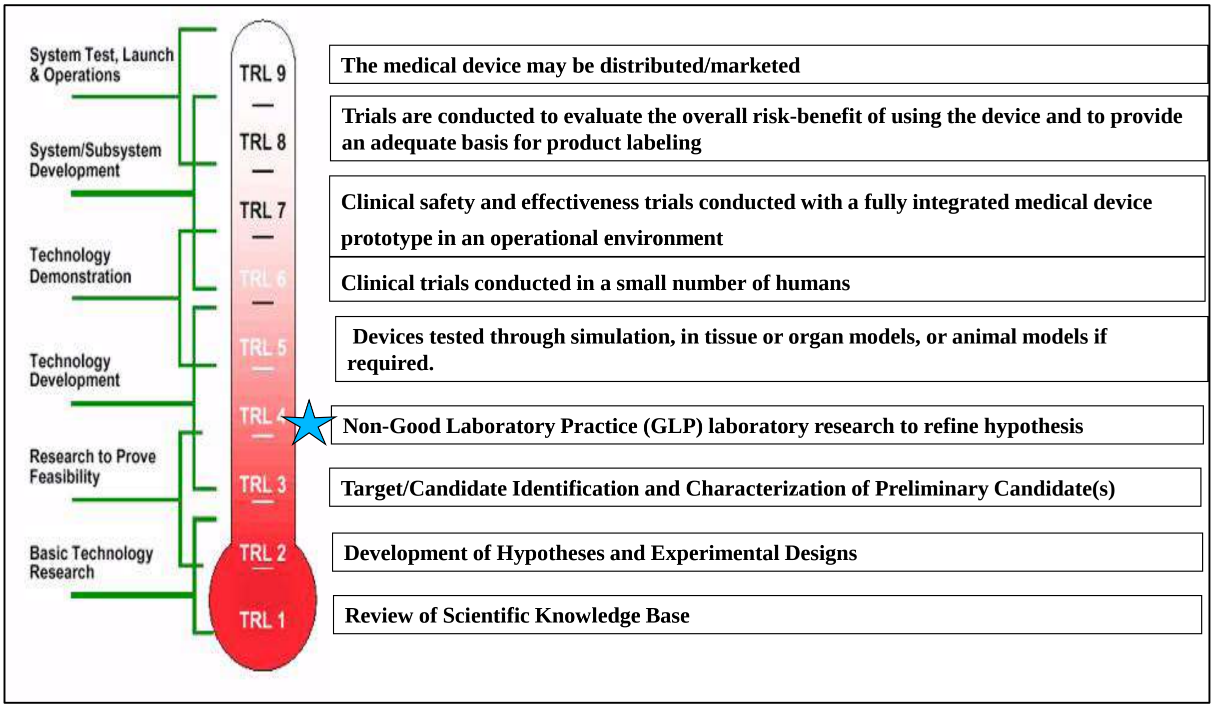
This project was based on the technology push model of innovation. The project leader initiated this project because he intended to develop the test kit for solving the counterfeit drug problem. However, before conducting this research, he did not survey the market's needs from the medical device companies and did not consult with Ministry of Public Health about funding for developing medical devices. As a result, the CFT did not have the budget for testing in the preclinical and clinical stages.

- **Technology Readiness Level (TRL)**

The NSTDA had to prioritize the budget for conducting the research. In case of drug/medical device development, the NSTDA strongly encouraged the researchers to cooperate with the external partners for developing the prototypes in the preclinical and clinical periods between TRL 5-TRL 8.

In this case, the CFT used ingredients that were similar to counterfeit drugs for conducting the research between TRL 1-TRL 4, but they were not real counterfeit drugs. In order to develop this research between TRL 5-TRL 8, the CFT needed to obtain a large amount of real counterfeit drugs. However, it did not have the connection with the Food and Drug Administration and the Ministry of Public Health to acquire counterfeit drugs legally. Therefore, this test kit was successfully developed only at TRL 4 (a laboratory environment) (Figure 5-21).

Figure 5-21: TRL of case study B



Source: Adapted from NASA and the US Army Medical Research Department

5.3 Materials Technology Case Studies

5.3.1) Characteristics of materials technology

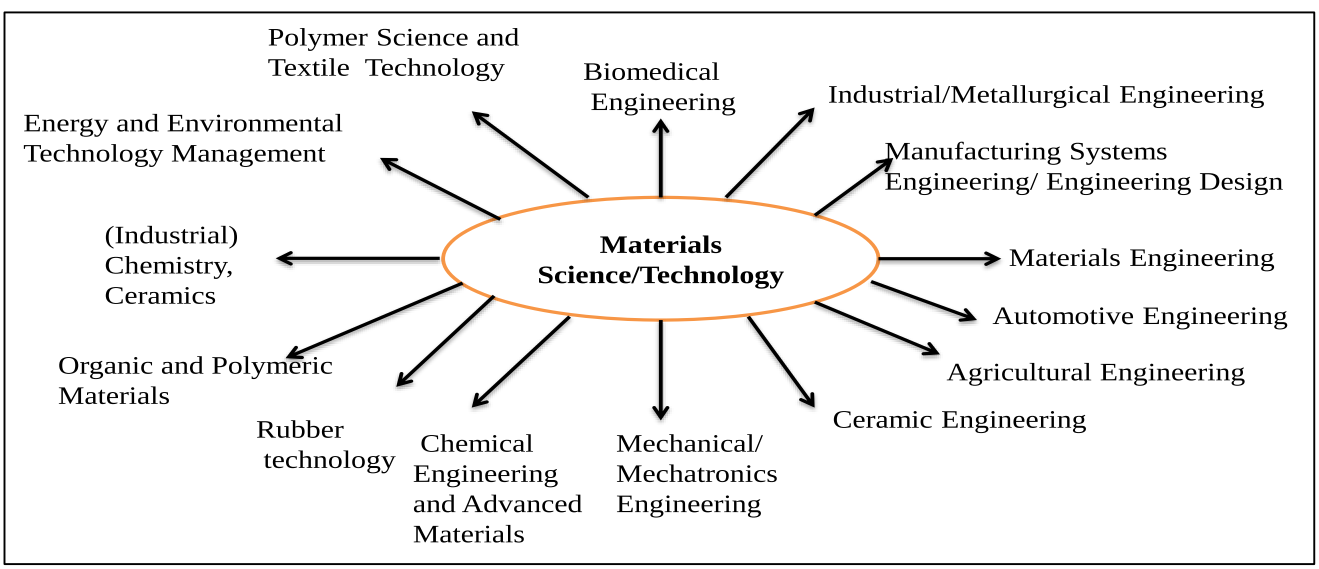
Materials science is a relatively new and very broad field. It involves applications from a number of scientific disciplines that contribute to the creation of new materials. Chemists play a predominant role in materials science because chemistry provides information about the structure and composition of materials, as well as the processes to synthesize and use them. In addition, materials scientists are employed by companies who make products from metals, ceramics, and rubber. They also work in the coatings (developing new varieties of paint) and biomedical industries (designing materials that are compatible with human tissue for prosthetics and implants). Other important areas are polymers (including biological polymers), composites (heterogeneous materials made of two or more substances), superconducting materials, graphite materials, integrated circuit chips, and fuel cells (ACS, 2018).

5.3.2) Relationship between the high diversity of functions and high diversity of educational fields

Results of the cross tabulation analysis showed that 58% of the H functions in materials technological projects had a high diversity of educational fields. They needed to cooperate with the expected licensees for testing the prototypes before licensing to them.

The core discipline for developing materials products is materials science/technology. The relevant fields of materials science/technology are (Industrial) Chemistry, Ceramics, Biomedical Engineering, Industrial/Metallurgical Engineering, Manufacturing Systems Engineering, Material Selection for Engineering Design, Materials Engineering, Automotive Engineering, Polymer Science and Textile Technology, Rubber Technology, Organic and Polymeric Materials, etc. (Figure 5-22).

Figure 5-22: Relevant fields of materials science/technology



Source: The author

The three examples show the combination between materials science and other fields for responding to the needs of companies in three sectors: agriculture, medical and ceramics.

5.3.3) Developing recycled latex inorganic substances from sediment waste (GRASS 3 technology)

- **Key milestones (see Figure 5-23)**

Natural rubber production's value chain comprises three stages: (1) latex production, (2) latex processing to produce crude rubber (concentrated rubber latex, rubber sheets and block rubber), and (3) rubber product manufacturing. The traditional crude rubber production (concentrated latex and dry rubber) was known for being environmentally unfriendly (NSTDA, 2012).

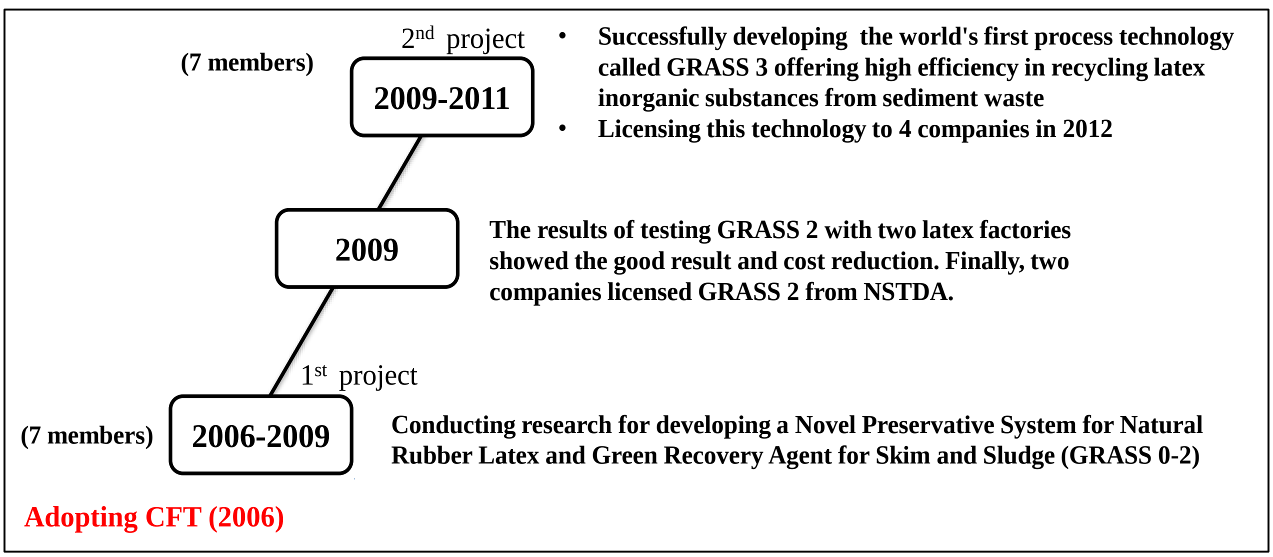
Between 2006 and 2009, a CFT in terms of the high diversity of educational fields adopted in 2006 successfully developed a compound called the Thai Advanced Preservative System (TAPS) for use in the rubber latex production process. TAPS was utilized to enhance the quality of the latex, yet posed no harm to the environment. It replaced ammonia as the latex preservative in the traditional process. Compounds called Green Recovery Agent for Skim and Sludge (GRASS) of the categories GRASS 0 and GRASS 1 were employed in place of sulfuric acid for the recovery of waste rubber from skim rubber latex with improved efficiency while yielding quality skim rubber.

Representatives of the Thai rubber companies read an article about recovering rubber solids from skim rubber. They contacted the NSTDA's Industrial Technology Development Division and consulted with the Rubber Laboratory. A research team successfully developed the new process of concentrated sulfuric acid to the skim rubber based on the laboratory environment (GRASS 0 and GRASS 1). However, the extracted rubber solid was generally of low quality and could only be used in the production of items; such as, rubber bands.

After visiting the MTEC laboratory, the five companies agreed to host visits by the MTEC researchers. They allowed the researchers to develop a pilot program testing the process on a large scale at their factories. As the project matured, the rubber companies realized that the new process required expensive additional equipment. Therefore, it was not commercialized by them.

Later, a CFT involved two companies for developing GRASS 2. It recovered rubber from washed water of centrifuging machines. The sulfate contamination problem in waste water and the annoying odor from the problem of hydrogen sulfide gas was solved, and these newly developed compounds had also improved the quality of the natural rubber waste. After successfully demonstrating GRASS 2, two companies licensed this technology from the NSTDA in 2009.

Figure 5-23: Key milestones of recycling latex inorganic substances from sediment waste



Source: The author

In terms of the development of GRASS 3, the research problem came from one of the participating companies of GRASS 0 and GRASS 1. The company approached the MTEC researchers to see an overlooked opportunity. If the rubber solids could be separated from inorganic material, it would result in two important economic opportunities. First, rubber output could be increased from the same input, and second, the removal of the inorganic material would allow the production of a high-grade fertilizer, which could be sold to offset the cost of chemicals used in the processing. This experience combined with an innovative approach – extracting the rubber from the chemicals – led to the successful development of a new way to extract rubber solids from sludge waste.

Finally, a CFT developed the world's first process technology called GRASS 3 to effectively recover rubber from natural rubber latex sludge. As a result, 20-30% of the sludge could be turned into reusable rubber. In addition to using fewer chemicals, the process reduced the water usage by over 50% compared with the traditional process. After testing GRASS 3 with six companies, four companies licensed it from the NSTDA in 2012.

- **Major changes of the project in terms of the objectives and management practices**

An initial objective was to develop a new method for the preservation of natural rubber latex using a methyl compound giving a neutral pH (pH ~ 7-8), low corrosive and low toxicity natural rubber latex, which could be stored for a long time. Although the new method of TAPS enhanced the quality of the latex, it had a high cost. Therefore, the CFT adjusted the objectives to develop GRASS 3. Moreover, it changed the management practices from waiting for expected licensees to approaching the expected licensees for testing the prototypes in the pilot scale. For example, this involved two companies for demonstrating GRASS 2, and six companies for testing GRASS 3 technology.

- **Comparison between the commercialization result before and after adopting a CFT**

This project had applied a CFTs approach since the first project. It had the high diversity of the functions/departments by cooperating with the Rubber Laboratory, Industrial Technology Development Division, and the expected licensees, while it had a combination of Organic and Polymeric Materials, Colloid Science, Materials Science, Chemistry, Rubber Technology, and Polymer Science and Technology as the high diversity of educational fields. Moreover, the Deputy Executive Director of MTEC who had expertise in the structures and properties of rubber, modifications of natural rubber, and green production technology of natural rubber acted not only as the main adviser of the team, but also the as the head of the NSTDA rubber researchers. The Deputy Executive Director of MTEC used his research network to help the CFT contact the expected licensees to demonstrate GRASS 2 and GRASS 3 technology. Therefore, executive management support led to both the diversification of the team and successful licensing.

After learning from the companies' feedback in developing GRASS 0 and GRASS 1, the CFT attached great importance to the expected customers during the demonstration phase. This could be observed from the two successful license agreements in GRASS 2 technology and four license agreements from GRASS 3 technology. The first license agreement of the GRASS 3 project occurred within two years after the project was completed in 2011.

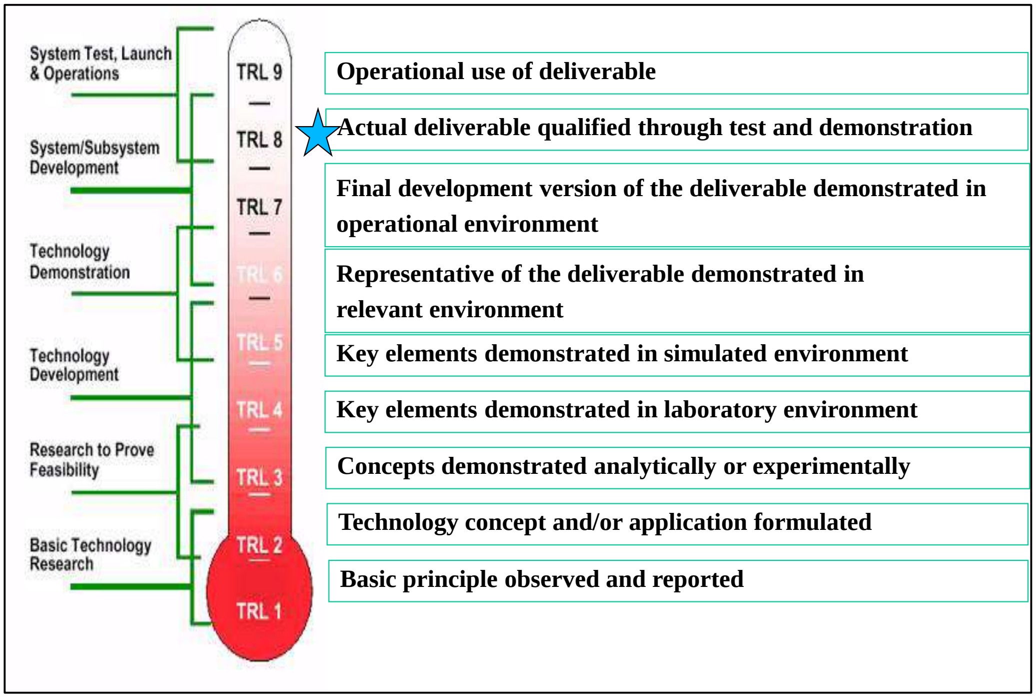
- **Technological system and innovation model**

A CFT developed GRASS 3 technology based on the market pull model of innovation. This model stresses on the importance of interacting with customers to achieve successful innovation (von Hipper, 1978, as cited in Trott, 2002). In case of GRASS 3, there was close interaction between the NSTDA researchers and expected licensees to generate the specifications.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

The first license agreement for the natural rubber sludge process (GRASS 3) was the company that suggested the idea for recovering rubber from sludge instead of skim rubber. Because of its early involvement, the company was granted a lower initial licensing fee. In summary, this research result was successfully developed in a laboratory environment at TRL4. After testing the prototypes with six companies in each company's factory for the pilot demonstration between TRL 5 and TRL 8, the researchers successfully developed this processed innovation to prepare for production at TRL8. Finally the company licensed this technology at TRL 8 (Figure 5-24) to four companies in 2012.

Figure5-24: TRL of recycling latex inorganic substances from sediment waste



Source: Adapted from NASA and the Sandia National Laboratory, USA.

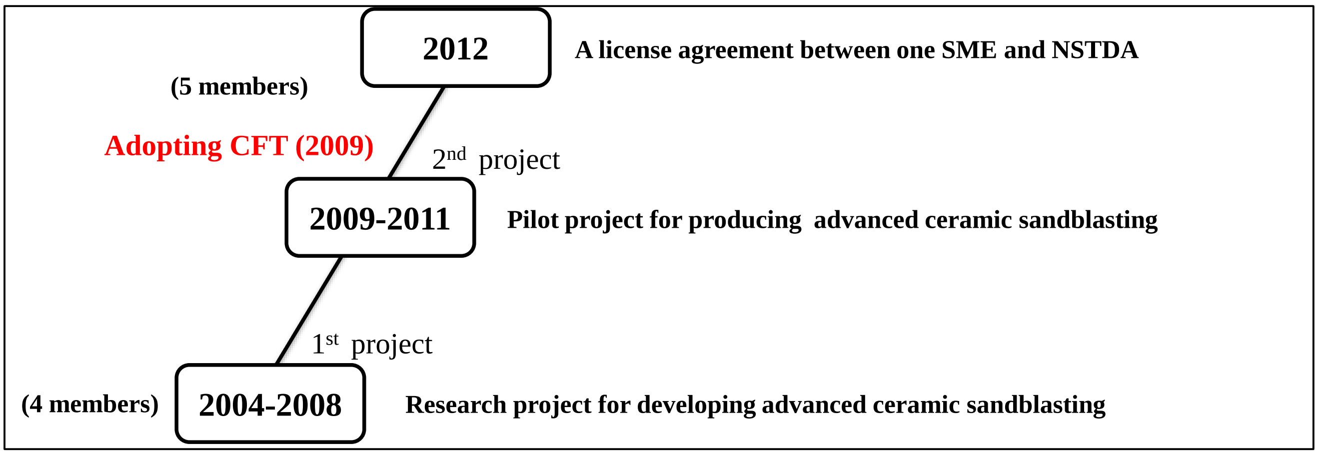
5.3.4) Advanced ceramic sandblasting

- **Key milestones (see Figure 5-25)**

The first project took four years to develop the prototype of ceramic sandblasting in the laboratory environment and the relevant environment because of its unique sandblasting characteristics. It was a piece of sandblasting equipment used to polish, clean or decorate the surface of the materials, which were burned at temperatures up to 1,600 degrees Celsius. Although one company was interested in this prototype, it did not have knowledge about the production of ceramics and did not trust the Thai product compared with imported ceramic sandblasting. As a result, the NSTDA initiated the pilot project for producing advanced ceramic sandblasting by cooperating with the expected licensee.

In the second project between 2009 and 2012, a CFT successfully tested this prototype in the company's factory and arranged a training program about the process of manufacturing advanced ceramic sandblasting to the company's staff. After receiving good feedback from the company's users in the trial period, it committed to license this technology in 2012.

Figure 5-25: Key milestones of advanced ceramic sandblasting



Source: The author

- **Major changes of the project in terms of the objectives and management practices**

There were no changes in the objectives for developing advanced ceramic sandblasting, which could substitute imported products. In order to convince the expected licensee and enhance its capability before licensing the technology, the head of the project had to adjust the management practices by creating a new project for training the company's employees to produce Thai ceramic sandblasting.

- **Comparison between the commercialization result before and after adopting a CFT**

There were no license agreements before using a CFT because the research team successfully developed only the laboratory prototype and simulated prototype. When initiating the second project in the pilot project for producing ceramic sandblasting, the research team had applied the CFT by cooperating between the Ceramics Laboratory, Business Development Division, and the expected licensee as the high diversity of functions. Moreover, increasing one member educated in Engineering helped the team train the company's employees in the processes for manufacturing and burning ceramic sandblasting. It was found that the percentage of the different disciplines compared with the team size (five members) was 80%, which was a result of the high degree of difference in educational fields: Materials Science, Ceramic Technology, Manufacturing Technician and Engineering.

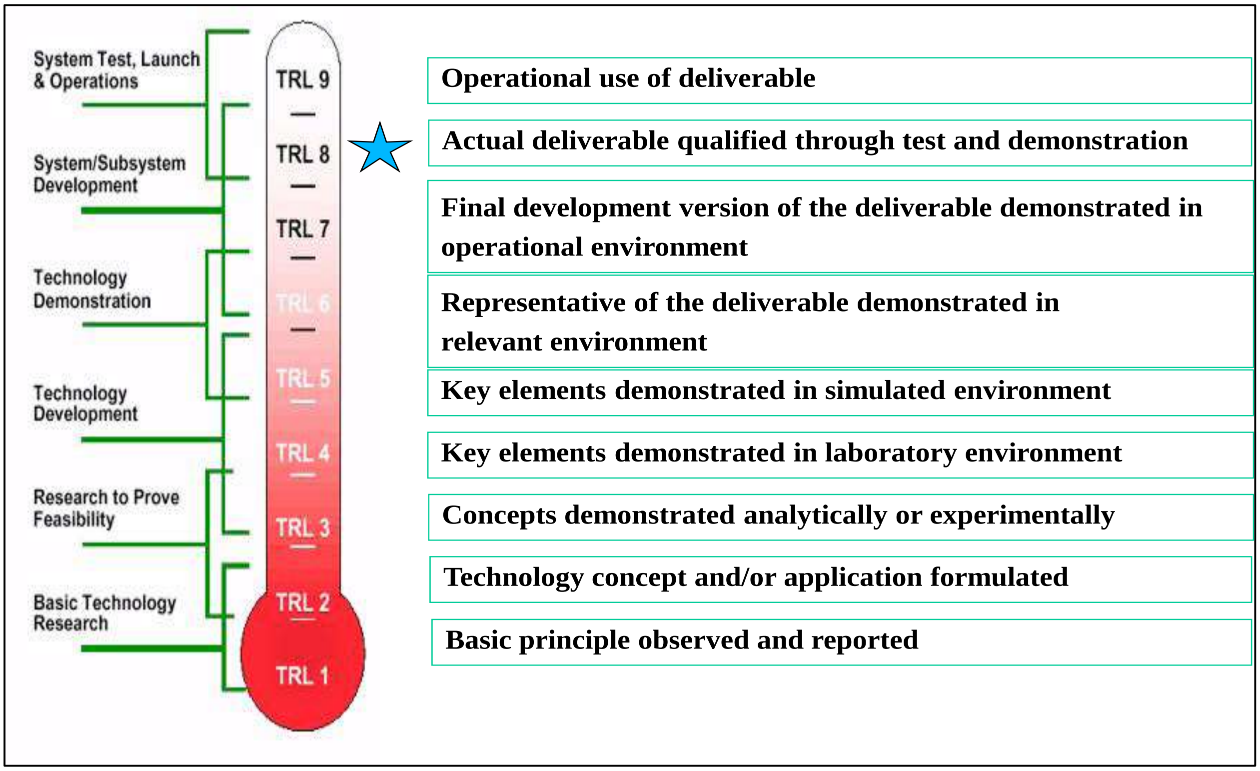
- **Technological system and innovation model**

When the research team studied the market's needs, it was found that all ceramic sandblasting in Thailand were imported from Japan, China and United States. However, the domestic demand for ceramic sandblasting equipment was about 2,000-5,000 pieces a month, or worth four million Baht a month. Based on the market pull model of innovation, a research team began the research project for developing ceramic sandblasting. The quality of the product was equivalent to Japanese sandblasting.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

Considering the good chance for import substitution, the small and medium enterprise (SME) company as the original equipment manufacturer (OEM) licensed this technology at TRL 8 (Figure 5-26). The research resulting from the first project was evaluated at TRL 6 and demonstrated in a relevant environment. In order to produce the research result in the company's factory, it would need to invest in machinery and understand how to develop ceramic sandblasting. Therefore, the company requested the research team to arrange a training program that resulted in the second project. After receiving technology transfer from the NSTDA researchers and getting good feedback from the company's users, it licensed this technology from the NSTDA in 2012. The first license agreement appeared within two years after the project was completed in 2011.

Figure 5-26: TRL of advanced ceramic sandblasting



Source: Adopted from Sandia National Laboratories, 2007

5.3.5) Hemostatic products for external use

- **Key milestones (see Figure 5-27)**

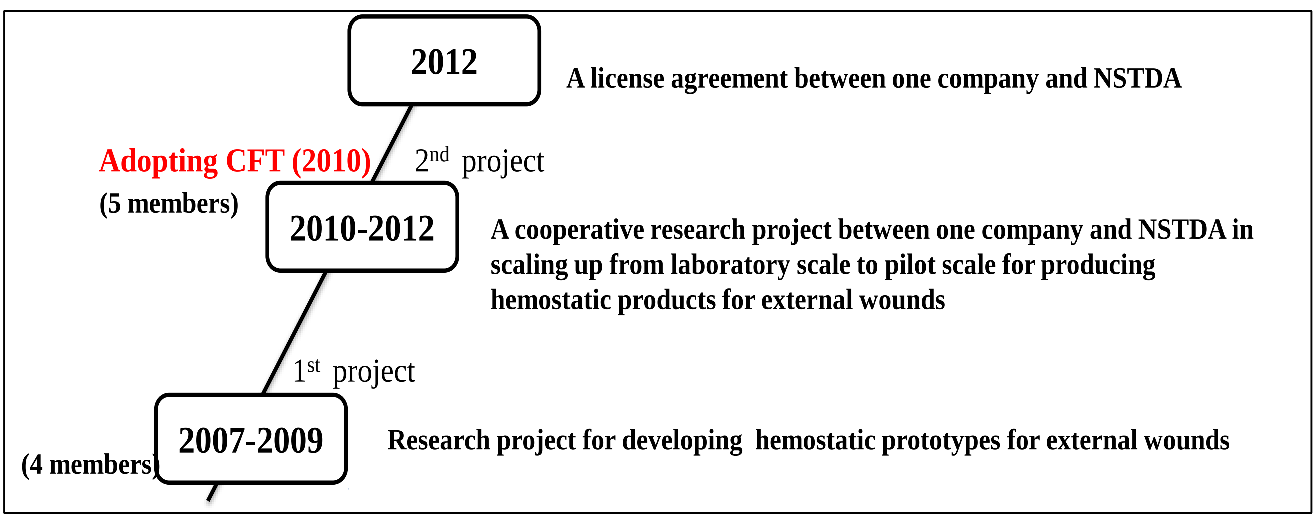
Between 2007 and 2009, a research team achieved the goal for developing the laboratory prototype. In 2010, the NSTDA team cooperated with one company to increase hemostatic products for external wounds from the laboratory scale to the pilot scale. Its hemostatic efficacy had been evaluated in both the in vitro and in vivo (animal model and clinical use) levels.

The in vivo efficacy of the hemostatic prototype in stopping bleeding was evaluated in Wistar rats. The results were quite satisfactory; the prototype could stop the bleeding from the tail excised wounds more efficiently than a commercial hemostat, Spongostan Standard. On the other hand, the hemostatic efficacy of a chitosan derivative-based prototype (CDP) was clinically evaluated in the treatment of split thickness skin graft donor sites in 17 patients in comparison with two commercial materials.

The results of this clinical study clearly demonstrated that an 8-minute CDP treatment could stop the bleeding from the split thickness skin graft donor sites more effectively than Spongostan® Standard and Algisite-M. From the visual observation and wound image analysis, the amount of blood ooze and the bleeding area after being left uncovered for 30, 60 and 90 seconds were significantly detected to be at a minimum in wounds treated with the CDP. Therefore, it was implied that the prototype could stop the bleeding most effectively (Janvikul et al., 2013).

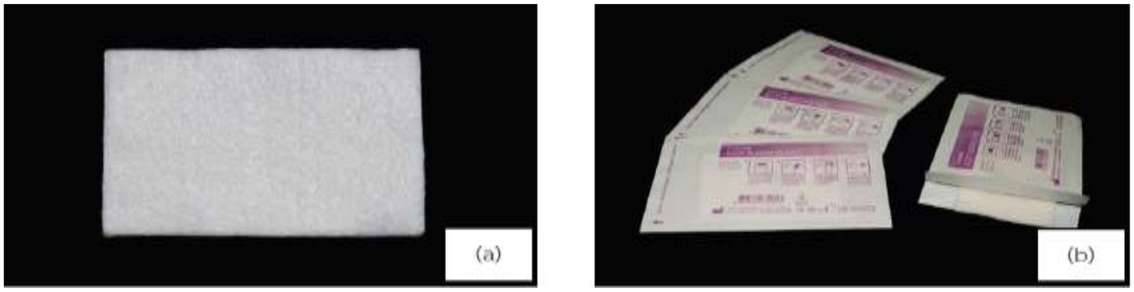
However, the produced prototype had been re-evaluated in both the in vitro and in vivo (animal model and clinical use) levels to acquire all the required data for the application of product registration. Finally, in 2012, the company had licensed this technology from the NSTDA (Figure 5-27 and Figure 5-28).

Figure 5-27: Key milestones of hemostatic products for external use



Source: The author

Figure 5-28: Image of (a) a hemostatic product and (b) the products in packages



Source: NSTDA, 2013b

- **Major changes of the project in terms of the objectives and management practices**

There were no changes in the objective and management practices for developing a hemostatic product.

- **Comparison between the commercialization result before and after adopting a CFT**

Before using a CFT, a research team successfully demonstrated only the laboratory prototype. Therefore, there were no license agreements. In 2010, a research team had applied a CFT by cooperating between the Biomedical Engineering Research Unit, Engineering Division, Angthong Hospital and the expected licensee as the high diversity of functions while it increased one member educated from the Engineering field for assisting in testing some parts of the prototype. This had a high degree of difference in educational fields: Materials Science and Engineering, Chemistry, Polymer Science, Biology and Engineering. However, the key success factor leading to the license agreement was the cooperation between the research team and the expected licensee for increasing the production of this hemostatic prototype from a laboratory scale to an industrial scale. The first license agreement occurred within one year after the project was completed.

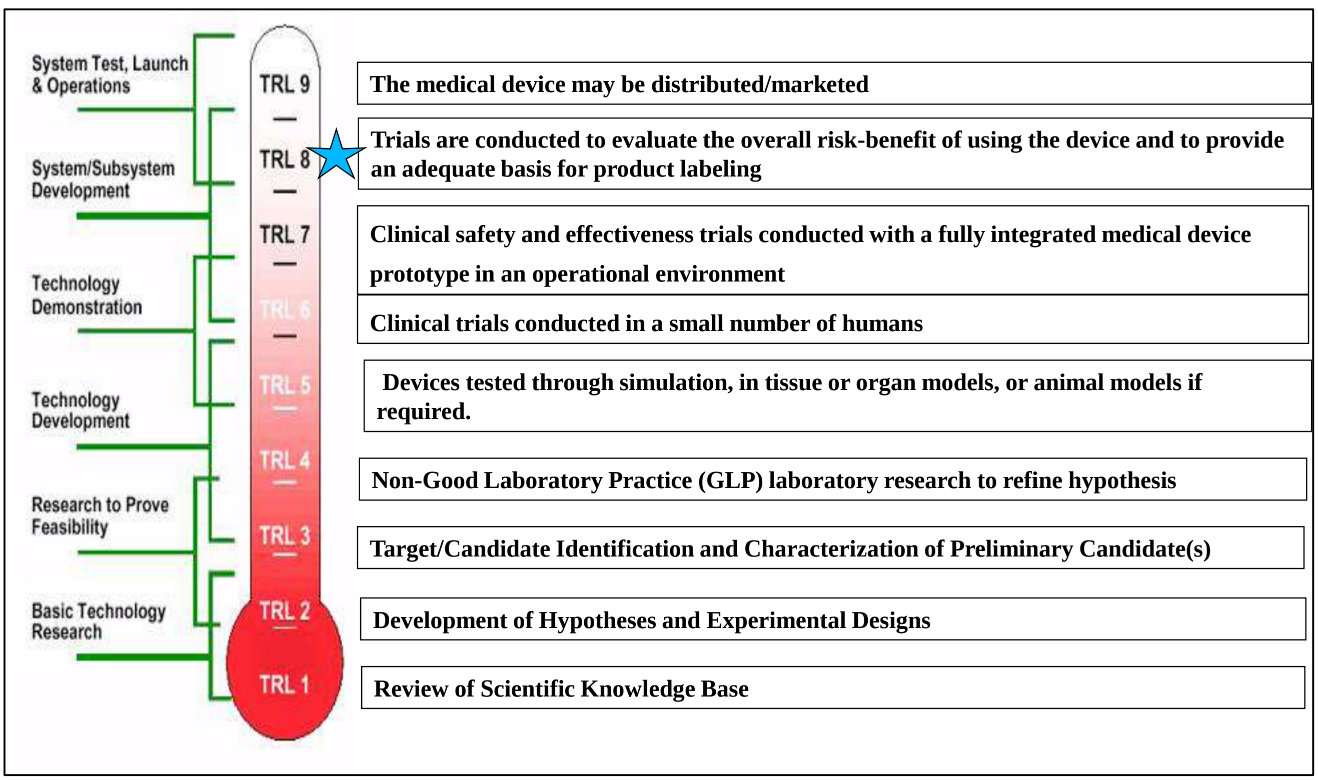
- **Technological system and innovation model**

In developing medical devices, the characteristics of this research project were related to the technology push model of innovation. Before launching a new medical device to the market, the prototype had to successfully pass animal testing, clinical trials and be certified by many standards; such as, ISO 13485, CE mark, etc. in order to receive customer acceptance in Thailand and foreign countries. Therefore, cooperation between the research team and the expected licensee in the second phase of the clinical trials could help the research team save the cost for testing the related standards.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

The research team cooperated with the expected licensee as the CFT for development between TRL 5 and TRL 8. This could be observed from the re-evaluated prototype in both the animal testing and clinical studies for the application of the product's registration (Figure 5-29).

Figure 5-29: TRL of hemostatic products



Source: Adapted from the US Army Medical Research and Material Command (MRMC), 2015.

In terms of the absorptive capacity of the licensee, the company was a medical device manufacturer and had certified quality management systems from ISO 13485. Therefore, it had the capability to produce hemostatic products.

5.3.6 Case study C

- **Key milestones**

Between 2014 and 2017, materials technology researchers developed electron-beam vulcanized natural rubber latex technology (e-latex) in order to replace sulfur. E-latex caused a breakdown in proteins, as it could be washed out easily and finally contained less allergenic proteins. Moreover, it was safer for employees in rubber factories than using sulfur.

A CFT tried to improve the Thai rubber product industries' competitive capability; i.e., increasing the machine and equipment efficiency in the rubber glove industry by creating a device that used an electron beam to vulcanize rubber and develop an innovation for safe rubber products.

When the project was finished in 2017, the CFT delivered the research results of only the laboratory prototypes of rubber gloves, a rubber dental dam, and catheter, but could not convince the expected customers to license this technology.

- **Major changes of the project in terms of the objectives and management practices**

There were no major changes in the objectives and management practices.

- **Comparison between the commercialization result before and after adopting a CFT**

Although a CFT had a high diversity of educational fields/expertise among 13 members by combining knowledge between Organic and Polymeric Materials, Polymer Science and Technology, Chemistry, Polymer Engineering, (Chemical) Engineering, Material Science, Physical and Theoretical Chemistry, Petrochemistry, Rubber Processing and Green Production Technology of Natural Rubber, as well as cooperation between the NSTDA laboratory, external partners, the Thailand Institute of Nuclear Technology and the expected companies, the CFT could not transfer these prototypes to the expected companies.

A main researcher and an analyst described that:

"When our team did not have the specialized machinery to produce a laboratory scale prototype of e-latex, it had to use the machinery at the Thailand Institute of Nuclear Technology once a week. That was our problem in the first year.

Even though my team bought and installed an electron beam processing system (250 keV) at our laboratory in the second year, it could not produce large amounts of e-latex to test in the factories of the expected companies. On the other hand, the test results of these prototypes could not convince the expected companies to allow our team to test in the operational environments of their factories. As a result, my team could not achieve the goal for transferring technology to the companies."

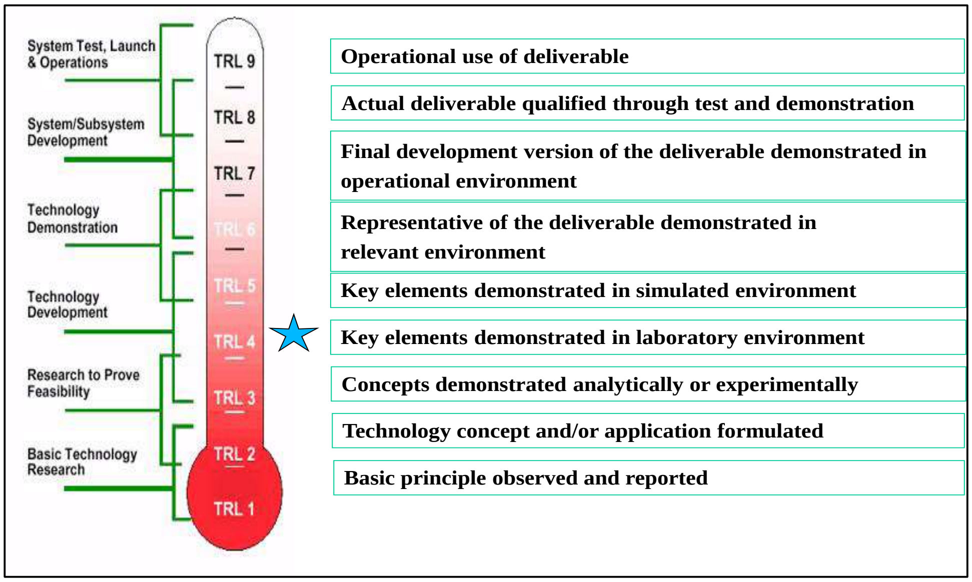
- **Technological system and innovation model**

This case study was related to the technology push model of innovation. The project leader intended to replace the existing technology with green technology, which was good for both the Thai environment and many employees engaged in the rubber factories. He considered that when his team had expertise and past achievements in developing technology for using in the rubber latex production process, it would be possible to produce rubber gloves, a rubber dental dam, and catheter by applying e-latex and transfer the products to the expected customers.

- **Technology Readiness Level (TRL)**

A CFT successfully developed e-latex only at TRL 4 (Figure 5-30). This was due to two main reasons. Firstly, it did not have the large specialized machinery to produce the effective e-latex as planned. Secondly, changing from existing technology to new technology is a critical challenge for rubber manufacturers. Therefore, the CFT had to take time for R&D in order to convince the expected companies in the next opportunity.

Figure 5-30: TRL of case study C



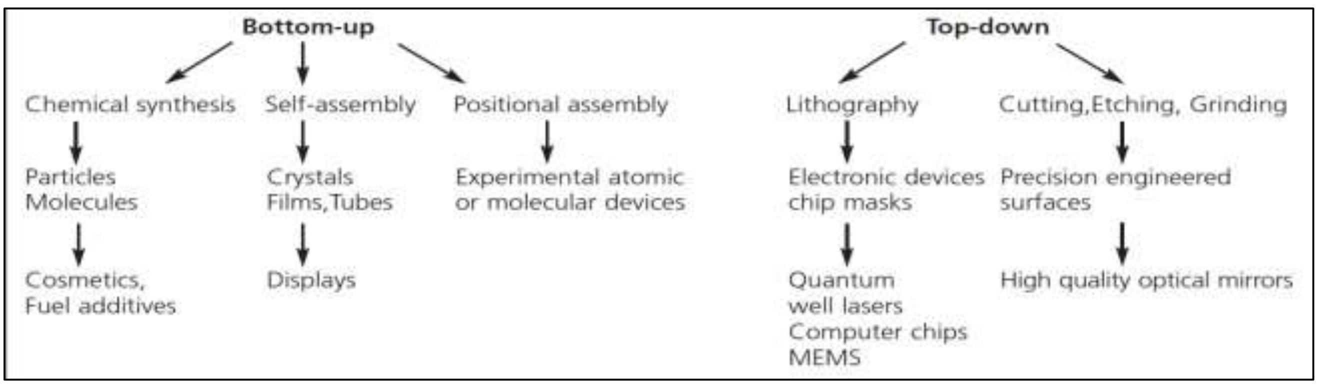
Source: Adapted from Sandia National Laboratories, 2007

5.4 Nanotechnology Case Studies

5.4.1 Characteristics of nanotechnology

Nanotechnology is a term that is used to describe the science and technology related to the control and manipulation of matter and devices on a scale less than 100 nm in dimension (Ahmed et al., 2009). Nanotechnology is set to play a key role worldwide in the 21st century, as it is generating major breakthroughs in all industrial areas and is advancing through an ever-growing number of discoveries. Due to the nanoscale and the typical quantum mechanical phenomena prevalent in industry, new functions and properties are added to improve or develop new products and application possibilities. Nanotechnology is a cross-sectoral technology, which is increasingly relevant in economic areas; such as, chemistry, medical technology, automobile and the foodstuff industries (Abicht et al., 2006). The two main approaches for explaining nanotechnology have become known as the ‘top-down’ approach and the ‘bottom-up’ approach. The top-down approach involves fabrication of device structures by means of monolithic processing on the nanoscale. This approach has been used with success in semiconductor devices used in consumer electronics. The bottom-up approach involves the fabrication of device structures through the systematic assembly of atoms, molecules or other basic units of matter. This is the approach nature uses to repair cells, tissues, living organs and organ systems in living things, as well as for life processes; such as, protein synthesis (Ahmed et al., 2009). The UK Royal Society and Royal Academy of Engineering (2004) have classified bottom-up and top-down nanotechnology manufacturing approaches as shown in Figure 5-31 below.

Figure 5-31: Bottom-up and top-down nanotechnology manufacturing approaches



Source: The UK Royal Society and Royal Academy of Engineering (2004)

5.4.2) Relationship between high diversity of functions and medium diversity of educational fields

According to the regression results in Chapter 4, there were no significant factors in terms of diversity in the functions/departments, educational levels, educational fields and experience supporting the CFTs to enhance the number of license agreements. After analyzing the relationship between the functions and educational fields by using cross tabulation, it was found that most nanotechnology licensed projects consisted of a low diversity of functions based on the same laboratory and had a medium diversity of educational fields. However, a few outstanding projects that had more than one license agreement consisted of a high diversity of functions and medium diversity of educational fields. This can be analyzed by two examples.

5.4.3) Water purification unit by using a mobile solar operating system (SOS)

- **Key milestones (see Figure 5-32)**

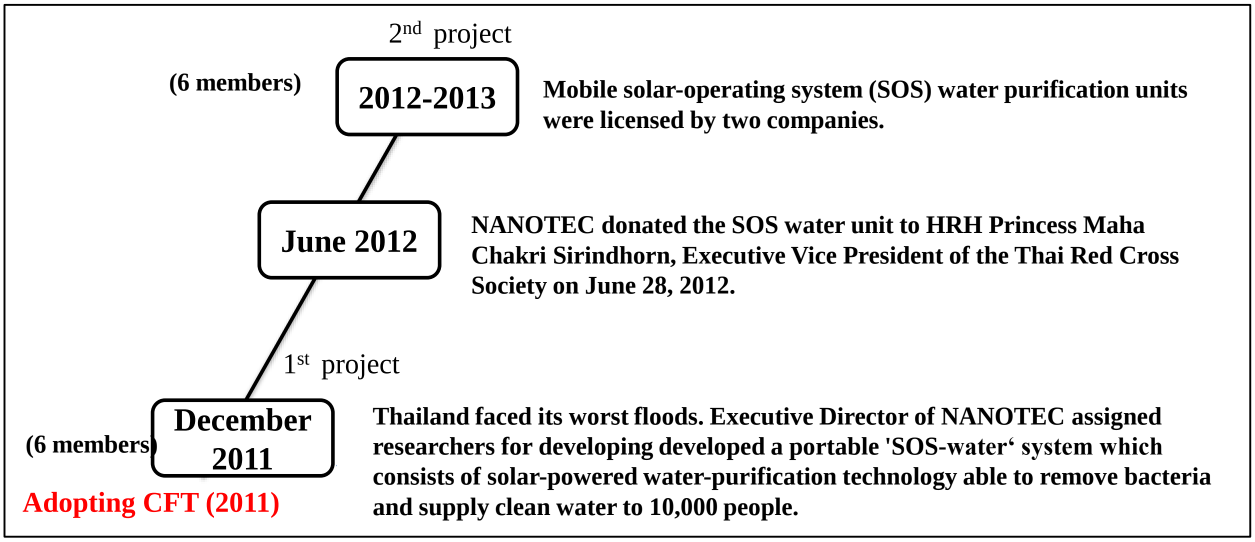
When Thailand faced its worst floods in 2011, the Executive Director of NANOTEC assigned a researcher at NANOTEC to set up her team and develop the first locally made prototype solar-powered water purification unit, “SOS water”, which combined the use of antimicrobial nanocoating to ceramic filters. Compared to a conventional ceramic filter, an antimicrobial nanocoating ceramic filter increased extra security by exterminating or incapacitating bacteria left in the water and preventing the growth of mold and algae in the body of the filter. The SOS water purification unit was a stand-alone unit, which could be set up and operated using solar energy within 10-15 minutes.

The quality of drinking water met the 2010 standard by the Department of Health, Ministry of Public Health, Thailand. The SOS water system was capable of producing 200 liters of drinking water per hour and was easily integrated into a pick-up vehicle, light truck, trailer or a flat hull boat.

The researchers had collaborated with the Thai Red Cross Society to do field testing of a prototype. When receiving positive feedback for field testing at the site in Angthong province, the NSTDA completed the first project within six months and donated the prototype SOS water purification unit to HRH Princess Maha Chakri Sirindhorn, Executive Vice President of the Thai Red Cross Society on June 28, 2012, for utilization by the community.

After donating the first prototype of the SOS water purification unit to the Thai Red Cross Society, the same team initiated the second project for developing it for industry. In 2013, a CFT completed the project by customizing this prototype by following the specifications of two companies and licensing them.

Figure 5-32: Key milestones of the water purification unit



Source: The author

- **Major changes of the project in terms of the objectives and management practices**

The initial object was to create the prototype for helping Thai communities in flooded areas. After donating the prototype, a CFT adjusted the specifications of the prototype for using in the private sector.

- **Comparison between the commercialization result before and after adopting a CFT**

This project had adopted a CFT since the first project. It was initiated and strongly endorsed by executive management support. In addition, it had the high diversity of functions. On the other hand, the CFT had the medium degree of educational fields. It had 66% of members educated from different fields: Chemistry, Biology, Materials Science and Electrical Engineering compared with the size of the team.

The project leader described that:
"When Thailand faced its worst floods in 2011, the Executive Director of NANOTEC assigned me to set up a CFT and develop the first locally made prototype solar-powered water purification unit, "SOS water", through the cooperation of the Nano-agriculture and

Environment Research Unit, Nanometrology and Characterizations and Engineering Unit, and the Thai Red Cross Society. Most members came from the Nano-agriculture and Environment Research Unit. In the last phase of development of this prototype, an electrical engineer from the Nanometrology and Characterizations and Engineering Unit was involved in designing the truck integrated with the solar-powered water purification unit, which combined the use of antimicrobial nanocoating to the ceramic filters. After the CFT had completed the first prototype, the NSTDA executive contacted the Thai Red Cross Society for testing. Finally, the NSTDA donated the first version of this prototype to the Thai Red Cross Society on June 28, 2012, for community relief efforts. After donating the prototype SOS water, the same team developed the next version. The NSTDA executives always showed this product to many stakeholders. As a result, two companies contacted the researchers for licensing this product. The first license agreement emerged within one year after the project was completed in 2013."

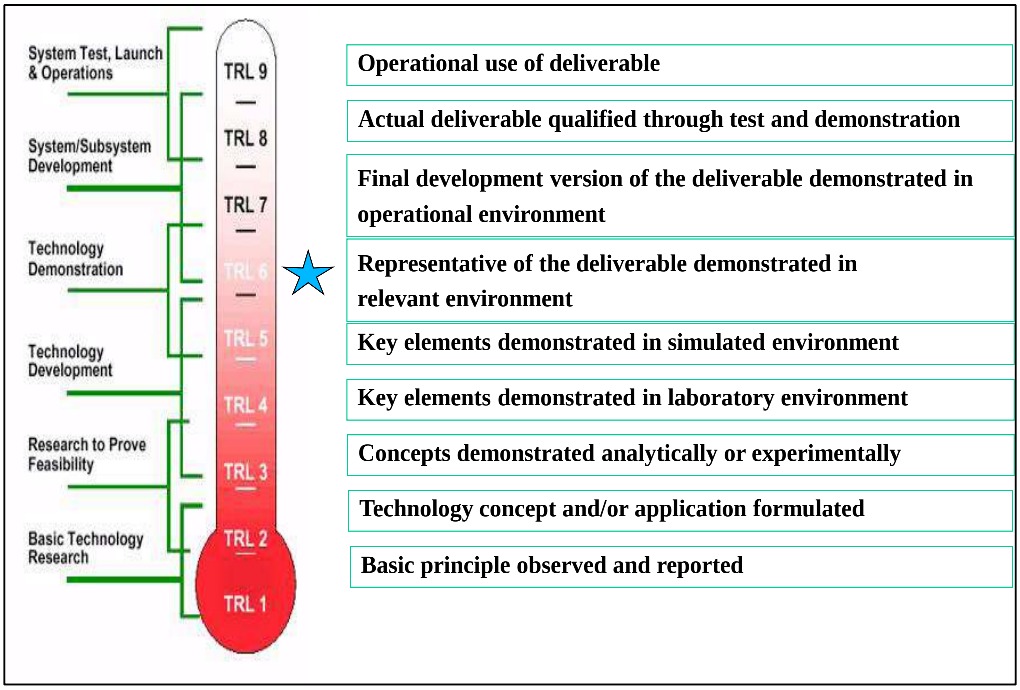
- **Technological system and innovation model**

Although the project was implemented as a result of the need to provide drinking water to communities affected by the 2011 floods in Thailand, the researchers did not survey the market's needs from the private sector. As a result, characteristics of this research project were related to the technology push model of innovation. Moreover, it needed to use specific expertise in antimicrobial nanocoating know-how for water filtration and assembled into the production of the SOS water purification unit.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

A CFT transferred technology to the licensees at TRL 6 (Figure 5-33) because two companies licensed the blueprint and antimicrobial nanocoating ceramic filter technology from the NSTDA. In terms of the absorptive capacity, the companies were filter technology manufacturers. Therefore, they had the capability to produce this technology for commercial purposes.

Figure 5-33: TRL of the water purification unit by using a mobile solar operating system (SOS)



Source: Adapted from NASA and Sandia National Laboratories.

5.4.4) Nanoemulsion containing mosquito repellent technology

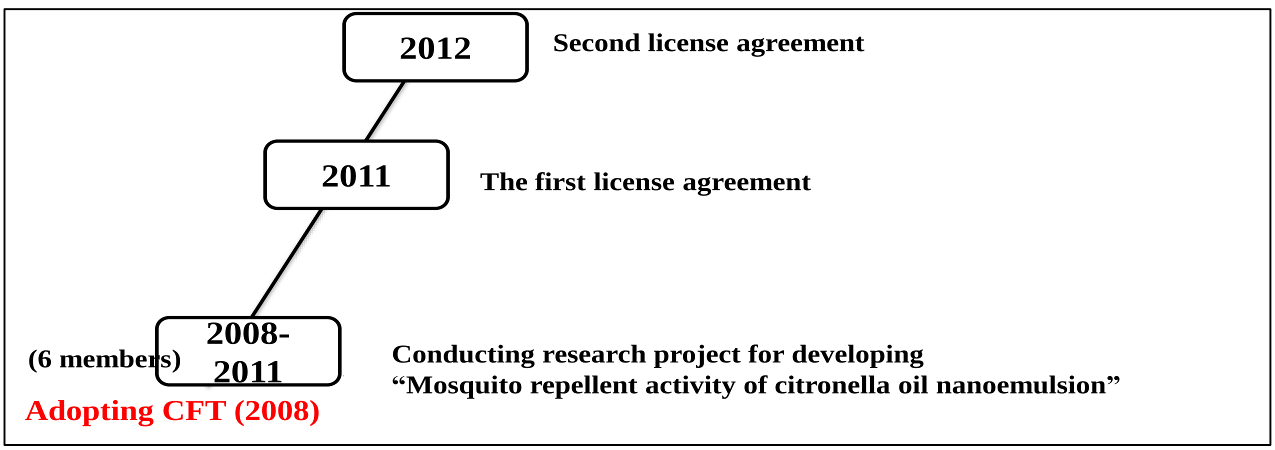
- **Key milestones (see Figure 5-34)**

Nanoemulsion is one of the encapsulation technologies, which represents an effective approach for encapsulating bioactive compounds of hydrophilic ingredients. Generally, nanoemulsion consists of the oil phase, surfactant and aqueous phase, which represents the oil droplet size in the range of 50-200 nm dispersed in the aqueous phase using the appropriate surfactant and its concentration (Surassmo et al., 2013).

Between 2008 and 2011, a research team using a CFT prepared the nanoemulsions composing of citronella oil, hairy basil oil, and vetiver oil with mean droplet sizes ranging from 150 to 220 nm that were investigated both in the in vitro and in vivo levels. The results indicated that the smaller droplet size of nanoemulsion showed better physical stability, a higher release rate, and longer mosquito repellent activity possibly due to higher thin film integrity on human skin.

In 2011, the CFT successfully developed nanoemulsion containing mosquito repellent technology consisting of three types of insecticidal herbal extracts: citronella oil, hairy basil oil, and vetiver oil. The highlights of this technology were to use herbal substances instead of chemicals and to prolong mosquito protection time to 4.7 hours due to the combination of these three essential oils as well as the small droplet size. This led to the achievement of two license agreements between 2011 and 2012.

Figure 5-34: Key milestones of nanoemulsion containing mosquito repellent technology



Source: The author

- **Major changes of the project in terms of the objectives and management practices**

There were no changes in both the objectives and management practices.

- **Comparison between the commercialization result before and after adopting a CFT**

This project used a CFT at the beginning of the project. The project leader explained that:

> *"I formed a CFT by inviting the external partners into a team at the beginning of the project because of two reasons. Firstly, the Traditional Thai Medicine Development Center, Ministry of Public Health, Thailand had knowledge about Thai herbs and could suggest to*

the NSTDA researchers how to use Thai herbs to develop a product that provided protection against mosquitoes and followed the safety and related standards. Secondly, I cooperated with a university researcher from Mahidol University because he had expertise in encapsulation technology and could help the team for increasing from a lab scale to a pilot scale. The cooperation between the NSTDA researchers and Ministry of Health by using the project leader's network could help the CFT convince the expected licensees to achieve the license agreements."

A CFT had the advantage in terms of the high diversity of the functions/departments. It established cooperation between the Nano-delivery System Laboratory, Business Development Division, Traditional Thai Medicine Development Center, Institute of Traditional Thai Medicine, Department for Traditional and Alternative Medicine, Ministry of Public Health, Thailand and Department of Manufacturing Pharmacy, Faculty of Pharmacy, Mahidol University. On the other hand, it comprised 66% of different educational fields compared with the six team members through a combination of DNA Delivery, Pharmaceutical Science, Biochemistry, and Biochemical Engineering. The first license agreement appeared within one year after the project was completed in 2011.

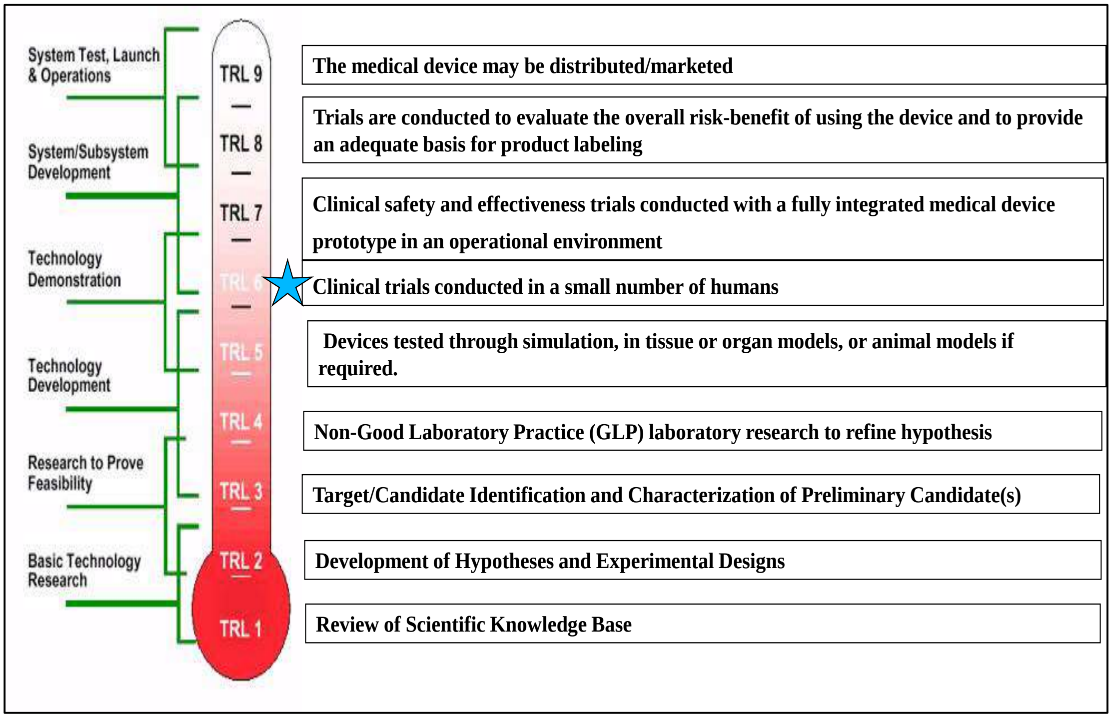
- **Technological system and innovation model**

The project was based on the technology push model of innovation because the research problem was derived from the head of the project consulting with the Department for Traditional and Alternative Medicine, Ministry of Public Health. As a result, citronella grass, a Thai herb that had the ability to exterminate mosquitoes, was integrated with nanoemulsion technology.

- **Technology Readiness Level (TRL) and the absorptive capacity of customers**

A CFT transferred technology to two licensees at TRL 6 (Figure 5-35). This technology passed the clinical trials of 30 volunteers, which was conducted by the Department of Medical Sciences, Ministry of Public Health, Thailand. In terms of the absorptive capacity, the companies were cosmetic producers in which their factories were certified by Good Manufacturing Practices (GMP). Therefore, they qualified for producing cosmetic products.

Figure 5-35: TRL of nanoemulsion containing mosquito repellent technology



Source: Adapted from the US Army Medical Research and Material Command (MRMC), 2015

As the research results were responding to the cosmeceutical sector, a lower absorptive capacity of the SMEs was one of the main obstacles for licensing nanotechnology. One of the main reasons was the production of real nanotechnology products that required a series of specialized and expensive machinery, specialized industrial installations, qualified scientists, as well as the sourcing of necessary unique raw materials (Nano4life, 2018). This was related to an analysis by Nature (2016).

> *"Nanotechnology is confronted with a critical bottleneck. The problem is twofold. First, the properties of matter change when scaled up, just like they change when scaled down to the nanoscale; in particular, the level of control that can be exerted at the nanoscale or at the single object level tends to wane at the meso- and macroscales or when dealing with a large number of objects. And second, industry is reluctant to invest money in*

developing new large-scale processes for nanomaterial fabrication unless they are guaranteed a sizeable profitable return."

The results of interviewing the TTOs confirmed that the production of nanotechnology products needs specialized and expensive machinery as well as specialized industrial installations.

> *"Although some companies are interested in licensing nanotechnology projects, they do not have specialized machinery for developing drugs and cosmetics, and they think that it is a high risk for investing in an expensive machine for one product. As a result, now NANOTEC has the Cosmetics Pilot Plant (GMP) for producing nanoparticles that can help companies save costs for developing cosmetic products."*

> *"In addition to the absorptive capacity of the companies, the national and international standards and rules relating to cosmetic products are other important factors for enhancing research commercialization. For example, one licensed project did not register with the Thai Food and Drug Administration (FDA) before licensing to the firm. It caused the firm's delay in manufacturing new products."*

5.4.5) Case study D

- **Key milestones**

Between 2011 and 2013, nanotechnology researchers developed the anti-acne pad made from the nanoencapsulation of mangosteen extract. It helped in easing the discomfort associated with acne and left no scar marks on the end-user. The project leader stated that *"One of the key strengths of the acne pad was that it was breathable, which was achievable by using an electrospinning technique. This technique created nanofibers and formed a three-layer patch that was closely attached to the skin."* In addition, the test results with some users showed that the acne pads could reduce acne inflammation within eight hours.

Although a CFT received both the Best Presentation Award and Outstanding Investor's Choice Award at the NSTDA Investor's Day 2012, it could not transfer technology to the customers/licensees.

- **Major changes of the project in terms of the objectives and management practices**

There were no major changes in the objectives and management practices.

- **Comparison between the commercialization result before and after adopting a CFT**

A CFT consisting of four members had a medium diversity of educational fields by integrating knowledge between Biotechnology, Biological Engineering and Microbiology. This case study was a project originating from two NSTDA laboratories (Nano-delivery System Laboratory and Nano Characterization Laboratory). After the CFT completed the field prototype testing, the business development officer assisted the CFT in preparing market information before participating in the NSTDA Investor's Day 2012.

Even though the CFT had advantage in terms of receiving an Outstanding Investor's Choice Award at the NSTDA Investor's Day 2012 and had a diversity of expertise, it could not license this technology to companies. The business development officer mentioned that *"This project could attract interested companies to consider entering into a business discussion either as research collaborators and/or a technology licensing agreement, but the companies needed to have specialized machinery to produce this product. This was the main obstacle for interested companies."*

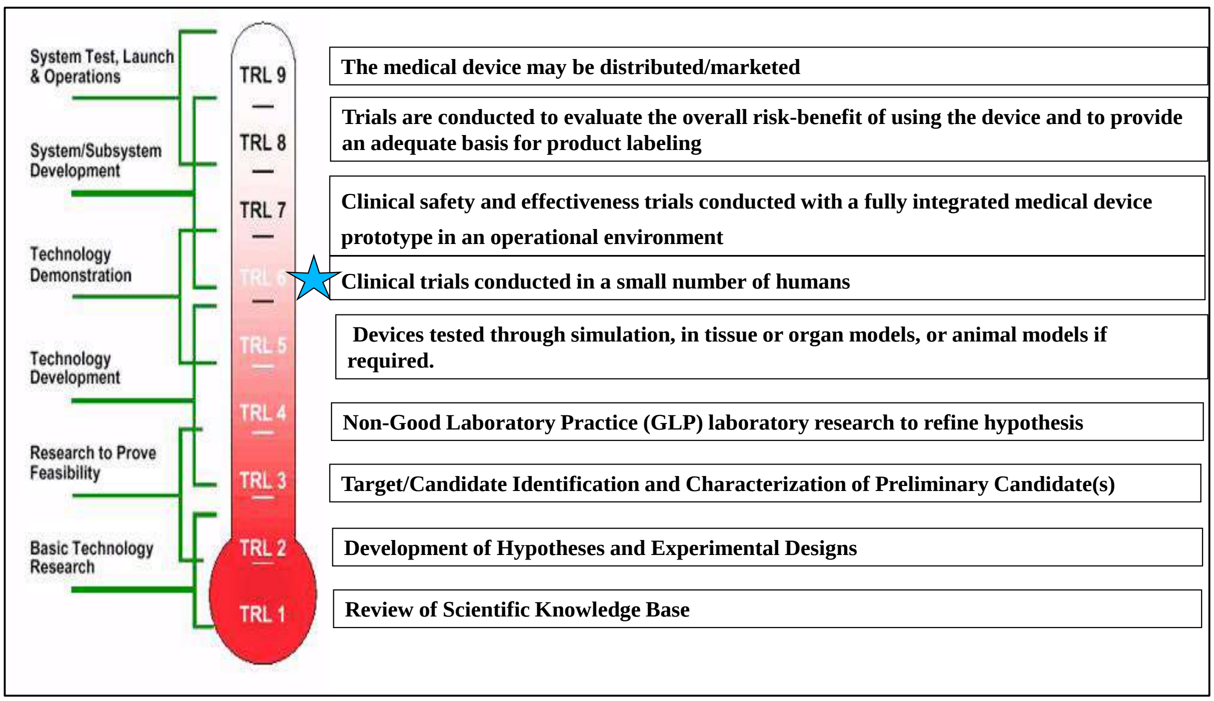
- **Technological system and innovation model**

This case study was related to the technology push model of innovation. One main researcher studied about the mangosteen extract, which inhibited the bacteria that caused acne as the title of a doctoral dissertation. In addition, the market of beauty products had grown significantly. The project leader discussed with the main researcher from a different laboratory to introduce and develop a thin anti acne pad to the market.

- **Technology Readiness Level (TRL)**

A CFT successfully developed the anti-acne pad at TRL 6 (Figure 5-36) because it could produce the nanofibers, which had a porous surface area. Each layer of fiber was unique, and the bottom layer had a special adhesive. The middle layer of the mangosteen extract was extracted from mangosteen peel to release the natural extracts to the surface. Moreover, the top layer of fiber had a special texture that fitted the color of each face. Most importantly, the results of the clinical tests proved that the pad was safe for the skin. However, the absorptive capacity of the interested companies was limited. As a result, the expected companies hesitated to buy the new specific machinery for this product.

Figure 5-36: TRL of case study D



Source: Adapted from NASA and the US Army Medical Research Department

5.5 Concluding remarks

This chapter investigates several case studies to prove the results of the Poisson regression and the cross tabulation analysis in four technological fields. The findings of three ICT case studies confirm that the high degree of difference in educational fields and team size influence the number of license agreements. However, there are differences between the software development projects and ICT hardware projects. The relationship between the high diversity of educational fields and low diversity of the functions/departments appears in software development projects; such as, the VAJA version 7.0 whereas developing ICT hardware; such as, the DentiiScan project and digital hearing aid project had a high diversity of educational fields and high diversity of the functions/departments. Moreover, the three ICT case studies confirm that the characteristics of ICT and the high diversity of the functions/departments are the significant factors influencing the duration for achieving the first license agreement.

On the other hand, university researchers are the external partners of the four biotechnology case studies. The results relate to the quantitative analysis in Chapter 4, as they had a high degree of difference in the functions/departments and medium diversity of educational fields. In contrast, the results of the materials technology case studies confirm that the high diversity of educational fields influences the number of license agreements. Furthermore, they prove that the high diversity of the functions/departments helps CFTs easily achieve the first license agreements. The three successful case studies involved the expected licensees to increase from a laboratory scale to a pilot scale, as well as train the expected licensees before licensing the technologies.

Although there are no significant factors influencing the number of license agreements in the Poisson regression, it is found that most nanotechnology projects had one license agreement per project and consisted of a low degree of difference in the functions/departments and low/medium diversity of educational fields. However, the two nanotechnology case studies that achieved two license agreements had the relationship between the high diversity of the functions/departments and medium diversity of educational fields.

The next chapter presents the cross-case analysis and implications.

Chapter 6

Cross-case Analysis

This chapter is divided into four sections. Sections 6.1 and 6.2 compare the findings of eleven effective case studies and four non-effective case studies in terms of team diversity and management practices. The main similarities and differences are summarized in Tables A2-1-Table A2-3). Alternatively, Section 6.3 analyzes the research contribution to the cross-functional teams (CFTs) approach. The final section (Section 6.4) concludes the key success factors to enhance technology transfer from public research institutions (PRIs) to the beneficiaries.

6.1 Team Diversity (Functions/Departments, Educational Levels, Educational Fields and Experience)

There are similarities among the 11 effective case studies represented by four technologies in terms of having the medium diversity of experience and educational levels except one ICT project and one materials technology project. In two projects, members educated with a bachelor's degree and in the Engineering field joined the CFTs in order to help the team develop hardware for DentiiScan versions 1.1 and 2.0 and engineer sandblasting. On the other hand, four non-effective case studies had both a high and medium diversity of experience as well as both a high and medium diversity of educational levels.

In terms of the functions/departments, it was apparent that universities were the key partners of biotechnology projects. One reason for supporting this result was having the Collaborative Research Units of the National Center for Genetic Engineering and Biotechnology (BIOTEC) under the NSTDA and the universities. However, the BIOTEC researchers cooperated with both the Collaborative Research Units and other universities. For example, the dengue vaccine project was a cooperation with the Medical Biotechnology Research Unit as the NSTDA's Collaborative Research Unit, the Center for Vaccine Development, Mahidol University, and Department of Microbiology, Faculty of Medicine, Chiang Mai University whereas the Department of Animal and Aquatic Science, Faculty of Agriculture, Chiang Mai University was the external partner of the pentosanase production technology project.

In contrast, medical doctors and the hospitals were the key partners for medical device research. For instance, the DentiiScan1.1. project tested prototypes with the Suthasinee Dental Center (SDC), Thammasat University Hospital and Faculty of Dentistry, Chiang Mai University while materials technology researchers tested prototypes with the Department of Surgery, Angthong Hospital, Angthong province in the clinical study of the hemostatic product project.

In terms of the roles of the technology transfer officers (TTOs), Tables 6.2, 6.3 and 6.4 show that the TTOs had limited participation in both effective and non-effective CFTs. They only helped the CFTs find the expected customers and negotiate with companies to achieve the licensing agreements.

Although Computer Science was the key educational field for developing software and computer programs, it was found that Electrical Engineering was the common field for developing both software and hardware innovations in ICT projects. In contrast, either Microbiology or Biotechnology was the key discipline used in biotechnology projects whereas Chemistry was the common discipline for developing materials technology and nanotechnology innovations.

6.2 Management Practices

6.2.1) Top management support (top-down policy)

There were different types of executive management support in the form of top-down policies by the NSTDA executives. First, they enhanced the diversity of a CFT and used their network for helping the CFT to find an external budget or testing with external partners; such as, for the VAJA version 7.0 project and the DentiiScan version 2.0 project. Second, they assigned a CFT to develop innovations based on existing knowledge in a short period of time; such as, the water purification unit by using a mobile solar operating system (SOS). Third, the research problems were derived from the NSTDA executives. For example, the initial objective of the recycling latex inorganic substances from sediment waste project to develop a new method for the preservation of natural rubber latex or the Thai Advanced Preservative System (TAPS) came from the Deputy Executive Director of MTEC. Moreover, the Deputy Executive Director of MTEC was not only the main adviser of the team, but also the head of the NSTDA rubber researchers.

6.2.2) The Other Management practices

- **Project leader (middle management)**

Changing the management practices of the project leaders was a key success factor for enhancing research commercialization. This can be observed from the three projects. First, the project leader initiated a new project for training the company's employees to produce Thai ceramic sandblasting. Second, the project leader sent questionnaires to survey the market's need of the Thai seed industry before conducting the second project. Third, the project leader changed the management practices from waiting for expected licensees to approaching them for testing prototypes at the pilot scale.

- **Government policy/receiving certification from related national and international standards**

The DentiiScan version 2.0 project benefited from the government policy, especially "The listing of Thai innovations and inventions and improving the regulations of the Office of the Prime Minister on the procurement of goods in 1992 to purchase goods or services related to the list of Thai innovations through special cases" (the Bureau of the Budget of Thailand, 2016). When the DentiiScan version 2.0 had been registered as a Thai innovation, already passed the radiation safety test from the related government agencies and was certified by ISO 13485: 2016, the Medical Device Quality Management System Standard, it received financial support from the Thailand Center of Excellence for Life Sciences (TCELS) and National Research Council of Thailand (NRCT) for producing version 2.0 and was installed in seven hospitals.

On the other hand, after the digital hearing aid P02 project was certified by CE Mark and ISO 13485 in 2012 and had been registered as a Thai innovation, the cooperation between the National Health Security Office (NHSO), Health Systems Research Institute (HSRI), and the NSTDA appeared in 2013. Two thousand digital hearing aids were distributed to people with disabilities through selection by the NHSO and HSRI.

6.2.3) Organizational incentives

In recent years, researchers have complained that the promotion criteria did not attract them to engage in research commercialization. Some researchers viewed that research commercialization took time to go through the development/testing phase and commercialization phase, but publishing articles received easier scores than research commercialization. At present, the NSTDA has five main promotion criteria for researchers (see Table 6-1). In order to stimulate researchers to commercialize their research more and more, the NSTDA has added the scores for patents, which has been utilized for the first time. According to the NSTDA's Researcher Promotion Criteria, the NSTDA tries to encourage researchers to cooperate with companies in both cooperative projects and commissioned research projects by getting double scores.

Table 6-1: Types of Incentives and Researcher Promotion Criteria in NSTDA

Type of outputs/works	Examples of works
1. Publication	• Articles publish in high impact factor international journals/ Thai journals

Type of outputs/works	Examples of works
	• Short communication • Proceedings/Abstract • Booklet/manual
2. Prototype	• Lab/ Field/ Industrial prototypes
3. Intellectual Property/licensing	• Filing patents/ petty patents • Licensing
4. Receiving external grants/ Cooperative research projects/ Contract research projects	• Receiving external grants from international organization • Cooperative research projects with government agencies/ private companies • Commissioned research projects with government agencies/ private companies
5. Consulting/Technical services	• with government agencies • with private companies

Source: The author.

However, there were no additional incentives for licensed projects. Researchers received incentives relating to normal financial and career path incentives. In case of a financial incentive, the NSTDA's researchers received 70% of all income up to a threshold of one million Thai Baht (approximately US $30,000). After this threshold was reached, the researchers received 30% of any additional income.

After interviewing the researchers as representatives of 15 case studies, it can be concluded that:

"In the last month of a budget year, each researcher is evaluated for his/her personal performance from the committed research output, and he/she accumulates scores for promotion to a higher position. The general criteria is five years to qualify for promotion in each position. Nevertheless, suggestions and agreements by the Research Unit Directors/Laboratory Heads as

the mid-tier management support are the key factors to get a promotion. For example, researchers qualify in five years and achieve accumulated scores in each position, but the Research Unit Directors/Laboratory Heads disagree. It means that the researchers cannot be proposed for consideration for promotion. In contrast, the Research Unit Directors/Laboratory Heads agree to propose researchers to be promoted for high positions, but the researchers do not have sufficient accumulated scores in accordance with the set criteria. As a result, they are not considered either. On the other hand, some researchers prefer to do basic research, write publications, and conduct applied research on a laboratory scale because they can get scores faster in one year, which can influence personal performance. However, some researchers prefer to conduct applied research on a pilot scale and cooperative research/commercialized projects. They take more than one year to produce quality prototypes responding to customers' needs. As a result, they do not have enough time to write publications which is one criterion for promotion. This is the disadvantage of these researchers. Therefore, the roles of the Research Unit Directors/Laboratory Heads as the mid-tier management support are significant in stimulating researchers for planning about their career paths."

6.2.4) Difference in the scientific nature of technology (ICT vs. biotechnology vs. materials technology vs. nanotechnology)

In considering the ICT software innovations, an ICT case study showed that ICT was a general purpose technology (GPT), which had been adopted in many sectors. It was clear that both offline and licensed VAJA version 7.0 software programs were used in companies, in e-learning for university students, for queuing systems used in more than 70 state hospitals, and as an interface for people with visual disabilities to access information in online newspapers.

In addition, from both the software and ICT hardware innovations based on the coupling model of innovation, the researchers generated technologies by developing prototypes and interacting with users. The alpha and beta versions of VAJA were tested by online and offline users before completing the VAJA versions 6.0 and 7.0 whereas DentiiScan versions 1.1 and 2.0 had field testing with hospitals and the Faculty of Dentistry, Chiang Mai University.

In contrast, the biotechnology and nanotechnology innovations were related to the technology push model of innovation. Life sciences and biotechnology were characterized by particularly long development and innovation cycles compared to other disciplines (Acatech, 2016). A "Dengue Vaccine Candidate" project confirmed that it took almost 10 years for passing animal testing (TRL 4) in mice and had good potential to be developed further as a vaccine candidate. Compared with a materials technology product, advanced ceramic sandblasting could deliver a finished prototype (TRL 8) within nine years. Another biotechnology project, pentosanase production technology, was based on the technology push model of innovation because the NSTDA provided the microbial bank (Microbe Bank of BIOTEC), which was a source of microorganisms providing more than 20,000 samples for the private sector.

On the other hand, two nanotechnology projects were initiated from the project leaders and executives. The researchers tried to develop products based on their existing knowledge. For example, NANOTEC researchers developed the first locally made prototype solar-powered water purification unit, "SOS water", by combining the use of antimicrobial nanocoating to ceramic filters for helping the Thai people in flooded areas while another nanotechnology project developed nanoemulsion containing mosquito repellent technology by using herbal substances instead of chemicals.

When analyzing materials technology case studies, the projects were characterized by both the market pull and technology push models of innovation. Both GRASS 3 technology and advanced ceramic sandblasting were based on the market pull model of innovation. One project received the research problem from the private sector before being initiated whereas another project studied the market's needs before conducting the first project. In contrast, one materials technology project was to develop a medical device initiated from the project leader. It was accelerated by conducting research, developing the prototype, and undertaking animal testing and clinical testing. After finishing the clinical study, a CFT contacted the expected licensees for investing in producing the product.

On the other hand, although the project leader consulted and involved the expected companies in some projects, this did not guarantee that the expected companies would finally receive the licensed technologies from the CFTs. The Technology Readiness Levels (TRLs) and the absorptive capacity of the customers were also significant factors for successful technology transfer.

6.2.5) Different Technology Readiness Levels (TRLs)

With the limited technological capabilities of the Thai SMEs, the NSTDA as the PRI has to play a specific role to support SMEs in enhancing their capabilities by using its R&D facilities to develop from basic research (low TRLs) to high TRLs. Among the 11 successful case studies, it is apparent that the NSTDA researchers transferred technologies to the licensees at high TRLs between TRL 6- TRL 9.

Different TRLs of various projects have an influence on their commercialization success. For example, software license agreements appeared between TRL 8 and TRL 9, and most licensees were companies whereas other users downloaded the beta versions (TRL 7) free of charge, which were not the full versions of the software. In comparison to other case studies, most companies were not interested in the research results at TRL 4 except the vaccine project. A large company which had a high absorptive capacity was pleased to license a dengue vaccine candidate at TRL 4 because it was the first time in the world for successfully developing four serotypes of a chimeric live-attenuated vaccine candidate.

6.3) The Research Contribution to the Cross-functional Teams (CFTs) Approach

In relation to the research gaps described in Chapter 2, the key findings can partially fill in the gaps in the existing literature on the CFTs approach based on the context of the PRIs, and they can present how CFTs work differently in different technological fields. This can be explained as follows:

6.3.1) ICT

- <u>Previous literature</u>

According to the characteristics of ICT, ICT-based converging technologies has both convergences between homogeneous technologies and between heterogeneous types of technologies (Kim, 2013). ICT technologies are intended as technologies fulfilling or enabling the function of processing information and communicating by an electronic means (Inaba and Squicciarini, 2017). Furthermore, ICT has created innovative applications that have resulted in making life easier in many sectors (Nwizege and Chukwunonso, 2011).

Moreover, ICT tools may shorten the distance between a company and users thereby increasing and strengthening user involvement and engagement in new product development. By combining various new technologies, companies can provide a range of online services to the customers that facilitate user involvement in NPD (Nambisan, 2002). Many software products also allow companies to establish virtual customers (Dahan and Hauser, 2002). In a medical device development project, the engineering (commercial manufacturing) division might get involved as the prototype development stage is reached, and the design review and feedback from the manufacturing, marketing, and regulatory divisions might become necessary (Mehta, 2008).

- <u>Current research contribution</u>

The key findings have shown that team diversity in ICT is larger than other technologies because CFTs have to use expertise in various disciplines to develop several subsystems integrated into one system. This provides new features resolving the existing problem or substituting the existing/imported software/device. The roles of CFTs in the three sectors are described below:

1) Software

In order to create a software program for use as a tool in many sectors, CFTs continue to develop newer versions to resolve the existing problems of previous versions.

A CFT should have two sub-teams. The first sub-team consists of researchers and assistant researchers that have expertise in theory; such as, Computer Science, IT and Software Architecture whereas the second sub-team comprises engineers to test the reliability, maintainability, extensibility, scalability, and security issues. However, the project that develops subsystems to work and react like humans needs to have members who are educated in Speech Technology and Linguistics to develop subsystems related to linguistic/prosodic processing.

After testing the alpha and beta versions, an engineering team can receive feedback from both online and selected end-users and resolve any problems. When releasing a new version, an engineering team can continue to check the performance and solve any software faults including conducting continuous development with the main researchers.

The TTOs participate in the CFTs to find the expected licensees after a CFT releases the final version of the software.

In terms of technology transfer to licensees, the TTOs negotiate with the expected licensees to achieve the license agreements, and the engineer team is the representative of the CFT to inform the technical functions of the software.

2) Medical electrical equipment for the medical and healthcare sector

CFTs integrate ICT disciplines that are a combination of ICT technologies and other technologies to develop electrical medical devices.

Electrical engineering is the key expertise to integrate with the other disciplines; such as, Image Processing, Software Development, Manufacturing Systems Engineering, Biomedical Engineering, Mechanical Engineering, Signal Processing Systems for Medical Applications, Embedded Systems, Rehabilitation and Assistive Technology, etc.

In the clinical testing stage, medical doctors and the hospitals are the key partners of the CFTs. In the interim, the expected companies should be involved with the CFTs in order to exchange ideas about the market survey and product design.

If the hospitals and expected companies are satisfied with the performance of the electrical medical devices, they will license them.

On the other hand, CFTs involve the TTOs in finding the expected licensees after the CFTs have successfully developed the field prototypes of the electrical medical devices.

3) Technologies for the agricultural sector

CFTs apply the ICT field to develop smart farm technologies and systems for farm management to increase the productivity and quality of agricultural products. These technologies enable agriculturists to know what seeds to plant, the most appropriate time, other conditions to plant, as well as the expected crop output.

Most technologies and systems rely on the Internet of Things (IoT) and the microelectromechanical systems (MEMS) wireless sensor network. As a result, the key areas of expertise in Microelectronics, Electrical Engineering, IoT, Sensor Technology, and MEMS are applied in developing ICT technologies for the agricultural sector.

In order to control and create the environments, which are suitable for different types of plants; such as, temperature, humidity, moisture and light, the key external partners of the CFTs for testing the performance of the prototypes are the agriculturists in different areas.

In addition, government agencies under the Ministry of Agriculture are another partner providing information about the soil type, weather including the best suited crops in each area of the country, and support the use of technologies for the agricultural sector.

After the CFTs have successfully tested the field prototypes in the relevant environments, the TTOs assist the CFTs to find the expected licensees.

6.3.2) Biotechnology

• Previous literature

Biotechnology products are related to technology push innovations (Hackings, 1986; Krimsky and Wrubel, 1996; Russell, 1991). Biotechnology uses biomolecules and organisms to develop pharmaceutical therapies, medical treatments and agricultural innovations. The molecules used may include antibodies, nucleic acids; such as, DNA and RNA, proteins and hormones, viruses, human cells and bacteria, and plant cells (Omninano, 2016).

The highly risky and expensive drug development process has been driven primarily by companies. Although basic research supported by public monies may be exploited by the private sector in their research, the drugs would not be released to the general public without substantial additional investment and risk-taking by industry (Mehta, 2004).

A new drug project team would typically have a biologist or biochemist, a medicinal chemist (a protein chemist or cell biologist in the case of a biological drug), and a project leader in the team, as the molecule goes through early discovery studies. With progression into advanced preclinical stages, a regulatory affairs and manufacturing person might be added to the team to help prepare for the first interactions with the FDA (Mehta, 2008).

- Current research contribution

Biotechnology is based more on basic research and a linear model of innovation compared to other technologies. CFTs use knowledge in the biotechnology fields to achieve research breakthroughs in drug/vaccine development. In the interim, they focus on both basic research and applied research to apply in the agricultural sector. The roles of CFTs in the two sectors are described below:

1) Drug/vaccine development for the pharmaceutical sector

In the process of vaccine development, CFTs need to successfully test the vaccine on animals and candidates in both the preclinical and clinical trials in the factories, research laboratories, and the hospitals that have been certified by international standards; such as, Good

Laboratory Practice (GLP), Good Manufacturing Practice (GMP), Good Clinical Practice (GCP), etc.

CFTs have to spend several years of laboratory research in order to collect knowledge to develop vaccine candidates. After successfully conducting animal tests, the CFTs try to find the expected licensees because licensing technology by the company before preclinical testing can help the PRIs reduce the technological risks. As a result, the TTOs engage in the CFTs earlier than they do in other technologies.

2) Products for the agricultural sector

CFTs conduct basic research by applying several disciplines involved in biotechnology to develop the core technologies, which are related to Microbial Technology, Plant Biotechnology, Animal Biotechnology, etc.

These key technologies are useful for further development in different applications by the companies.

On the other hand, the CFTs develop product innovations based on the linear model of innovation. The university researchers and government agencies under the Ministry of Agriculture are the key partners of the CFTs. After successfully developing the prototypes in the relevant environments, the TTOs cooperate with the CFTs to find the expected licensees and achieve the license agreements.

6.3.3) Materials technology

• Previous literature

Materials technology is a relatively comprehensive field comprising the structure, properties, and use of materials; such as, metals, plastics, composites, ceramics, etc. The development of materials has been applied to almost all fields of technology and industrial applications; such as, the vehicle industry, medical field, semiconductor development, and the energy section (Awa, 2017).

Technical barriers may hinder the adoption or commercialization of new materials. This is because new materials may be initially unsuitable for existing market applications because they exhibit significantly different specifications or physical properties than conventional materials, or because of their high initial unit costs (U.S. International Trade Commission, 1998).

Increasing the amount of a new material from laboratory quantities to pre-commercial, and eventually commercial quantities often results in unforeseen obstacles, thus posing a formidable risk to the industrial developer. The cost of the scaling-up is especially severe for small entrepreneurial companies whose resources are often too limited to invest in new processing and manufacturing equipment (National Materials Advisory Board, 1993).

• Current research contribution

CFTs combine the key expertise in Materials Science, Engineering and other disciplines like Chemistry, Polymer Science, Computer Science, Mechanical Engineering, Mechatronics Engineering, Ceramics Technology, Chemical Engineering and Biomedical Engineering in order to develop new materials, new technologies and new products to replace existing materials and/or imported products. The roles of the CFTs in two sectors are described below:

1) Materials technologies for the industry sector

CFTs try to build industrial prototypes in order to provide the technical/practical solutions and/or propose product/process innovations for specific industries. Therefore, the expected companies are involved in the CFTs for testing the prototypes and providing the feedback during the pre-commercial stage.

If the performance of the industrial prototypes is related to all the requirements, the expected companies would coordinate with the TTOs and license them.

2) Medical materials for the medical and healthcare sector

The CFTs have to pass animal testing, and preclinical and clinical testing for evaluating the efficacy of the medical materials. The key external partners of the CFTs are medical doctors and the hospitals.

In order to produce medical materials relating to the market's needs, the CFTs need to cooperate with the expected companies as soon as possible. The expected companies are the key partner to increase the prototype from the laboratory scale to the industrial scale. Moreover, they can support the CFTs in the market trials.

If the companies would like to license the technologies, the TTOs would engage in the CFTs to deal with the license agreements.

6.3.4) Nanotechnology

• Previous literature

Nanotechnology encompasses the work of nanoscale science, increases understanding of the interactions in the atomic or molecular scale, and has the capability to characterize and control materials using nano tools (Miyazaki and Islam, 2007). True nanotechnology must be based on new science or phenomena in order to achieve breakthroughs based on nano level phenomena (Kamei and Kobayashi, 2012).

Commercialization of nanotechnology from research to an economically viable product is particularly vulnerable to the "Valley of Death" point of commercialization graph compared to any other technologies due to the reasons related to product focus, market engagement, scale-up, and product development (Craig et al., 2013).

• Current research contribution

CFTs integrate knowledge between the basic sciences like Chemistry, Physics, Materials Science, Polymer Science, Pharmaceutical Science, Biology, Biochemistry, and engineering disciplines like Biological Engineering, Biomedical Engineering and Electrical Engineering in order to develop frontier research and product innovations based on the technology push model.

CFTs also closely cooperate with government agencies to guarantee the safety of nano products. In order to solve the problems of SMEs without specialized machinery, the TTOs are engaged in the CFTs to offer the service of trial production and produce the nanoparticles for the expected customers.

6.4 Concluding Remarks

Although CFTs have the medium/high diversity in terms of educational fields/expertise and functions, they do not guarantee that CFTs can achieve the license agreements with the companies. The degree of diversity of the CFTs may be a key success factor to enhance technology transfer from the PRIs to the beneficiaries, but it needs to have other important factors complementing each other; such as, executive management support, middle management, TRLs, the absorptive capacity of companies, etc.

The next chapter is a conclusion of the main findings (Chapters 4, 5 and 6) and presents theoretical contributions, policy implications and implications for future research.

Chapter 7

Conclusions and Implications

Chapter 7 consists of two sections. Section 7.1 summarizes the main conclusions discussed in Chapters 4, 5 and 6. This comprises the influence of team diversity to support CFTs enhancing research commercialization in the PRIs, the comparison between the commercialization results before and after adopting CFTs, and the impact of top management support on CFTs. Section 7.2 concludes the implications for the theory, policy and future research.

7.1 Main Conclusions

7.1.1 The influence of team diversity supporting CFTs to enhance research commercialization

This study extends the research on team diversity in the context of public research institutes (PRIs) which is different from the previous studies that had mainly focused on the private sector. It examines the effect of team diversity on the number of license agreements by employing Poisson regression analysis. The key findings indicate that the high diversity of the functions/departments and educational majors/fields are the significant factors influencing the number of license agreements. This also contributes to the cognitive resource theory. It suggests that diversity facilitates a more complex problem solving process; that is, a higher quality of decision-making from different perspectives that group members bring to their team (Gruenfeld et al., 1996).

In contrast, the high degree of difference in educational levels has negative relationship with the number of license agreements. This was not consistent with that reported by Gaunya

(2015), who found a statistically significant positive relationship between the diversity of educational level and employee performance. Although Gaunya and this current research are similar in that they investigate team diversity in the public sector, different organizational contexts and different definitions of the variables may deliver different results. First, Gaunya focused on 180 line officers and 10 management level officers from the Department of Probation and Aftercare Services in Kenya, but the present study concentrates on 163 CFTs in a PRI in Thailand. Second, Gaunya investigated the difference in educational levels by individual, but this present study examines the degree of difference in educational levels in each CFT.

In summary, in the full model (163 projects), the results of the Poisson regression analysis indicate that the high degree of difference in the functions/departments and high degree of difference in educational fields had statistically significant effects on the number of license agreements while the high diversity of educational levels and the high diversity of experience factors are not significantly related to the number of license agreements (see Table 7-1). However, no differences are found between the technological fields in the fixed effects model because the differences are fixed. After dividing the data into four technological fields: information and communications technology (ICT), biotechnology, materials technology and nanotechnology, and being analyzed by the Poisson regression method, the results show that there are differences in the team diversity factors supporting the CFTs in each field (Table 7.2). It is implied that different technological contexts have a significant impact on the CFTs (Table 7-1).

Moreover, my study also examines the relationship between the degree of diversity in the functions/departments and degree of diversity in educational fields in each technological project by using cross tabulation analysis. The findings of the case studies confirm the results of the quantitative analysis of both the Poisson regression results and cross tabulation results. On the other hand, the results of the Poisson regression analysis show that ICT and the high diversity of functions were significant factors influencing the duration for achieving the first license agreement (Table 7.1).

Table 7-1: Summary of the influence of team diversity and different technological contexts on enhancing the number of license agreements and the duration for achieving the first license agreement

<table>
<tr><td colspan="2">1) What degree does team diversity support CFTs to enhance successful research commercialization in the public research institute (PRI)?</td></tr>
<tr><th>Hypothesis</th><th>Poisson regression results</th></tr>
<tr><td>H1a: High degree of difference in the functions/departments.</td><td>Significantly supports CFTs to enhance successful research commercialization.</td></tr>
<tr><td>H1b: High degree of difference in educational levels.</td><td>Does not significantly support CFTs to enhance successful research commercialization.</td></tr>
<tr><td>H1c: High degree of difference in educational fields.</td><td>Significantly supports CFTs to enhance successful research commercialization.</td></tr>
<tr><td>H1d: High degree of difference in the years of work experience in each position.</td><td>Does not significantly support CFTs to enhance successful research commercialization.</td></tr>
<tr><td colspan="2">2) What degree does team diversity influence the duration for achieving the first license agreement?</td></tr>
<tr><th>Hypothesis</th><th>Poisson regression results</th></tr>
<tr><td>H2a: High degree of difference in the functions/departments.</td><td>Significantly influences the duration for achieving the first license agreement.</td></tr>
<tr><td>H2b: High degree of difference in the years of work experience in each position.</td><td>Does not significantly influence the duration for achieving the first license agreement.</td></tr>
<tr><td colspan="2">3) To what extent do different technological contexts have an impact on CFTs in enhancing successful research commercialization?</td></tr>
<tr><th>Hypothesis</th><th>Poisson Regression Result</th></tr>
<tr><td>H3: Different technological contexts have a significant impact on CFTs.</td><td>Has a significant impact on CFTs in enhancing successful research commercialization.</td></tr>
</table>

4) To what extent do different technological contexts have an impact on the duration for achieving the first license agreement?	
Hypothesis	**Poisson Regression Result**
H4: Different technological contexts have an impact on the duration for achieving the first license agreement.	ICT has a significant impact on the duration for achieving the first license agreement.

Source: The author.

Table 7-2: Summary of the influence of team diversity and control factors in each technological field in supporting CFTs to enhance research commercialization

	ICT (58 projects)		Biotechnology (39 projects)		Materials technology (37 projects)		Nanotechnology (29 projects)	
Parameter	B	Sig	B	Sig	B	Sig	B	Sig
(Intercept)	-3.955	0.001	-0.568	0.718	-4.697	0.003	-0.844	0.700
Mfunctions	0.539	0.151	0.416	0.425	0.469	0.310	0.743	0.315
Hfunctions	0.749	0.098	**0.849**	**0.028**	0.601	0.110	0.249	0.639
Medulevels	0.239	0.427	0.076	0.899	-0.413	0.347	0.579	0.394
Hedulevels	0.017	0.964	0.200	0.570	-0.107	0.820	0.340	0.573
Medufields	0.452	0.332	-0.322	0.416	0.555	0.349	-1.405	0.093
Hedufields	**0.914**	**0.002**	-0.276	0.513	**1.326**	**0.028**	-0.413	0.670
Mexperience	0.319	0.484	-0.428	0.458	0.494	0.245	0.066	0.916
Hexperience	-0.161	0.697	-0.329	0.598	0.664	0.128	-1.052	0.227
Team size (Control factor)	**0.270**	**0.002**	0.137	0.418	**0.179**	**0.021**	0.218	0.173
Years from project completion (Control factor)	0.166	0.062	-0.039	0.708	**0.364**	**0.032**	-0.007	0.965

Source: The author.

7.1.2 The comparison between the commercialization results before and after adopting a CFT

The key findings from the effective case studies indicate that several case studies achieved the license agreements with the companies after the project leaders had adopted a CFTs approach. However, the key findings from the non-effective case studies prove that the medium/high diversity in terms of educational fields and functions by themselves could not guarantee that the CFTs could achieve the license agreements. For example, the important problem of case study C was the lack of support from the executive management to purchase large specialized machinery whereas the CFT in case study B did not receive the policy support from the executive to create a linkage between the NSTDA and Food and Drug Administration to acquire counterfeit drugs legally for preclinical testing. On the other hand, the low absorptive capacity of the customers/expected licensees was the important obstacle of the two case studies. For instance, the expected companies did not obtain the license for the anti-acne pads because they hesitated to purchase the new specific machinery for producing this product.

In summary, the degree of diversity of the CFTs may be a key success factor to enhance technology transfer from the PRIs to the beneficiaries, but it may also need to rely on other important factors as follows:

1) Team diversity and absorptive capacity of licensees causes successful licensing.

The project leader of the dengue vaccine candidate project formed a CFT by inviting key members who had complementary expertise from the NSTDA and different universities. Complementary expertise could help the CFT achieve successful licensing. The NSTDA researchers had expertise in subunit vaccine whereas the Chiang Mai University researchers helped the team study the response of the virus, and a Mahidol University researcher had expertise in DNA vaccine.

Therefore, after receiving positive results from the animal testing and the dengue vaccine candidate had good potential to be developed in preclinical and clinical studies, it was immediately licensed by a large company.

2) The goal setting of CFTs for technological licensing causes team diversity.

In the early period of the project (hemostatic products for external use), the research team had applied a CFT for clinical testing by cooperating between the Biomedical Engineering Research Unit, Engineering Division and Angthong Hospital, Angthong province. In order to achieve the license agreement, the project leader contacted the expected licensee and worked together to scale up the production of this hemostatic prototype from a laboratory scale to an industrial scale. The prototype from the industrial production was packed in the company's packages and distributed for market trials."

Another project was the pentosanase production technology project. In order to produce low-cost enzyme products for agriculturists, the NSTDA researchers developed the first project as the technology push model by using team diversity in terms of educational fields and functions. They did not know whether the project would have license agreements or not. When the company licensed the product from the first project, achieving the license agreements was set as the goals for the second and the third projects. As a result, the expected licensing led to the diversification of the CFT by cooperating with the NSTDA researchers, the university researcher and the company staff.

3) Top management support causes team diversity and successful licensing.

- The SOS water purification unit project had adopted a CFT since the first project. It was initiated and strongly engaged by executive management support. A CFT consisted of the Nano-agriculture and Environment Research Unit, Nanometrology and Characterizations and Engineering Unit, and the Thai Red Cross Society. Most members came from the Nano-agriculture and Environment Research Unit. In the last phase of development of this prototype, an electrical engineer from the Nanometrology and Characterizations and Engineering Unit was involved for designing the truck to be integrated with the solar-powered water purification unit. When the CFT completed the first prototype, the NSTDA Executive contacted the Thai Red Cross Society for testing. Finally, the NSTDA donated the first version of this prototype to the Thai Red Cross Society on June 28, 2012, for community relief efforts. After donating the prototype SOS water, the same team developed the next version. The NSTDA executives always showed this product to many stakeholders. As a result, two companies contacted the researchers for licensing this product.

- The GRASS 3 technology project had applied a CFTs approach since the first project. The Deputy Executive Director of MTEC who had expertise in the structures and properties of rubber, modifications of natural rubber, and green production technology of natural rubber acted not only as the main adviser of the team, but also as the head of the NSTDA rubber researchers. The Deputy Executive Director of MTEC used his research network to help the CFT contact the expected licensees for testing the GRASS 3 technology. Therefore, executive management support led to both the diversification of the team and successful licensing.
- The DentiiScan project was initiated by the adviser of the NSTDA President. He considered that this project needed to have the CFT that consisted of members who had skills and knowledge in the ICT field, Materials Technology and Mechanical Engineering. Executive management support led to both successful licensing and the diversification of the team because the adviser of the NSTDA President suggested the team to cooperate with a veterinarian for animal testing following the ethical research on humans and radiation safety. Moreover, he used his network to find the expected licensees and external budget for conducting research in new projects."
- The VAJA versions 6.0 and 7.0 projects were a top-down policy for initiating this project. The second NSTDA President assigned a team to develop the VAJA software as an option for people with disabilities and suggested the team to invite a member educated in Assistive Technologies for People with Disabilities into the CFT. Later, the fourth NSTDA President suggested the team should develop software based on portable devices. To achieve the goal for licensing technology and

commercialization, the CFT had to divide the team into two sub-teams. The first sub-team consisted of researchers and assistant researchers that had expertise in theory, language and system software architecture whereas the second sub team comprised engineers to test the reliability, maintainability, extensibility, scalability, and security issues. During the alpha and beta tests, the second sub-team could receive feedback and resolve any problems/faults.

4) The project leader who has a close connection with the university researchers and government agencies causes team diversity and successful licensing.

- The project leader of the nanoemulsion project formed a CFT by inviting the external partners into the team at the beginning of the project because of two reasons. Firstly, the Traditional Thai Medicine Development Center, Ministry of Public Health, Thailand had knowledge about Thai herbs and could suggest to the NSTDA researchers how to use Thai herbs to develop a product that caused prevention against mosquitoes and followed safety and the related standards. Secondly, a CFT cooperated with a university researcher from Mahidol University because a university researcher had expertise in encapsulation technology and could help the team for scaling up from the lab scale to the pilot scale. As a result, the cooperation between the NSTDA researchers and Ministry of Health by using the project leader's network could help the CFT to convince the expected licensees to achieve the license agreements.
- Another project was the strip test for detection of bacterial fruit. The project leader formed a CFT by relying on my close relationship with a NSTDA researcher from a different laboratory and inviting the university researchers and the representative of the Department of Agriculture, which had close collaboration with the NSTDA and my main researcher. The NSTDA researchers produced a monoclonal antibody whereas the university researchers prepared plant pathogenic bacteria for testing. On the other hand, a member from the Department of Agriculture, Ministry of Agriculture and Cooperatives had the main responsibility for developing the strip test.

7.1.3 The impact of top management support on CFTs

According to the last research question (How does executive management contribute to CFTs in enhancing successful research commercialization in the PRI?), the key findings from the case studies indicated that the executive management of the NSTDA was one of the key factors for supporting the CFTs enhancement of research commercialization.

Top management support referred to experience and the expertise of the NSTDA executives' influence on the NSTDA's policies about enhancing research commercialization. During the period that Dr. Thaweesak Koanantakool was the NSTDA President, outstanding policies were the NSTDA Investors' Day exhibition, applying a Stage-Gate approach for innovation management, using Technology Readiness Levels (TRLs) as a method for research management, the Giga Impact Initiative (GII) projects, pre impact assessment, systematic criteria for researching the economic impact assessment, etc.

Evidence from the case studies showed that there were different types of executive management support as follows:

First, executive/top management support enhanced the diversity of a CFT and used its network for helping the CFT to find external budget or testing with external partners. For example, in developing the VAJA software, the second NSTDA President assigned a team to develop the software as an option for people with disabilities and suggested the team to invite a member educated in Assistive Technologies for People with Disabilities into the CFT while the adviser of the NSTDA President enhanced the team diversity of the DentiiScan team by increasing the number of members who were educated in Manufacturing Systems Engineering, Material Selection for Engineering Design, Biomedical Engineering, and Mechanical Engineering into the team in order to improve the rotation accuracy of the X-ray tube relating to the software's operation. In contrast, for the materials technology project, the Executive Director of MTEC added the team diversity of the CFT by contacting the expected licensees for testing the GRASS 2 and GRASS 3 technology.

Second, the executive assigned a CFT to develop a water purification unit by using a mobile solar operating system based on existing knowledge in a short period of time for helping the Thai people in flooded areas.

Third, the executive was not only the main adviser of a CFT, but also the main researcher. This can be observed from the DentiiScan project and GRASS 3 project.

Fourth, the NSTDA President helped CFTs contact government agencies for adopting Thai innovations derived from the NSTDA's research. For instance, the NSTDA President cooperated with the Health Systems Research Institute (HSRI) to propose the policy recommendation to the National Health Security Office (NHSO) in order to adopt INTIMA hearing aids. Finally, the NHSO had accepted it and launched a pilot program that was offered to 13 standardized hospitals.

7.2 Implications for Theory, Policy and Further Research

The objectives of the PRIs in developed and developing countries may be different, but the channels of the PRIs in terms of enhancing research commercialization; such as, R&D licensing are not so different. Although the current study focuses on one PRI, the NSTDA conducts research in four technological fields: ICT, biotechnology, materials technology and nanotechnology. Therefore, the implications for the theory and policy could apply to other PRIs.

7.2.1 Implications of the cross-functional teams (CFT) approach

Based on the private sector context, the particular focus in studies of CFTs has been the integration of firms' R&D and marketing functions and the discovery and development functions (Robertson and Langlois, 1995; Zeller, 2002). The general concept of CFTs puts emphasis on the members from different departments; such as, R&D, marketing, engineering, design, and production, as well as participants from outside the organization (suppliers, key customers, or consultants). There have been no studies done on the impact of the following factors on CFTs and research commercialization in the public sector context.

A) The impact of the technological field and the impact of the industrial sector

Although the study by Faulkner and Senker (1995) examined the linkage between industry and public research in three technologies: biotechnology, engineering ceramics and parallel computing by interviewing 35 companies in the United States and United Kingdom, it mostly focused on the companies' policies and how the companies interacted with and obtained knowledge from researchers in academia and government laboratories. It did not explain the milestones and how the CFTs worked in each project. Therefore, this present study is an extension of Faulkner and Senker (1995), as it analyzes 163 research projects in four technologies: ICT, biotechnology, materials technology and nanotechnology. In addition, the researcher explained different viewpoints from Faulkner and Senker (1995) by presenting the viewpoints of a PRI. For example, how the governmental researchers set the objectives to develop research projects in different technologies, how the researchers contacted and obtained knowledge from the external partners/companies, and how the researchers achieved research commercialization. Moreover, my study investigates the effects of team diversity, the component of CFTs, why the CFT added members, and linkage between TRLs and firms' absorptive capacity based on the PRI context.

Basically, there were differences in the nature of the technologies between ICT, biotechnology, materials technology and nanotechnology; however, the previous studies did not investigate how CFTs worked differently in different technological fields. Therefore, my study proposes as follows:

Table 7-3: What and how CFTs influence research and commercialization in different technological fields?

	How technology is created and commercialized (summarized from the literature)?	**How and in what way do CFTs influence research and commercialization (from the case studies and questionnaires)?**
ICT	ICT-based converging technologies have both convergences between homogeneous technologies and between heterogeneous types of technologies (Kim, 2013). ICT technologies are intended to be technologies fulfilling or enabling the function of processing information and communicating by electronic means (Inaba and Squicciarini, 2017), and ICT has created innovative applications that have led to making life be more convenient in many sectors (Nwizege and Chukwunonso, 2011).	Team diversity in ICT is larger than other technologies because CFTs have to use expertise in various disciplines to develop several subsystems integrated into one system that provides the new features resolving the existing problem or substituting the imported software/device. The technology transfer officers (TTOs) participate in CFTs to find the expected licensees after the CFTs release the final version of the software or successfully test the field prototypes in the relevant environments.
Biotechnology	Biotechnology products relate to technology push innovations (Hackings, 1986; Krimsky and Wrubel, 1996; Russell, 1991). It uses biomolecules and organisms to develop pharmaceutical therapies, medical treatments and agricultural innovations. The molecules used may include antibodies, nucleic acids; such as, DNA and RNA, proteins	Biotechnology is based more on basic research and a linear model of innovation compared to other technologies. CFTs use knowledge in biotechnology fields to achieve research breakthroughs in drug/vaccine development. As a result, TTOs engage in the CFTs earlier than they do in other technologies. In the interim, the CFTs focus on both basic

	How technology is created and commercialized (summarized from the literature)?	How and in what way do CFTs influence research and commercialization (from the case studies and questionnaires)?
	and hormones, viruses, human cells and bacteria, and plant cells (Omninano, 2016).	research and applied research to apply in the agricultural sector.
Materials Technology	Materials technology is a relatively comprehensive field comprising the structure, properties, production and use of materials; such as, metals, plastics, composites, ceramics, etc. The development of materials applies to almost all fields of technology and industrial applications; such as, the vehicle industry, the medical field, semiconductor development, and the energy section (Awa, 2017). Scaling-up a new material from laboratory quantities to pre-commercial, and eventually commercial quantities, often results in unforeseen obstacles, thus posing formidable risks to the industrial developer (National Materials Advisory Board, 1993).	CFTs combine the key knowledge between Materials Science and Engineering, as well as other disciplines like Chemistry, Polymer Science, Computer Science, Mechanical Engineering, Mechatronics Engineering, Ceramics Technology, Chemical Engineering and Biomedical Engineering in order to develop new materials, new technologies and new products to replace the existing materials and/or imported products. The expected companies are involved in the CFTs for testing the prototypes and providing feedback during the pre-commercial stage. If the performance of the industrial prototypes relates to all requirements, the expected companies will coordinate with the TTOs and license them.

	How technology is created and commercialized (summarized from the literature)?	How and in what way do CFTs influence research and commercialization (from the case studies and questionnaires)?
Nanotechnology	Nanotechnology encompasses the work of nanoscale science, increased understanding of interactions in the atomic or molecular scale and the capability to characterize and control materials using nano tools. An important feature of nanotechnology is that it is not restricted to the realm of advanced materials, extending also to manufacturing processes, biotechnology and pharmacy, electronics and IT, as well as other technologies (Miyazaki and Islam, 2007). Commercialization of nanotechnology from research to an economically viable product is particularly vulnerable to the "Valley of Death" point of commercialization graph compared to any other technologies due to the reasons related to the product's focus, market engagement, scale up, and product development (Craig et al., 2013).	CFTs integrate knowledge between the basic sciences like Chemistry, Physics, Materials Science, Polymer Science, Pharmaceutical Science, Biology, and Biochemistry, as well as Engineering disciplines like Biological Engineering, Biomedical Engineering and Electrical Engineering in order to develop frontier research and product innovations based on the technology push model. CFTs closely cooperate with government agencies to guarantee the safety of nanoproducts. The TTOs are engaged in the CFTs to offer the service of trial production and producing the nanoparticles for the expected customers.

Source: The author.

B) The roles of top management and the middle level management

Top management is the executives and heads of major divisions. More generally, they control the resource allocation decisions including capital expenditure and budget. The roles of executive management and middle managers are complementary. Efficient operations, informed and controlled by middle managers, enable ordinary capabilities. Without adequate 'translation' by middle managers, the strategic vision of the executive management will not be correctly communicated and enacted at the lower levels of the organization (Lee and Teece, 2013).

Although there has been some research on the role of the executive management on performance (Crossland and Hambrick, 2011) and of middle managers on performance (Burgelman, 1983; Floyd and Wooldridge, 1994), efforts to simultaneously illustrate the relative impact of middle and executive managers on firm performance are still lacking (Lee and Teece, 2013). Moreover, the literature on public management has largely highlighted competition between professional and managerial cadres, and the shifting balance of power between the two (Farrell and Morris, 2003), or alternatively, the leadership responsibilities of the most senior managers or professional elite (Currie et al., 2012).

On the other hand, the studies of the performance of CFTs on innovation have shown that the organizational context, specifically top management support has had a more significant influence on team success than internal team characteristics (Hitt et al., 1999), and top management is the most critical factor in the success of technology transfer (Roupas, 2004). However, previous literature did not explain how the roles of top management and middle management supported the CFTs to enhance research commercialization in the PRIs. Therefore, this current study explained the linkage between the executive management and the middle level management through the Research Unit Directors (RUDs) and the Laboratory Heads for supporting the CFTs.

The key findings of the case studies prove that the executives' expertise and work experience is one of the significant factors for adding members to CFTs. If the research projects had a close linkage between the executives and the RUDs/Laboratory Heads, this would lead to enhanced research commercialization. Specifically, individual management of the middle level management is another key factor for supporting CFTs enhancement of research commercialization. The three types of linkages between top management and middle level management are summarized as follows:

1) The executive is a member of a CFT.

The executives work as a main researcher of a CFT and adviser of this project. Their direct experience and networks can help the RUDs/Laboratory Heads invite new members into the CFTs. The executives always guide CFTs on how to develop prototypes that respond to the needs of the industrial sector. Important decisions of CFTs also depend on the executives. For example, the adviser of the NSTDA President who had experience in developing the first CT scan in Thailand and was educated in Electronic and Computer Engineering who collaborated on the DentiiScan project formed a CFT consisting of ICT and materials technology researchers. Moreover, he used his network to consult with hospitals for allowing the CFT to test the DentiiScan version 1.1 and found external research budget in conducting research in new projects.

On the other hand, the Deputy Executive Director of MTEC who had expertise in the modifications of natural rubber and green production technology of natural rubber acted not only as the main adviser of the team, but was also the head of the NSTDA rubber researchers. The Deputy Executive Director of MTEC used his research network to help the CFT contact the expected licensees to test the GRASS 2 and GRASS 3 technology.

2) Close collaboration between the top management and the middle level management

The executives provide recommendations about how to add members to a CFT and develop innovations from the existing expertise and knowledge of researchers. Nevertheless, significant management relies on RUDs/Laboratory Heads (middle level management). For instance, the second NSTDA President assigned a team to develop the VAJA software as an option for people with disabilities and suggested the team invite a member educated in

Assistive Technologies for People with Disabilities into the CFT, and the fourth NSTDA President guided the team to develop software based on portable devices. After receiving directions from the executives, the RUD as the VAJA project leader studied the best practices of foreign countries, licensed a local Thai language module from a doctoral student, and trained a research specialist to work as the marketing engineer of the CFT. This research specialist was the representative of the CFT to contact and find potential customers. Moreover, the RUD separated the CFT into two sub-teams. The first sub team had expertise in theory, language and system software architecture whereas the second sub-team comprised engineers to test the reliability, maintainability, extensibility, scalability, and security issues.

3) The executives support a CFT by coordinating with other government agencies to apply the research results. For instance, the RUD as the project leader consulted with the NSTDA President on how to commercialize the research result. As a result, the NSTDA President coordinated with the Health Systems Research Institute (HSRI) about the dissemination of the research results. Later, the HSRI proposed the policy recommendation to the National Health Security Office (NHSO) in order to adopt INTIMA hearing aids. Finally, the NHSO had accepted it and launched a pilot program that was offered to 13 standardized hospitals.

C) The impact of different TRLs

The previous studies mostly focused on guide books and white papers for the technology readiness levels (TRLs) assessment, but there was little previous work that had systematically evaluated the state of the TRL implementations (Olechowski et al., 2015). However, my study explained why different TRLs have the impact on CFTs and their advantage for research commercialization.

The key findings prove that different technological projects require different expertise from members. However, the common characteristic as the key success factor of CFTs in different technological projects was to involve the key partners/the expected licensees for clinical testing/testing in the operational environment (TRL 6-7). If the expected licensees were satisfied with the results of the preclinical and clinical testing, as well as the testing in their factories, they would license these technologies.

It is apparent that most research results were transferred to the licensees at high TRLs between TRL 7- TRL 9 because the PRI has the important role to support and enhance the capabilities of SMEs by using its R&D facilities to build from basic research (low TRLs) to high TRLs. Nevertheless, licensing technologies at low TRLs will occur if the companies have a high absorptive capacity in budget, human resources and infrastructure.

Most research projects were successful in the laboratory prototypes, but they did not convince the customers to license these prototypes. In comparison to other technological fields, most companies were not interested in the research results at TRL 4 except the drug/vaccine project because it needed to invest large sums of money for conducting research. The characteristics of the drug/vaccine project based on the technology push model of innovation took more than 10 years for developing the new drug/vaccine. For example, the large company was pleased to license a dengue vaccine candidate at TRL 4 because it was the first time in the world for successfully developing four serotypes of a chimeric live-attenuated vaccine candidate.

In the case of the software programs, they were transferred to the licensees at TRL 8 because they released only version 1.0 to the end-users. However, some projects that had v1.x, v2.x, etc. were licensed at TRL 9.

7.2.2 Policy recommendations for research management of public research institutes (PRIs)

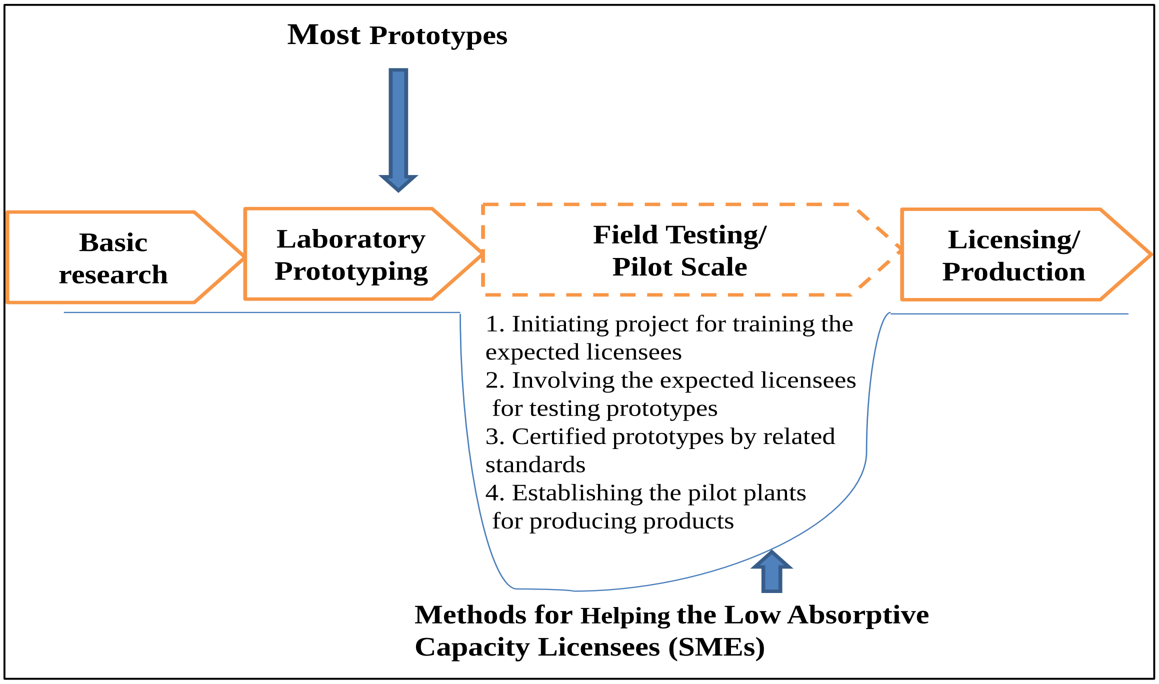
Helping domestic industries is one of the important missions for PRIs even when the countries have become industrialized and firms' technological capabilities are high. PRIs aim to upgrade existing industries, especially small and medium-sized enterprises (SMEs), as well as spearhead new ones (Intarakumnerd and Goto, 2016). On the other hand, the methods for stimulating researchers to engage in commercial activities are one of the key factors for enhancing research commercialization in the PRIs. As a result, this section proposes the policy recommendations in a broader perspective for PRIs both in developed and developing countries.

1) Methods for assisting low absorptive capacity licensees receive new innovations/technologies.

In the context of developing countries, most private firms are small and medium enterprises (SMEs). They tend to be followers that provide the same products as existing businesses. The drive for entrepreneurship is hindered by a fear of failure (UNCTAD, 2015). Even in the traditional sectors of developed countries, the capacity of SMEs to actively engage in knowledge transfer activities is typically limited by constraints in human and financial resources (European Commission, 2007). On the contrary, the findings of my study show that most researchers of PRIs successfully developed only laboratory prototypes. A working prototype for a product or service could not be developed sufficiently to deliver for commercialization because the researchers did not test in the pilot scale or demonstrate with their external partners. Therefore, the PRIs should have the important role to link between their research results and build SMEs' technological capabilities.

Although previous research offers many recommendations aimed at encouraging SMEs to absorb new and external knowledge for faster innovation; such as, innovation voucher scheme, hiring qualified staff, carrying out R&D, developing links into knowledge networks, etc. (European Commission, 2007; Lazzeri and Pisano, 2014; Scott-Kemmis et al., 2008), this current study attempted to provide some practical mechanisms of PRIs assisting the low absorptive capacity licensees (SMEs) to receive new innovations/technologies (Figure 7.1).

Figure 7.1: Methods for Helping the Low Absorptive Capacity licensees (SMEs)



Source: The author

First, some companies are interested in new technologies but they do not have the know-how for producing the technologies. If the PRI offers the project for training the company's staff, it will help them enhance their capacity for receiving these technologies.

Second, involving the expected licensees for testing the prototypes in the pilot scale can help CFTs to convince them for licensing the new prototypes in the near future. However, it depends on the researchers' networks. Moreover, the close cooperation between researchers and the expected licensees can lead to collaborative research projects between them in the future.

Third, during testing with the expected licensees, CFTs need to certify their prototypes in accordance with the related standards. These certifications can prove that the prototypes have quality for licensing to the customers. For example, when the P02 digital hearing aid was certified by CE Mark and ISO 13485 in 2012 as the new model, P02-INTIMA, it resulted in a collaborative project between the National Health Security Office (NHSO), Health Systems

Research Institute (HSRI) and the NSTDA. Finally, 2,000 digital hearing aids were distributed to people with disabilities through the selection of the NHSO and HSRI.

Fourth, the PRI establishes the pilot plants to produce products for SMEs. For instance, the NSTDA has the Cosmetic Production Plant certified by GMP. This provides services and consultancy; such as, trial production, nanoparticle production service, nano cosmetic manufacturing services from herbs and natural products, verification of the physical and microbiological properties of the product, etc.

2) Incentives/Career path

Previous studies suggest that PRIs should not only have financial incentives, but also promote career progression and have a positive link between the financial incentives and the motivations of inventors to patent and commercialize the research results (Lach and Schankerman, 2008; Lam, 2010; Owen-Smith and Powell, 2001; Thursby et al., 2001). However, they did not propose how to develop incentives to attract researchers for commercial engagement.

Evidence based on the interviews showed that most completed research projects always delivered the laboratory prototypes and the simulated prototypes that did not transfer the technologies to customers. Therefore, the PRIs should offer additional incentives to stimulate the researchers conducting research from the working prototypes to transferring technologies to the beneficiaries in terms of research commercialization. The incentives should link to the career path of each researcher; such as, collecting scores in order to be promoted to a higher position. For example, if the researchers can achieve two license agreements with different companies per one project for two consecutive years, they will receive extra scores for promotion or an extra financial incentive.

Although inviting a large company with a high absorptive capacity as a partner of the research project can be another strong incentive for researchers. Thus, the PRIs should prevent the problem of corruption resulting from a personal linkage with the large companies by encouraging the researchers to transfer technology to SMEs. For example, if the research results of the researchers can create a large economic impact by clearly enhancing the capability of SMEs, the researchers will receive additional scores for their career path promotion.

However, the roles of RUDs/Laboratory Heads as the mid-tier management are the key factor to promote researchers from low positions to high positions. If they assign the research projects and set the targeted output for each researcher under the research unit following the criteria for promoting to higher positions, this would be an incentive for researchers to involve research commercialization.

3) Personnel rotation

Previous research found that an informal mode like mobility of researchers, engineers and managers is an effective way of promoting knowledge exchange, mitigating network failures, and strengthening relationships based on trust and longer-term benefits between the PRIs and industry (Intarakumnerd and Goto, 2016). However, the key findings showed that working across laboratories was a key success factor to solve complex research problems. As a result, the PRIs should set "personnel rotation across laboratories in the short period" as one of the key performance indicators (KPIs) for researchers who are candidates for being promoted from researchers to senior researchers. If they can adjust themselves to new CFTs/new environments and deliver the research results to customers, they will be ready for the new positions as senior researchers. This policy can help researchers learn new knowledge and solve different problems.

7.2.3 Policy recommendations for the government

1) The government should attach great importance to the cooperation between the Ministry of Science and Technology and Ministry of Industry in order to link PRIs and private firms. This would be a channel for matching the market's needs and the existing research/new

research. Moreover, it could help researchers enhance team diversity, find the expected licensees for testing their prototypes, and lead to achieving license agreements or collaborative projects.

2) The government should use an existing R&D consortium or set up new R&D consortiums that have members in both the related government agencies and related private firms (both large firms and SMEs) in order to create large research projects that deliver economic and societal impacts.

On the other hand, the formal R&D consortiums could help the PRIs enhance team diversity from the external partners and achieve license agreements in existing/new projects. For example, PRIs have software programs and products that can help companies increase their competitiveness. When these companies know information from the consortium, they will contact the PRI and achieve the license agreements. In contrast, these consortiums stimulate the cooperation between the government agencies and PRIs for supporting Thai research and using Thai products as the public procurements.

7.2.4 Implications for future research

This study does not analyze the relationship between top management support and team diversity in the Poisson regression, but some case studies show that top management support may have direct impacts on enhancing the team diversity of the CFTs supporting research commercialization. Therefore, future study should investigate this relationship between them. In addition, this study has the limitation about the number of case studies. Therefore, future research should examine additional case studies in order to understand many characteristics of technological projects and compare the effects of TRLs on research commercialization.

Appendix

Appendix 1: Appendix to Chapter 2

Table A1-1: Literature Review: The Roles of CFTs in the Private Sector and Using CFTs in the Public Sector

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Ancona and Caldwell (1990)	Cross-functional teams: Blessing or Curse for New Problem Development	45 new product teams in five high-technology companies	Quantitative study	The results show that diversity appears to have contradictory, complex effects that sometimes facilitate, and sometimes hinder innovation success. In order to turn this diversity into an asset mechanism, it needs to be put in place to accentuate the positive and overcome the negative effects of diversity.
Holland, et al. (2000)	Critical success factors for Cross-functional Teamwork in New Product Development	Companies	Literature review	Using a heuristic team effectiveness model, these are categorized into six groups: task design, group composition, organizational context, internal processes, external processes and group psychosocial traits. Recent theory on group effectiveness has increasingly recognized the significance of a supportive organizational context, and this is particularly pertinent for cross-functional

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				teams. Key success factors include strategic alignment between functions, a climate supportive of teamwork and team-based accountability. The findings are integrated into a diagnostic model which is intended to be of practical benefit to people designing, leading and facilitating cross-functional new product development teams.
Shen, X. (2002.)	Factors Affecting Multifunctional Teams in Innovation Processes	Companies	Literature review	Ford Motor Company has taken the multifunctional team approach towards process improvement and creation with workshops known as Ford RAPID. Ford believes that getting people from all parts of the process is the key for creativity and innovation (CEPT, 2001).
Xie, et al. (2003)	Antecedents and Consequences of Goal Incongruity on New Product Development in Five Countries	1,083 firms in five culturally distinct areas—-the United States, Great Britain,	Quantitative study	The results underscore the importance of people-side issues, and of national culture, in cross-functional integration. Perceived goal incongruity among marketing, R&D, and

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
		Japan, Hong Kong (a special administrative region of China), and mainland China		manufacturing impairs all three components of cross-functional integration. In United States and British firms, goal incongruity generally is attributed to motivational factors. Finally, the results show that the two types of managerially controllable variables interact. For example, joint rewards and job rotation strengthen each other's tendency to reduce goal incongruity in all five samples. This suggests that job rotation promotes the development of joint goals more effectively when it is accompanied by a joint reward system.
Tushman, et al. (2003)	Innovation Streams and Ambidextrous Organizational Designs: On Building Dynamic Capabilities	Companies: 15 business units and 36 innovation episodes	Quantitative study	Ambidextrous designs significantly outperform both CFTs as well as unsupported innovation teams. These patterns are most clearly seen when a business unit tried multiple organizational designs to execute a single non-incremental innovation. For

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				example, HP's Scanner division is executed through heavyweight teams. This heavyweight team could get neither senior management support nor support from the rest of the scanner organization. Future research could more fully explore the characteristics of ambidextrous designs and the characteristics of senior teams that can manage these complex forms.
Athanasaw (2003)	Team Characteristics and Team Member Knowledge, Skills, and Ability Relationships to the Effectiveness of Cross-Functional Teams in the Public Sector	The public sector, i.e., federal, state, county, city, and other local governments, throughout the United States	Quantitative study	CFTs in the public sector have shown that they have the knowledge, skills, and ability (KSA) to be effective teams. It is necessary for management to pick up the torch and show the way for the employees to encourage and support team building, training, and recognizing those teams that have positively impacted the organization and its customers. Moreover, CFTs should not only continue in

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				the public sector, but should be a way of conducting business within agencies.
Alexander, et al. (2005)	Cross-Functional Team Processes and Patient Functional Improvement	40 teams in 16 Veterans Affairs hospitals across the United States	Quantitative study	Findings support that team process has important implications for patient outcomes. The results suggest that the level of participation by the team as a whole may be a more important process attribute, in terms of patient improvements in activities of daily living (ADL), than the team's smooth functioning. These findings indicate the potential appropriateness of managerial interventions to encourage member investment in team processes.
Love, et al. (2006)	Organizing Innovation: Complementarities between Cross-Functional Teams	UK and German manufacturing plants	Quantitative study	The results suggest that the potential importance of cross-functional team working increases their innovation outputs. Using optimal combinations of CFTs in the innovation process increases innovation

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				success in the UK by 29.5% compared to 9.5% in Germany.
Rivera and Valdez (2007)	Cross-functional Teams and Informal Social Networks: A Case Study of Project Development and Performance in a Multidisciplinary Science and Technology National Laboratory	A multidisciplinary science and technology national laboratory in the United States	Qualitative study	The study's findings indicate that the institutional support mechanisms fail to sustain CFTs when they are not specifically aimed at the utilization of networks to generate knowledge and other resources.
Cortese (2007)	Samsung Profile	Samsung company	Literature review	The Catalyst Development Team creates CFTs from diverse backgrounds to solve complex technical challenges and develop advanced materials.
Kim and Kang (2008)	Cross-functional Cooperation with Design Teams in New Product Development	Electronic companies	Quantitative study	The findings indicate that the elements of cooperation with a design team correlate to greater performance success, providing tentative evidence that the NPD process has a role as a component of integration with a design team.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Sosa and Mihm (2008)	Organization Design for New Product Development	Companies	Literature review	A key role of internal communication is to overcome cross-functional integration issues within the team. They observe that those teams that use a highly interactive and iterative approach to overcome cross-functional barriers instead of 'over-the-wall' approaches were the ones that ended up with a successful product.
Gallup Organization, (2009)	Innobarometer 2009	Companies	Literature review	Innovation trends are investigated between 2006 and 2009 in sectors of industry that are supposed to be innovative. There are differences between large and small companies. Of the large companies, 69% create cross-functional/departmental teams in innovation projects, whereas only 28% of the small companies do so.
Schilling & Werr (2009)	Managing and Organizing for Innovation in Service Firms	Service companies	Literature review	The results of the healthcare sector show that multidisciplinary is positively related to the

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				quality of team innovation, given that the teams have good team processes.
Bunduchi, (2009)	Implementing Best Practices to Support Creativity in NPD Cross-Functional Teams	HEA - small business unit of a large telecom company	Qualitative study	Limited resources lead to ineffective use of CFT and delay the process and the ability of the unit to develop innovative new products.
Allarakhia (2011)	Novartis Institutes for Biomedical Research (NIBR)	PRIs	Literature review	NIBR uses CFTs in every project. Each CFT comprises scientists, chemists, disease area specialists, and clinicians. Within NIBR, some groups of scientists specialize in disease areas while others focus on ―platforms‖ – fundamental technologies that apply across a broad spectrum of diseases.
Gemser and Leenders (2011)	Managing Cross-Functional Cooperation for New Product Development Success	40 NPD projects in the consumer electronics and pharmaceuticals industries	Quantitative study	The results show that the contributions of cross-functional cooperation to NPD success are contingent on the type of market and technology opportunities being pursued. More specifically, they suggest that when a project team pursues an opportunity characterized by the high levels of

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				technological and market risks, investments in high levels of cross-functional cooperation are warranted to increase NPD success.
Roucan-Kane, et al. (2011)	Approaches for Selecting Product Innovation Projects in U.S. Food and Agribusiness Companies	100 companies in the U.S. food and agribusiness sector	Quantitative study	The results show that the food and agribusiness companies usually involve more than three departments/functional areas in the selection of product innovation projects. Researchers indicate that it is critical for managers to form CFTs that use a variety of selection methods to successfully assess product innovation projects. They also suggest that this assessment should be done frequently to continuously evaluate the potential success of the innovations, reduce the risk of potential failure, and limit the research and development costs.
Santa, et al. (2011)	The Role of Cross-Functional Teams on The Alignment Between Technology Innovation	Service organizations	Quantitative study	The findings indicate that CFTs have an indirect influence on continuous improvement of operational performance

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
	Effectiveness and Operational Effectiveness			through the alignment between technology innovation effectiveness and operational effectiveness.
Piercy, et al. (2012)	Change Management in the Public Sector: The Use of Cross-Functional Teams	3 case studies in the UK public sector	Qualitative study	They identify four requirements for the success of CFTs The first three key factors concur with established private sector research on cross-functional working (the need for the organizational leader to clearly support the team; cultural and structural issues that support cross-functional integration; funding support). Their research also uncovers a fourth critical requirement. It is the need to break the status-quo and overcome resistance to change. They find no evidence that these conditions cannot be met in the public sector and suggest that the CFTs approach is a positive approach to be integrated in public sector change programs.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Gouanlong and Tsapi (2012)	The Procedures for Strategic Management of New Products for Small, Medium and Large Firms in Cameroon	Sixty five innovative companies in Douala and Yaounde cities, Cameroon	Quantitative study	The findings indicate that significant differences exist between the perceived importance of cross-functional team composition and firm size. The results highlight the virtual absence of cross-functional team formation by SMEs.
Ju (2012)	An Evaluation of Critical Factors Influencing Product Innovation in the Food Industry – A Case Study of China Mengniu Dairy Company	A Chinese food industry	Qualitative study	The food industry is highly market driven and is the most important influencer of NPD success, indicating a relatively high level of external uncertainty. Therefore, it has a stronger need for cross-functional collaboration to deal with this external uncertainty. Moreover, technology is one of the critical factors influencing the product innovation in the food industry. It can accelerate the manufacturing process and assist with new product development.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Ersun and Karabulut (2013)	Innovation Management and Marketing in Global Enterprises	BMW company	Literature review	The companies explore strategies to improve their performances through innovation and creativeness. They form the cross-functional teams. For example, BMW applies this practice to design cars. The project team members from different departments work in the company's Research and Innovation Center for a certain time (Dumitrescu et al., 2011).
Rahmat (2013)	A Case Study of Cross-Functional Teamwork Factors in Determining New Product Performance in Mitsubishi Electric (Malaysia) Sendirian Berhad	Mitsubishi Electric (Malaysia) Sdn. Bhd	Qualitative study	The respondents involve in this study is engineer and manager level. The effective and efficiency teamwork factor is found that lead to the enhancement of product performance. However, the result and outcome of the study is only applicable for Mitsubishi Electric (Malaysia) Sdn. Bhd. and related industry only.
Sabir, et al. (2014)	Cross Functional Teams and Innovation Management	3 telecom companies in Pakistan	Quantitative study	Team performance, organizational performance and innovativeness are the

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				significant factors to influence on the CFT capabilities level. When there are conflicts and lack of trust among CFT members, the performance and innovativeness will be reduced. However, this study had research limitations. Three telecom companies are used for data collection so the generalizability of this study is low.
Blindenbach-Driessen (2015)	The (In)Effectiveness of Cross-Functional Innovation Teams: The Moderating Role of Organizational Context	95 companies	Quantitative study	It investigates the moderating role of organizational context on the relationship between CFTs and performance. A multilevel sample of 142 projects in 95 firms is used to demonstrate that cross-functionality contributes to the performance of innovation projects in more functionally organized firms, with a separate innovation unit, and above-average levels of organizational connectedness. Other types of

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				organizations may need to reconsider the use of CFTs for their innovation projects.

Source: Compiled by author

• Methods are: literature review, quantitative study and qualitative study

- A literature review surveys books, scholarly articles, and any other sources relating to a particular issue, area of research, or theory. It provides a description, summary, and critical evaluation of these works in relation to the research problem being investigated (Fink, 2014).
- Quantitative study is concerned with numerical measurement and statistics data. It uses mathematical models to test the hypotheses, and the objective reality can be accessed and measured (Saunders et al., 2003).
- Qualitative study is used when the topic is new and it has never been addressed with a certain sample or group of people. Moreover, the existing theories do not apply with the particular sample or group under study (Morse, 1991)

Table A1-2: Literature Review: The Roles of Public Research Institutes (PRIs) in Terms of Transferring Technology to Companies and Using CFTs in PRIs as One Method to Enhance Research Commercialization

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Faulkner and Senker (1995)	Knowledge Frontiers: Public Sector Research and Industrial Innovation in Biotechnology, Engineering Ceramics, and Parallel Computing	PRIs	Qualitative study	They have explored the content of knowledge flow between the private sector and the public research organizations. Industrial use of public sector research (PSR) is characterized by considerable diversity: both the nature and extent of linkage varies according to, amongst other factors, firm size, industrial sector and research field. Knowledge Frontiers investigates the research links and knowledge flows between industrial and public sector research in three new and promising fields of advanced technology - biotechnology, engineering ceramics, and parallel computing. Differences between these fields suggest that policies to promote

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				public-private research linkage should be more effectively targeted. The study indicates a need for such targeting of industry-PSR linkage both between and within technological fields. The significant factors relate not only to sector characteristics such as firm size, identified previously, but also to the knowledge base of both PSR and companies, and to the character of the technology itself. They suggest that the taxonomy is broadly applicable to other fields of advanced technology.
OECD (2003)	Turning Science into Business. Patenting and Licensing at Public Research Organizations	PRIs	Qualitative study	The OECD survey shows the channels most often used by TTOs to seek licensees are informal relations and networks of researchers. Advertising or technology broker networks are used less frequently. There is no "one size fits all" approach to

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				technology transfer. There are important differences among PRIs that shape TTO structures and affect patenting and licensing strategies. Universities, fundamental research organizations, government labs and contract research organizations play different roles in innovation systems, generate different types of knowledge for different clients and therefore require different IP management processes.
European Commission (2007)	Improving Knowledge Transfer Between Research Institutions and Industry across Europe	European PRIs	Qualitative study	To perform knowledge transfer activities effectively, PRIs need to have sufficient autonomy to recruit experienced knowledge transfer staff on a competitive basis. Increased mobility between the public and private sectors will help research institutions' researchers and managers to identify shared needs with industry.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				However, certain rules and administrative obstacles can discourage such mobility.
Gulbrandsen, and Rasmussen (2008)	Indicators for The Commercialization of Research: What Do They Tell Us? The Case of Norway	PRIs and universities in Norway	Qualitative study	This study shows how the picture of commercialization of public research varies based on the indicators that are used. The successful cases of commercialization may be found outside of the large universities and PRIs. In Norway, a new "results-based" funding system for the higher education institutions has been implemented. Only academic publishing is rewarded with points based on a fairly complex journal rating system. A new indicator for the "third mission" is underway where patenting and other activities are supposed to be the major components.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Evan (2008)	Strategic Patent Licensing for Public Research Organizations: Deploying Restriction and Reservation Clauses to Promote Medical R&D in Developing Countries	PRIs in Developing Countries	Qualitative study	Patenting of basic research and patenting by PRIs raises new issues regarding the conditions of access to the outcome of that research, particularly in developing countries where systems of finance and innovation are immature. When buying technology, instances and threats of restricted access (for example, for genetic testing) to proprietary research tools create the risk of slowing research and raising costs in developing countries (Heller, 1988). This study has shown how patent licensing offers a self-regulatory solution to the potential conflict of interest associated with strong intellectual property protection and the dissemination of publicly funded medical research. However, many

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				inventions do not merit the expense of filing for patent protection. They depend on technology transfer officers utilizing an appropriate mix of licenses and drafting terms that promote pharmaceutical R&D for the greater welfare of under-served patient populations.
OECD (2009)	Enhancing Public Research Performance through Evaluation, Impact Assessment and Priority Setting	PRIs	Qualitative study	An important issue highlighted by several evaluations was that research alone does not necessarily add value. Thinking about how results will be converted into further research advances or innovations must be an important part of the design of PRIs and their programs. Ensuring that industries have the absorptive capacity to utilize research results is also crucial. Some institutes directly engage with firms to demonstrate research results and build capacity for future knowledge transfer.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				Further analysis would be useful in this area. Moreover, although the path to economic impact and effects on innovation is particularly difficult to measure, this issue should not be ignored because of methodological difficulties. One way forward would be to take a longer-term view and include more in-depth analyses in evaluations.
European Commission (2009)	Metrics for Knowledge Transfer from Public Research Organizations in Europe: Report from the European Commission's Expert Group on Knowledge Transfer Metrics	European PRIs	Qualitative study	The purpose of this study is to improve the possibility for individual PRIs and Member States to monitor and compare their achievements in this field against themselves over time and against each other, in order to identify trends and to support work on improvements if needed. There are recommended core performance indicators for the PRIs served by the knowledge transfer offices (KTOs):

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				• Research agreements • Invention disclosures • Patent applications • Patent grants • Licenses executed • License income earned • Spin-offs established
Chandran, (2010)	R&D Commercialization Challenges for Developing Countries: The Case of Malaysia	Public organizations	Literature review	The paper illustrates the attempt of Malaysian government in commercialization and the challenges (barriers of commercialization) they face. The finding suggests for rethinking the role of availability of commercialization funds, government industry and university linkages, internal structure including IP management and institutional effectiveness to enhance the success rate of commercialization.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Sharif and Baark, (2011)	The Transformation of Research Technology Organizations (RTOs) in Asia and Europe	PRIs in Asia and Europe	Literature review	PRIs face the pressures for increased commercialization and internationalization. For Asian economies, the weak institutional frameworks for research and the lack of absorptive capacity of potential users remain endemic in developing and emergent economies. Therefore, PRIs have had to adjust their approaches to these conditions.
Gutierrez, and Correa (2012)	Commercialization of Publicly Funded Research and Development (R&D) in Russia	PRIs in Russia	Qualitative study	Important steps to foster technology commercialization have been taken by reforming the IP legislation through the Civil Code Section IV and Federal Law 217. However, technology transfer can be further encouraged by assigning full ownership to PRIs including transferability rights (with minimum royalty payment to research team). This can be accomplished for all research institutions by amending the

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				mentioned legislation pieces as they apply both to the Russian Academy of Sciences (RAS) affiliated research institutes and higher education institutions.
European Commission (2012)	The Intellectual Property in The Collaboration between Public Research Organizations and Industry	European PRIs	Qualitative study	By establishing better foundations for successful research partnerships and knowledge exchange, it reinforces the value of the PRI within society, thereby enhancing the prospect for continued top-quality research and education. They conclude that one of the most critical point is to find a convenient balance point between the need of a wide diffusion of research results, especially trough scientific publications, and the need of careful protection of confidential information and the adoption of patent strategies for commercial purposes.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
OECD (2013)	Commercializing Public Research: New Trends and Strategies	PRIs and universities	Qualitative study	A key message from this report is that national policies and strategies for the commercialization of public research should be strengthened not only with regard to patenting and licensing efforts but especially towards emerging channels like student entrepreneurship.
Zuniga and Correa (2013)	Technology Transfer from Public Research Organizations: Concepts and Market and Institutional Failures	PRIs	Literature review	Technology transfer depends on contextual factors including adequate financing mechanisms and the presence of a strong IPR regime. Limitations on scientists in PRIs to engage in entrepreneurial endeavors and technology commercialization activities must be addressed. Most importantly, the stock of human capital and the diversity of skills necessary for effective technology transfer must also be enhanced and maintained through the competitive wages and flexible staffing regulations.

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
Lee and Kim (2013)	Promoting Technology Commercialization of Universities and Government-Funded Research Institutes	PRIs	Qualitative study	Key success factors of technology commercialization at foreign universities and PRIs can be explained as follows: - Organizations in charge of technology commercialization are independent and specialized. - A stable funding for technology commercialization is provided by raising its own investment funds. - Education and training as well as incentives are being offered to nurture entrepreneurship.
Basis, et al (2015)	Technology Transfer: An Interdisciplinary Process	PRIs	Qualitative study	This study describes the importance of technology transfer process for PRIs and its necessity to be planned from a research project design. It also presents a comparative analysis of technology transfer process between the Brazilian Agricultural Research Enterprise (Embrapa) and the

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				Agricultural Research Service (ARS). Results demonstrate that both institutions rely on a structured technology transfer process. However, this process is more effective in ARS than at Embrapa. One cause supports the research model used in ARS. It is the reverse linear model (demand pull), which considers market demands in the development of research project.
Cheah and Yu (2016)	Assessing Economic Impact of Research and Innovation Originating from PRIs And Universities	PRIs and universities in Singapore	Quantitative	The results show that firms that incur higher IP licensing fees with universities/PRIs have lower propensity to repeat their IP licensing transactions, thereby reducing academic innovation impact on firms. On the other hand, firms that attain higher levels of Realized Imputed Commercial Value (RICV) with universities/PRIs are found to have higher propensity to repeat their license transactions, indicating an

Author (year)	Title of article/report	Organizational context	Method	Results/Suggestion for further research
				increase in academic innovation impact on firms. With results confirming the hypotheses, they contribute to the literature of impact studies by proposing new secondary RICV indicators to estimate the economic impact of public-funded technological innovation at the firm, industry and national levels.

Source: Compiled by the author

Methods are: literature review, quantitative study and qualitative study

- A literature review surveys books, scholarly articles, and any other sources relating to a particular issue, area of research, or theory. It provides a description, summary, and critical evaluation of these works in relation to the research problem being investigated (Fink, 2014).
- Quantitative study is concerned with numerical measurement and statistics data. It uses mathematical models to test the hypotheses, and the objective reality can be accessed and measured (Saunders et al., 2003).
- Qualitative study is used when the topic is new and it has never been addressed with a certain sample or group of people. Moreover, the existing theories do not apply with the particular sample or group under study (Morse, 19

Appendix 2: Appendix to Chapter 6

Table A2-1: Comparison Effective Case-Studies between ICT and Biotechnology Case-Studies

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
The establishment year of the research project	• VAJA version 1.0 (1998) • VAJA version 2.0 (1999) • VAJA version 3.0 (2001)	• Version 1.0 (2007) • Version 1.1 (2008) • Version 2.0 (2012)	• PDN-01 (2008) • P02 (2010) • P02-INTIMA (2013)	• First project for producing monoclonal antibodies to Acidovorax avenae subsp.	2004	• First project (2007) • Second project (2010) • Third project (2012)

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
	• VAJA version 4.0 (2004) • VAJA version 5.0 (2006) • VAJA version 6.0 (2008) • VAJA version 7.0 (2011)			Citrulli (Aac) (2006) • Second project for developing strip test (2009)		

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
The initial objective	To produce a text-to-speech synthesis that can synthesize a natural sound. The targeted customers are people with disabilities.	To produce first Thai-made prototype of computerized X-ray machine for dental treatment	To conduct research and develop a cost-effective digital hearing aid appropriating for Thai users in rural areas	To focus on monoclonal antibody production and immunoassay development for efficient detection of plant pathogens	To conduct basic research in molecular virology and utilize the infectious DNA clones of dengue viruses for developing	To develop enzyme for increasing digestion capability, making nutrients more accessible than traditional feed formulas.

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
					novel dengue vaccine candidates	
The number of members at the beginning of project	1 member	4 members	3 members	6 members	5 members	4 members
Diversity						

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
• **Team size**	• Version 1 (1 member) • Version 2-3 (3 members) • Version 4-5 (5 members) • Version 6-7 (8 members)	• Version 1 (4 members) • Version 1.1 (8 members) • Version 2 (8 members)	• PDN-01, (3 members) • P02 AND P02 - INTIMA (5 members)	• First project (6 members) • Second project (7 members)	5 members	• First project (4 members) • Second and third project (5 members)

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
• **Functions/ Departments**	• Lfuctions (Version 1) • Hfunctions (Version 2) • Lfunctions (Version 3-7)	Hfunctions	• Lfunctions (PDN-01) • Hfunctions (P02 and P02-INTIMA)	Hfunctions (Cooperation between Monoclonal Antibody Production Laboratory, Microbial Cell Factory	Hfunctions (Cooperation between Medical Biotechnology Research Laboratory, Business Development Division,	Hfunctions (Cooperation between Food Biotechnology Laboratory, Bioprocess Technology Laboratory, Chiang Mai

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
				Laboratory, Kasetsart University and Khon Kaen University, Department of Agriculture, Ministry of	Mahidol University and Chiang Mai University)	University and a company)

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
				Agriculture and Cooperatives		
• **The involvement of TTOs**	Only licensing stage					

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
• **External partners**	Ratchasuda College (Version 2)	SDC Dental Center, Thammasat University Hospital and Faculty of Dentistry, Chiang Mai University	A company and the Rural ENT Foundation of The Royal College of Otolaryngologists-Head and Neck Surgeons of Thailand and	• First project (Khon Kaen University, Kasetsart University) • Second project (adding a member from)	Mahidol University and Chiang Mai University	Ching Mai University and the company

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
			Department of Otorhinolaryngolog, Khon Kaen University.	Department of Agriculture, Ministry of Agriculture and Cooperatives (Thailand)		
• **Educational levels**	• Version 1 (Master degree)	• Version 1.0 (Master degree and doctoral degree)	PDN-01, P02, P02-INTIMA (Master	master degree and doctoral degree	Master degree and doctoral degree	Master degree and doctoral degree

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
	• Version 2-7 (Master degree and doctoral degree)	• Version 1.1 and version 2.0 (Bachelor degree, master degree and doctoral degree)	degree and doctoral degree)			
• **Educational fields**	• Version 1 (Computer Science)	• Version 1.0 (Electrical Engineering, Information/	• PDN-01 (Signal processing systems for medical	Biology, Agricultural Biotechnology,	Pathobiology, Microbiology and	Food Science Technology, Biotechnology and Zoology

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
	• Version 2-3 (Computer Science and Information and Telecommunication Studies) • Version 4-5 (Increasing members from	Image Processing, software development and cone beam computed tomography (CT)) • Version 1.1 and version 2.0 (Increasing	application, Embedded systems and Electrical Engineering) • P02 and P02-INTIMA (Increasing members from	Plant pathology and Microbiology	Medical Technology	

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
	Speech Technology and Assistive Technology for the Deaf) • Version 6-7 (Increasing members from Linguistics	members from Manufacturing Systems Engineering, Materials Selection for Engineering Design, Biomedical	Rehabilitation and Assistive Technology and Electronics hardware)			

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
	Electrical Engineering and Computer Engineering)	Engineering and Mechanical Engineering)				
• **Working experience**	• Version 1 (1-5 years) • Version 2-5 (1-years) • Version 6-7	1-5 years and more than 9 years)	• PDN 01 (1-5 years) • P02 and P02-INTIMA	Over 5-9 years and more than 9 years	Over 5-9 years and more than 9 years	Over 5-9 years and more than 9 years

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
	(1-5 years and over 5-9 years)		(1-5 years and over 5-9 years)			
The year of adopting a CFT	VAJA version 4	DentiiScan version 1.1	At the beginning of development digital hearing aid version P02	At the beginning of the first project, 2006	At the beginning of the first project, 2004	At the beginning of the first project, 2007
Additional member (s)	• A member who had expertise in	A materials technology team	New two members who had expertise in	A member who had expertise in	Chiang Mai university	A representative of the Company

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
	Linguistics and Engineering disciplines		Rehabilitation and Assistive Technology and Electronics hardware	developing strip test	researchers and a Mahidol researcher	
Initiative of project leader or top management	Initiative of the project leader and supporting from NSTDA Presidents	Initiative of the former NSTDA President	Initiative of the project leader	Initiative of the project member	Initiative of the project leader	Initiative of the project leader

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
Major change (s) in the project in terms of objectives, management practices	Synthesizing all Thai words in version 6.0, reading mixed Thai/English and supporting multiple platforms in version 7.0	• Government policy • Certified by ISO 13485 in 2016	• Government policy • Certified by ISO 13485 and CE mark in 2013	Sending the survey to explore the market needs from many Thai seed companies	No changes	No changes

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
Comparison commercialization result before and after adopting a CFT	No license agreements until version 6.0 and version 7.0	No license agreements before adopting a CFT	No license agreements before adopting a CFT	Adopting a CFT at the beginning of the first project	Adopting a CFT at the beginning of the first project	Adopting a CFT at the beginning of the first project
Additional incentive (s)	None					

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
Management practice (top-down, bottom-up, etc.)	Top-down policy	Top-down policy	Bottom-up	Bottom-up	Top-down policy	Bottom-up
Different models of innovation model	Coupling model	Coupling model	Coupling model	Technology-push	Technology-push	Technology-push

	ICT case-studies			Biotechnology case-studies		
Issues	**VAJA software version 7.0**	**DentiiScan version 2.0**	**Digital hearing aid (P02-INTIMA)**	**Strip test for detection of bacterial fruit blotch disease in cucurbit**	**Dengue vaccine candidate**	**Pentosanase production technology for animal feed industry**
Technology Readiness Level (TRL)	TRL 9	Dentiiscan 1.1 (TRL 8) and Dentiiscan 2.0 (TRL 9)	TRL 9	TRL 8	TRL 4	TRL 7
Licensee (s)	Universities, hospitals, SMEs, large company, individual user	Universities and hospitals	SMEs and individual user	SME and a large company	A large company	SME

Source: The author.

Table A2-2: Comparison Effective Case-Studies between Materials Technology and Nanotechnology Case-Studies

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
The establishment year of the research project	• First project (2006) • Second project (2009)	• First project (2004) • Second project (2009)	• First project (2007) • Second project (2010)	• First project (2011) • Second project (2012)	2008
The initial objective	To develop a new method for preservation of	To develop advanced ceramic sandblasting	To develop the hemostatic product for external use	To develop water purification unit by using mobile solar-	To develop nano-emulsion containing mosquito repellant

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
	natural rubber latex using methylol compound giving neutral pH, low corrosive and low toxicity natural rubber latex			operating system (SOS) for helping Thai people in flooding areas	technology by using Thai herbs.
The number of members at the	7 members	4 members	4 members	6 members	6 members

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
beginning of project					
Diversity					
• **Team size**	7 members	• First project (4 members) • Second project (5 members)	5 members	6 members	6 members

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
• **Functions/ Departments**	Hfunctions (Cooperation between Rubber Laboratory, Industrial Technology Development Division, and expected licensees)	Hfunctions (Cooperation between Ceramics Laboratory, Business Development Division, and the expected licensee)	Hfunctions (Cooperation between Medical Device Laboratory, Engineering Division, Research Support Division, Engineering Division, Angthong Hospital and the expected licensee)	Hfunctions (Cooperation between Nano-agriculture and Environment Research Unit, Nanometrology and Characterizations and Engineering Unit and the Thai Red Cross Society	Hfunctions (Cooperation between Nano - delivery System Laboratory, Business Development Division, the Traditional Thai Medicine

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
					Development Center, The Institute of Traditional Thai Medicine, Department for Traditional and Alternative Medicine, Ministry of Public Health,

	Materials technology case-studies			**Nanotechnology case-studies**	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
					Thailand and Department of Manufacturing Pharmacy, Faculty of Pharmacy, Mahidol University
• **The involvement of TTOs**	Only licensing stage				

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
• **External partner(s)**	Two companies (GRASS 2) six companies (GRASS 3)	Testing prototypes with one expected licensee	Testing prototypes with the Department of Surgery, Angthong Hospital in the clinical study and the expected licensee	Testing with the Thai Red Cross Society	Traditional Thai Medicine Development Center, The Institute of Traditional Thai Medicine, Department for Traditional and Alternative

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
					Medicine, Ministry of Public Health, Thailand and Department of Manufacturing Pharmacy, Faculty of Pharmacy, Mahidol University

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
• **Educational levels**	Master degree and doctoral degree	Bachelor degree, master degree and doctoral degree	Master degree and doctoral degree	Master degree and doctoral degree	Master degree and doctoral degree
• **Educational fields**	Organic and Polymeric Materials, Colloid science, Materials Science, Chemistry, Rubber technology and	• First project (Materials Science, Ceramic Technology, Manufacturing technician)	Materials Science and Engineering, Chemistry, Polymer Science, Biology and Engineering	Chemistry, Biology, Materials Science and Electrical Engineering	DNA Delivery filed, Pharmaceutical Science, Biochemistry and Biochemical Engineering.

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
	Polymer Science and Technology	• Second project (Increasing a member educated from Engineering)			
• **Working experience**	Over 5-9 years, more than 9 years	1-5 years and over 5-9 years)	1-5 years and more than 9 years	1-5 years and more than 9 years	1-5 years and over 5-9 years)

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
The year of adopting a CFT	At the beginning of the first project (2006)	At the beginning of the second project (2009)	At the beginning of the first project	At the beginning of the first project	At the beginning of the first project
Additional team member(s)	No additional team members	One member educated from Engineering field and the company	One member educated from Engineering field	No additional team members	No additional team members
Initiative of project leader	Initiative of Deputy Executive Director of MTEC	Initiative of the project leader	Initiative of the project leader	Initiative of Executive Director of NANOTEC	Initiative of the project leader

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
or top management					
Major change (s) in the project in terms of objectives, m anagement practices	• Adjusting objectives to develop Green Recovery Agent for Skim and Sludge (GRASS)	Initiating the second project for transferring technology to the expected licensee	No changes	Changing the specifications of the prototype for the private sector in the second project	No changes

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
	• Changing management practice				
Comparison commercialization result before and after adopting CFT	Adopting a CFT at the beginning of the second project	No license agreements before adopting a CFT	Adopting a CFT at the beginning of the second project	Adopting a CFT at the beginning of the project	Adopting a CFT at the beginning of the project

	Materials technology case-studies			Nanotechnology case-studies	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
Additional incentive (s)	None				
Management practice (top-down, bottom-up, etc.)	Top-down	Bottom-up	Bottom-up	Top-down	Bottom-up
Different models of	Market-pull model	Market-pull model	Technology-push	Technology-push	Technology-push

	Materials technology case-studies			**Nanotechnology case-studies**	
Issues	**Recycled latex inorganic substances from sediment waste (GRASS 3 technology**	**Advanced ceramic sandblasting**	**Hemostatic products for external use**	**Water purification unit by using a mobile solar operating system (SOS)**	**Nanoemulsion containing mosquito repellent technology**
innovation model					
Technology Readiness Level (TRL)	TRL 8	TRL 8	TRL 8	TRL 6	TRL 6
Licensee (s)	SMEs	SME	SME	SMEs	SME and a large company

Source: The author

Table A2-3: Comparison among Non-Effective Case-Studies

	Case study A	**Case study B**	**Case study C**	**Case study D**
Technology	ICT	Biotechnology	Materials Technology	Nanotechnology
The establishment year of the research project	2015	2011	2014	2011
The initial objective	To build a working prototype of a smart sensor to enable farmers monitoring their products in real-time and adjusting input accordingly	To develop an artemisinin test kit in counterfeit drug based on fluorescence technology	To develop electron-beam vulcanized natural rubber latex technology (e-latex) replacing sulfur	To develop the anti-acne pad made from nano-encapsulation of mangosteen extract

	Case study A	Case study B	Case study C	Case study D
Technology	ICT	Biotechnology	Materials Technology	Nanotechnology
The number of members at the beginning of project	9 members	3 members	13 members	4 members
Diversity				
• **Team size**	9 members	3 members	13 members	4 members
• **Functions/ Departments**	Hfunctions (One Laboratory and testing with some greenhouses of farmers)	Lfunctions	Lfunctions	Lfunctions

	Case study A	Case study B	Case study C	Case study D
Technology	ICT	Biotechnology	Materials Technology	Nanotechnology
• **The involvement of TTOs**	Only finding the expected customers			
• **External partners**	Testing with the some greenhouses of farmers	Consulting with the hospital	Consulting with expected companies about the research results	Discussing about the research results with interested companies in NSTDA Investor Day 2012
• **Educational level**	Bachelor degree, master degree and doctoral degree	Master degree and doctoral degree	Master degree and doctoral degree	Bachelor degree, master degree and doctoral degree
• **Educational fields**	Microelectronics, Electrical Engineering, Technology	Clinical Chemistry and Pharmacology, Industrial	Organic and Polymeric Materials, Polymer Science and Technology, Chemistry,	Biotechnology, Biological Engineering and Microbiology

	Case study A	Case study B	Case study C	Case study D
Technology	ICT	Biotechnology	Materials Technology	Nanotechnology
	Management, Electronics and Computer Science, System Engineering, Sensor Technology and Micro-Electro-Mechanical Systems (MEMS)	Chemistry and Organic Chemistry	Polymer Engineering, (Chemical) Engineering, Material Science, Physical and Theoretical Chemistry, Petrochemistry, Rubber Processing and Green Production Technology of Natural Rubber	
• **Working experience**	Over 5-9 years and more than 9 years	1-5 years	1-5 years, over 5-9 years and more than 9 years	Over 5-9 years
The year of adopting a CFT	2015	2011	2014	2011
Additional member (s)	None			

	Case study A	Case study B	Case study C	Case study D
Technology	ICT	Biotechnology	Materials Technology	Nanotechnology
Initiative of project leader or top management	Initiative of the project leader			
Major change (s) in the project in terms of objectives, manage ment practices	None			
Comparison commercialization result before and after adopting a CFT	No license agreements			

	Case study A	Case study B	Case study C	Case study D
Technology	ICT	Biotechnology	Materials Technology	Nanotechnology
Additional incentive (s)	None			
Management practice (top-down, bottom-up, etc.)	Bottom-up			
Different models of innovation model	Coupling model	Technology-push	Technology-push	Technology-push
Technology readiness levels (TRLs)	TRL 6	TRL 4	TRL 4	TRL 6
Licensee (s)	None	None	None	None

Source: The author.

Appendix 3: Questionnaire

Survey Questionnaire for Studying Impacts of Research Team Diversity and Top Management on Research Commercialization of a Public Research Institute in Thailand

---

Section 1: Basic information

1.1 Name:

……………………………………………………………………………………………

1.2 Gender (Please tick (✓) appropriate box)

☐ Male ☐ Female

1.3 What is your highest academic degree? (Please tick (✓) one box only)

☐ Vocational Certificate/High vocational Certificate ☐Bachelor degree

☐ Master degree ☐ Doctoral degree

1.4 Do you have a highest degree in …? (Please tick (✓) one box only)

☐ Biology or other life science ☐ Physics ☐ Chemistry

☐ Engineering ☐ Earth or space science ☐ Biochemistry and Molecular Biology

☐ Materials Science ☐ Computer Science ☐ Biomedical Sciences

☐ Nanotechnology ☐ Others please specify

…………………………………………………..

1.5 Please select your age range (Please tick (✓) one box only)

☐ 25 and under ☐ 26-29 ☐ 30-34 ☐ 35-39

☐ 40-44 ☐ 45-49 ☐ 50-54 ☐ 55 and over

1.6 Please select your position in Organization (Please tick (✓) one box only)

☐ Research Unit Director ☐ Laboratory Head ☐ Senior Researcher
☐ Researcher ☐ Research Assistant ☐ Engineer

☐ Technical staff ☐ Technology Transfer Officer
☐ Others please specify …………………………

1.7 Your experience in your position in licensing technology/product/projects (in years): (Please tick (✓) one box only)

☐ 1-3 years ☐ over 3 years – 5 years ☐ over 5 years – 7 years

☐ Over 7 years – 9 years ☐ Over 9 years

1.8 Number of licensing projects you have been involved between 2011and 2016 (Please tick (✓) one box only)

☐ 1 project ☐ 2-3 projects ☐ 4-5 projects ☐ More than 5 projects

Section 2: **Team Diversity**

2.1 For the head or main researcher, please explain details of team diversity

The name of Technology/Product/Prototype/Project ……………………………………………………………… …………………………………………………………………………………………………… ………………..
Please select your position in the project ☐ Head of project ☐ member of project
The field of research is engaged in: ☐ Information and communications technology (ICT) ☐ Biotechnology ☐ Materials technology ☐ Nanotechnology
Number of companies you have licensed: (Please tick (✓) one box only) ☐ 1 company ☐ 2-3 companies ☐ 4-5 companies ☐ More than 5 companies
The size of companies that licensed from your technology/product/prototype/project ☐ small and medium companies ☐ large companies in your country ☐ Transnational corporations (TNCs)
Does the project aim to have final destination for licensing at the beginning of the project? ☐ Yes ☐ No
Gender Team Size …………………………… ☐ All members are men ☐ All members are women ☐ Team has members both women and men Number of Males in team (in FTE) ……………………………………….. Number of Females in team (in FTE) ………………………………………
Degree of difference in educational level of team members (Please tick (✓) all that apply in each degree and tick (✓) all that apply in each major) ☐ …….. person (s) in Vocational Certificate/High vocational Certificate

The name of Technology/Product/Prototype/Project …………………………………………………………………. …… ………………..
☐ …….. person (s) in Bachelor degree and major in (Please tick (✓) all that apply) ☐ Biology or other life science ☐ Physics ☐ Chemistry ☐ Engineering ☐ Earth or space science ☐ Materials Science ☐ Biochemistry and Molecular Biology ☐ Computer Science ☐ Biomedical Sciences ☐ Nanotechnology ☐ Others please specify …………………………… ☐ …….. person (s) in Master degree and major in (Please tick (✓) all that apply) ☐ Biology or other life science ☐ Physics ☐ Chemistry ☐ Engineering ☐ Earth or space science ☐ Materials Science ☐ Biochemistry and Molecular Biology ☐ Computer Science ☐ Biomedical Sciences ☐ Nanotechnology ☐ Others please specify ………………………… ☐ …….. person (s) in Doctoral degree_and major in (Please tick (✓) all that apply) ☐ Biology or other life science ☐ Physics ☐ Chemistry ☐ Engineering ☐ Earth or space science ☐ Materials Science ☐ Biochemistry and Molecular Biology ☐ Computer Science ☐ Biomedical Sciences ☐ Nanotechnology ☐ Others please specify …………………………

The name of Technology/Product/Prototype/Project …………………………………………………………… ……………………………………………………………………………………………… ………………..
For example: Your team has 4 members. 1. Chief scientist is 49 years old. 2. There are two research scientists. First scientist is 44 years old and second research scientist is 37 years old. And 3) Technical staff is 37 years old. According this example, you can tick (✓) 2 choices. ☑ 35-44 ☑ 45-54 Degree of difference in ages of team members as at project licensing year (Please tick (✓) all that apply) ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55 and over
Degree of difference in experience in each position of team members as at project licensing year (Please tick (✓) all that apply) ☐ 1-3 years ☐ over 3 years – 5 years ☐ over 5 years – 7 years ☐ over 7 years – 9 years ☐ over 9 years
Degree of difference in functional background of team members as at project licensing year (Please tick (✓) all that apply and indicate number of persons in each function) ☐ Research Unit Director …….. person (s)

The name of Technology/Product/Prototype/Project …………………………………………………………………… …… ………………..
☐ Laboratory Head …….. person (s) ☐ Senior Researcher…….. person (s) ☐ Researcher…….. person (s) ☐ Tenure Researcher …….. person (s) ☐ Special Researcher …….. person (s) ☐ Junior Researcher …….. person (s) ☐ Research Assistant…….. person (s) ☐ Visiting/invited Researcher …….. person (s) Nationality ………………… ☐ Postdoctoral Researcher …….. person (s) Nationality ………………… ☐ International/visiting Researcher …….. person (s) Nationality ………………… ☐ Engineer …….. person (s) ☐ Technical Staff/technicians …….. person (s) ☐ Technology Transfer Officer (s) …….. person (s) ☐ Support Staff skilled in collection of information …….. person (s) ☐ Student Trainee …….. person (s) ☐ University researcher (s) …….. person (s) ☐ Researcher from other public research institutes …….. person (s)
Which Laboratory do all members work for? (Please tick (✓) one box only) ☐ Same Laboratory: Please indicate the name of Laboratory ………………………………………….....

The name of Technology/Product/Prototype/Project ………………………………………………………………. ……………………………………………………………………………………………… ………………..
……………………………………………………………..   ☐ Different Laboratories: Please indicate the name of Laboratory ………………………………………..   ……………………………………………………………..   …………………………………………………………….
Do you have external partners (university researchers, related government agencies, etc.)   ☐ Yes   ☐ No
Degree of difference in participation from licensees (Please tick (✓) all that apply)   ☐ Scoping Stage   ☐ Research Stage   ☐ Testing and Validation Stage   ☐ Licensing Stage

2.2 Do you think that team diversity (in functional background, educational level, age, experience and in participation from companies/beneficiaries) facilitate research commercialization?

☐ Yes, team diversity facilitates research commercialization

☐ No, team diversity hinders research commercialization

Section 3: **Institutional factors supporting research commercialization in public research institutes (PRIs)**

Institutional factors mean top management support by executives and incentive in terms of financial incentive and career path incentive.

Top management support means special support by executives. Example: Suggesting that team should have key members from difference fields, using their network help team to contact with key partners, prioritizing budgets for market trials, providing closely advice about market needs, facilitating quickly process involving licensing, etc.

3.1 Did your project have top management support by executives for supporting research team in achieving goal for R&D licensing?

- ☐ Yes
- ☐ No

3.2 Did you have incentive for achieving goal for R&D licensing?

- ☐ Yes, please tick types of incentives
  - ☐ Financial incentive
  - ☐ Career path incentive
- ☐ No

3.3 What other factors do stimulate licensing and research commercialization in your organization?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………

3.4 What phase of the project should incorporate technology transfer officer into the team? (Please tick (✓) one box only)

☐ Research agenda setting/scoping phase ☐ Development phase

☐ Prototype/test phase ☐ Licensing/utilization phase

3.5 What factors do hamper research commercialization in your organization?

………………………………………………………………………………………………

References

Catechu (2016): Innovation Potential of Biotechnology (acatech IMPULSE), Munich: Herbert Utz Verlag.

Akhilesh, K.B. (2014). R&D Management.1; edn, Springer India, New Delhi.

Alexander JA, Lichtenstein R, Jinnett K, Wells R, Zazzali J. Liu D. (2005.) Cross-Functional Team Processes and Patient Functional Improvement. Health Services Research, Volume 40(5), pp.1335–55.doi: 10.1111/j.1475-6773.2005.00418.x.

Allarakhia, M. (2011). Novartis Institutes for Biomedical Research (NIBR). CanBiotech Inc.

Amabile, T. M. (1983). The social psychology of creativity. Journal of Personality and Social Psychology, Volume 45, pp. 357-376.

Amason, A. C. (1996). Distinguishing the effects of functional and dysfunctional conflict on strategic decision making: Resolving a paradox for top management teams. Academy of Management Journal, Volume 39, pp.123–148.

American Chemical Society (ACS) (2018). Materials Science. Retrieved from https://www.acs.org/content/acs/en/careers/college-to-career/chemistry-careers/materials-science.html.

Ancona, D. G., and Caldwell, D.E. (1990). Cross-functional teams: blessing or curse for new problem development. Working Paper, Sloan School of Management, Massachusetts Institute of Technology, July 1990.

Arlinghaus, R. (2014), Are current research evaluation metrics causing a tragedy of the scientific commons and the extinction of university-based fisheries programs? Fisheries, Volume 39, pp. 212–215.

Arredondo. (1996). Successful Diversity Management Initiatives. San Francisco: Berrett-Koehler Publishers.

Ashforth, B.E., Mael, F., (1989). Social identity theory and the organization. Academy of Management Review, Volume 14 (1), pp. 20–39.

Arza, V. and Vazquez, C. (2010). Interactions between public research organizations and industry in Argentina. Science and Public Policy, Volume 37 (7), pp. 499-511.

Athanasaw, Y.A., (2003). Team characteristics and team member knowledge, skills and ability relationships to the effectiveness of CFTs in the public sector. International Journal of Public Administration, Volume 26 (10 & 11), pp. 1167-1205.

Audretsch, D., Aldridge, T. and Oettl, A. (2006). “The Knowledge filter and Economic Growth: The Role of Scientist Entrepreneurship”. Ewing Marion Kauffman Foundation.

AWA (2017). Materials Technology & Nanotechnology. Retrieved from https://www.awa.com/en/our-services/industries/materials-technology-and-nanotech.

Bantel, K. and S. Jackson (1989):'Top management and innovations in banking: Does the composition of the top team make a difference?', Strategic Management Journal, Summer Special Issue, 10, pp. 107-124.

Bassi, N. S. S., Christian Luiz da Silva, Santoyo, A. H. (2015). Technology Transfer: An Interdisciplinary Process, European Scientific Journal /Special/ edition Vol.2.

Bekkers, R., & Bodas Freitas, I. M. (2008). Analyzing knowledge transfer channels between universities and industry: To what degree do sectors also matter?" Research Policy, Volume 37, pp. 1837-1853.

Bell, S.J., Whitwell, G.J. and Lukas, B.A. (2002) 'Schools of thought in organizational learning', Journal of the Academy of Marketing Science, Volume 30 (1), pp.70–86.

Bercovitz, J., Feldman, M., Feller, I. & Burton, R., (2001). Organizational Structure as a Determinant of Academic Patent and Licensing Behavior: An Exploratory Study of Duke, Johns Hopkins, and Pennsylvania State Universities. The Journal of Technology Transfer, Volume 26, pp. 21-35.

Bhamarapravati, N. and Sutee, Y. (2000) Live Attenuated Tetravalent Dengue Vaccine. Vaccine, 18, pp. 44-47.

Bishop, S. K. (1999). Cross-functional project teams in functionally aligned organizations. Project Management Journal, Volume 30(3), pp. 6–12.

Blindenbach-Driessen, Floortje (2015). The(In) Effectiveness of Cross-Functional Innovation Teams. The Moderating Role of Organizational Context. In IEEE Trans. Eng. Manage. Volume 62 (1), pp. 29–38.

Boeker, W. (1997). Strategic change: The influence of managerial characteristics and organizational growth. Academy of Management Journal, Volume 40(1), pp. 152-170.

BOI (Thailand Board of Investment (BOI) (2015). SUBCON THAILAND 2015. Thailand Investment Review, 25, No.6.

Boland T., Fowler A. (2000), A system perspective of performance management in public sector organization, in: "The Internal Journal of Public Sector Management", Volume 13 (5), pp. 417-446.

Bonner, J.M., Ruekert, R.W. and Walker, O.C. (2002). “Upper management control of new product development projects and project performance”, Journal of Product Innovation Management, 19 (3), pp. 233-245.

Bönte, W. (2011). “What do scientists think about commercialization activities”, in D. Audretsch, O. Falk, S. Heblich and A. Lederer (eds), Handbook of Research on Innovation and Entrepreneurship, Cheltenham, UK and Northamton, MA: Edward Elgar, pp. 337-53.

Bowers, C. A., Pharmer, J. A., & Salas, E. (2000). When member homogeneity is needed in work teams: A meta-analysis. Small Group Research, Volume 31(3), pp.305-327.

Branstetter L. and Ogura Y. (2005). Is academic science driving a surge in industrial innovation? Evidence from patent citations. NBER Working Paper Series, No. W11561.

Breznitz, S. M. (2011). Improving or impairing? Following technology transfer changes at the University of Cambridge. Regional Studies 45, pp. 463-478.

Brown, S.L. and Eisenhardt, K.M. (1995). Product development: Past research, present findings, and future directions. Academy of Management Review, Volume 20 (2), pp. 343-378.

Bunduchi, R. (2009). Implementing best practices to support creativity in NPD cross-functional teams. International Journal of Innovation Management, Volume 13(4), pp. 537-554 doi: 10.1142/S1363919609002406.

Burgelman, R.A. (1983). Corporate entrepreneurship and strategic management: Insights from a process study. Management Science, 29: pp.1349-1364.

Byrne, D. E. (1971). The attraction paradigm. New York: Academic Press.

Calantone, R. and Cooper, G. (1981). New product scenarios: Prospects for success, Journal of Marketing, Volume 45, pp. 48-80.

Carpenter, M. A., Geletkanycz, M. A., & Sanders, W. G. (2004). Upper echelons research revisited: Antecedents, elements, and consequences of top management team composition. Journal of Management, Volume 30(6), pp. 749–778.

CFPT: Cross Functional Project Teams (2001), ―MFTM‖ retrieved from thebesemer.com/ currentmarketplace.html. #crossfunctional.html.

Chakraborty, A.K. and O'Keefe, R.D. (1977). A study of key communicators in research and development. Group and Organization Studies, Volume 2, pp. 336-346.

Chandran V.G.R. (2010). R&D commercialization challenges for developing countries: The case of Malaysia. Tech Monitor, Nov-Dec 2010, pp.25-30.

Cheah, L. Y. S. and Yu, C (2016), "Assessing economic impact of research and innovation originating from public research inisitutions and universities - case of Singapore PRIs", Triple Helix, Volume 3 (1), pp.1-36.

Christensen, C. M., Anthony S. D., E. A. Roth. (2004). Seeing what’s next: Using the Theories of Innovation to Predict Industry Change. Harvard Business School Press, Boston Massachussets.

Christensen, C. and Raynor. M. (2003). The Innovator’s Solution. Harvard BusinessSchool Press, Boston, MA.

Ćirić, D., Lalić, B., Gračanin, D. (2016). International Journal of Industrial Engineering and Management (IJIEM), Volume 7 (1), pp. 31-41.

Clark, B. R., (1998). Creating Entrepreneurial Universities: Organizational Pathways of Transformation. Pergamon Press. Oxford.

Cockburn. I. and R. Henderson (2000), Publicly Funded Science and the Productivity of the Pharmaceutical Industry, Volume I, Cambridge, MA: MIT Press.

Cohen, S.G. (1993), ‘New approaches to teams and teamwork’, in J.R. Galbraith, E.E. Lawler III and Associates, Organizing for the future: the new logic for managing complex organizations, San Francisco: Jossey-Bass Publishers, pp.194-226.

Cohen, S. G. and Bailey, D. E. (1997). What makes teams work: Group effectiveness research from the shop floor to the executive suite? Journal of Management, Volume 23, pp. 239-290.

Cohen, W. and Levinthal D. (1990), 'Absorptive capacity: a new perspective on learning and innovation'. Administrative Science Quarterly, Volume 35. pp 128-152.

Cooper, R.G. (1995). Developing new products on time, in time. Research Technology Management. Volume 38(5), pp. 49–57.

Cooper, R.G. (1979). The dimensions of industrial new product success and failure. Journal of Marketing, 43: 93-103.

Cooper, R.G. and Kleinschmidt, E.J., (1995). Benchmarking for firm's critical success factors in new product development. Journal of Product Innovation Management, Volume 12, pp. 374–391.

Cooper, R.G., Edgett S. J., Kleinschmidt E. J. (2004). "Benchmarking Best NPD practices—II." Research-Technology Management 47 (3), 50–59.

Cortese, A. (2007). Samsung profile. Samsung in coordination with Cheil Communications Inc. and IC Group, Samsung Moonwha Printing Co., Seoul, Korea.

Costa Póvoa, L.M., Rapini, M.S. (2010). Technology transfer from universities and public research institutes to firms in Brazil: what is transferred and how the transfer is carried out. Science and Public Policy, 37(2), pp. 147-159(13).

Cox, T., & Blake, S. (1991). Managing cultural diversity: Implications for organizational competitiveness. Academy of Management Executive, Volume 5(3), pp. 45-56.

Craig B., Richard M., Grant E., and Darren M. (2013). Success factors to a nanotech-enabled whole product, in Nanotechnology Commercialization edited by Takuya Tsuzuki, Pan Stanford Publishing Pvt. Ltd. p. 171.

Crossland C. and Hambrick D.C. (2011). Differences in managerial discretion across countries: How nation-level institutions affect the degree tonnwhich CEOs matter. Strategic Management Journal. 32: pp.797-819.

Creswell, J. W. (1994). Research Design Qualitative and Quantitative Approaches. Thousand Oaks. CA Sage.

Creswell, J. W. (2003). Research design: Qualitative, Quantitative and Mixed Methods Approaches (2nd Ed.).Thousand Oaks, CA: SAGE Publications.

Creswell, J. W. (2014). Research Design Qualitative, Quantitative and Mixed Methods Approaches (4th Ed.). Thousand Oaks, CA Sage.

Currie, G., A. Lockett, R. Finn, G. Martin, and J. Waring. 2012. “Institutional Work to Maintain Professional Power: Recreating the Model of Medical Professionalism.” Organization Studies 33 (7): pp. 937–962. Doi: 10.1177/0170840612445116

Dahlin, K. & Weingart, L. R. (1996). "Absorptive Capacity-A Link between Group Diversity and Group Performance," Paper presented at the Annual Meeting of the Academy of Management, Cincinnati.

Davies, A. (1996). Innovation in Large Technical Systems: The Case of Telecommunications,” Ind. Corporate Change, Volume 5 (4), pp. 1143–1180.

De Poel, F. M., Stoker, J. I., & Van der Zee, K. I. (2014). Leadership and organizational tenure diversity as determinants of project team effectiveness. Group & Organization Management, Volume 39(5), pp. 532-560.

De Smith M J (2015). STATSREF: Statistical Analysis Handbook - a web-based statistics resource.

Decter, M., Bennett, D. & Leseure, M. (2007). University to business technology transfer and USA comparisons. Technovalion, Volume 27(3), pp.145-155.

Denison, D. R.; Hart, S. L.; and Kahn, J. A. (1996) "From chimneys to cross-functional teams: Developing and validating a diagnostic model" Academy of Management Journal, Volume 39 (4), pp. 1005-1023.

Dereti, R. (2009). Transferência e validação de tecnologias agropecuárias a partir de instituições de pesquisa. Desenvolvimentoe Meio Ambiente, n. 19, pp. 29-40.

Dongfeng, S. (2013). Research on diversity, conflicts and performance in creative team management. African Journal of Business Management, Volume 7(39), pp. 4139-4148.

Dougherty, D. 1992. Interpretive barriers to successful product innovation in large firms. Organization Science, Volume 3 (2), pp. 179–202.

Dumitrescu, L., Stanciu, O., Tichindelean, M., & Vinerean, S. (2011). Pursuing a customer–driven approach for innovation and marketing excellence. Studies in Business and Economics, 16(2), pp. 19–26.

Dutrenit, G. De Fuentes, C. and Torres, A. (2010). Channels of interaction between public research organizations and industry and their benefits: Evidence from Mexico. Science and Public Policy, Volume 37 (7), pp. 513-526.

Dutton, J., & Duncan, R. (1987). The creation of momentum for change through the processes of strategic issue diagnosis. Strategic Management Journal, 8, pp. 279-296.

Dweck, C (2016). What Having a “Growth Mindset” Actually Means. Harvard Business Review, January, Harvard Business School Publishing, USA.

Eisenhardt, K. M., Kahwajy, J. L., & Bourgeois III, L. J. (1997). How management teams can have a good fight. Harvard Business Review, Volume 75, pp. 77-85.

Ely, R. J. (2004). A field of group diversity, participation in diversity education programs, and performance. Journal of Organizational Behavior, Volume 25, pp. 755–780.

Ersun, A. N., & Karabulut, A. T. (2013). Innovation management and marketing in global enterprises. International Journal of Business and Management, 8(20), pp. 76-86.

Etzkowitz, H., 1998. The norms of entrepreneurial science: Cognitive effects of the new university-industry linkages. Research Policy, Volume 27, pp. 823-833.

European Commission (2007). Improving knowledge transfer between research institutions and industry across Europe, Luxembourg: Office for Official Publications of the European Communities.

European Commission (2009). Metrics for Knowledge Transfer from Public Research Organizations in Europe: Report from the European Commission’s Expert Group on Knowledge Transfer Metrics, Luxembourg: Office for Official Publications of the European Communities.

European Commission (2012). The Intellectual Property in the collaboration between Public Research Organizations and industry, Biochem-project, Competitiveness Innovation Framework programme 2007-2013.

Evans, G. (2008). Strategic Patent Licensing for Public Research Organizations: Deploying Restriction and Reservation Clausesto Promote Medical Research [online]. American Journal of Law & Medicine, Volume 34(2), pp.175–223. Available from: http://www.wolfpublishers.com/harnessingipr/Reference%20list%20Part%20III.pdf .

Farrell, C., and J. Morris. 2003. "The 'Neo-Bureaucratic' State: Professionals, Managers and Professional Managers in Schools, General Practices and Social Work." Organization 10 (1): pp. 129–156. Doi: 10.1177/1350508403010001380.

Faulkner, W. and Senker, J. (1995) Knowledge Frontiers: Public Sector Research and Industrial Innovation in Biotechnology, Engineering Ceramics and Parallel Computing. Oxford: Clarendon Press.

Fay, D., Borrill, C., Amir, Z., Haward, R. and West, M. A. (2006). "Getting the most out of multidisciplinary teams: a multi-sample study of team innovation in health care." Journal of Occupational and Organizational Psychology, Volume 79, pp. 553-567.

Fay, D and Guillaume, YRF (2007). 'Team diversity'. In SR Clegg & J Bailey (Eds), International encyclopedia of organization studies. Sage, Thousand Oaks, CA (US), pp. 1510-1513.

Feng, B., Jiang, Z.-Z., Fan, Z.-P., and Fu, N. (2010). A method for member selection of cross-functional teams using the individual and collaborative performances. European Journal of Operational Research, 203(3), 652–661. DOI:10.1016/j.ejor.2009.08.017.

Fine, M.G. (1995) Building successful multicultural organizations. Quorum Books: Westport, CT.

Fink, A. (2014). Conducting Research Literature Reviews: From the Internet to Paper. Fourth edition. Thousand Oaks, CA: SAGE.

Finkelstein, S. and D. C. Hambrick (1996) Strategic Leadership: Top Executives and their Effects on Organizations. West, St. Paul, MN.

Floyd, S.W., & Wooldridge, B. 1997. Middle management's strategic influence and organizational performance. Journal of Management Studies, 34: pp. 465-485.

Friedman, Y. (2009). Biotechnology commercialization: Getting past the technology-push. Journal of Commercial Biotechnology, 15, 1 – 2.

Galbraith, J.R. (1977), Organization Design, Addison-Wesley, Reading, MA.

Gallup Organization (2009), Innobarometer 2009, European Commission, Brussels.

Gardenschwartz, L., & Rowe, A. (1993). Managing diversity: A complete desk reference & planning guide. Irwin Press: New York.

Gaunya, C. R. (2015). Effect of workforce diversity management on employee performance in the Public Sector in Kenya. Journal of Resources Development and Management, 13, pp. 9-15.

Gemser G., Leenders M.A.A.M. (2011). Managing Cross-Functional Cooperation for New Product Development Success, Long Range Planning, Volume 44 (1), pp. 26-41.

Ghorbani H. & Azamni A. (2014), “An Exploration of Effective Factors in New Product Development (NPD) Project Success”, International Journal of Academic Research in Business and Social Sciences, Volume 4 (3), pp. 409-419.

Gouanlong, N. I. and Tsapi, V. (2012). The procedures for strategic management of new products for small, medium and large firms in Cameroon: An exploratory study. African Journal of Marketing Management, Volume 4(4), pp. 118-129.

GovLeaders (2014). Management Challenges: Government vs. Private Sector. Retrieved from http://govleaders.org/matrix.htm.

Griffin, A. (1997). "PDMA Research on New Product Development Practices: Updating trends and Benchmarking Best Practices." Journal of Product Innovation Management, Volume 14: pp. 429-458.

Gross C.M. (2009). Technology transfer: opportunities and outlook in a challenging economy. The Journal of Technology Transfer, Volume 34(1), pp. 118-120.

Gruenfeld, D.H, Mannix, E.A., Williams, K.Y., & Neale, M.A. (1996). Group composition and decision making: How member familiarity and information distribution affect process and performance. Organizational Behavior and Human Decision Processes, 67, pp. 1–15.

Guinet, J. (2010). “The Changing Role of Role of Government Research Institutes in Innovation Systems”, STI Policy Review, Inaugural issue, STEPI, Seoul.

Gulbrandsen, M. and Rasmussen, E. (2008). "Indicators for the commercialization of research: What do they tell us? The case of Norway." Paper, PRIME Indicators Conference, Oslo.

Gulledge, T.R. and Sommer, R.A. (2003). Business process management: public sector implications. Business Process Management Journal, Volume 8 (4), pp. 364-376.

Gutierrez, J. J., & Correa, P. (2012). Commercialization of Publicly funded Research and Development in Russia. Policy Research Working Paper, 6263.

Guzzo, R. A., & Dickson, M. W. (1996). Teams in organizations: Recent research on performance and effectiveness. Annual Review of Psychology, Volume 47, pp. 307-338.

Hackings, A.J. (1986). Economic Aspects of Biotechnology. Cambridge Studies in Biotechnology 3. Cambridge, U.K.: Cambridge University Press.

Hacklin, F., Marxt, C., and Fahrni, F. (2009). "Coevolutionary Cycles of Convergence: An Extrapolation from the ICT Industry," Technol. Forecasting Soc. Change, Volume 76 (6), pp. 723–736.

Halligan, M. G. (1997). Integrated product team pricing. Contract Management, Volume 37: pp. 14–17.

Halvorsen, T., Hauknes, J., Miles, I and Røste, R. (2004). Innovation in the public sector: On the differences between public and private sector innovation. Publin Report No. D9.

Hambrick, D.C. and Mason, P.A. (1984) Upper Echelons: The Organization as a Reflection of Its Top Managers. Academy of Management Review, 9, pp.193-206.

Hambrick, D. C., Cho, T. S., & Chen, M. (1996). The influence of top management team heterogeneity on firms' competitive moves. Administrative Science Quarterly, Volume 41, pp. 659-684.

Harman, R.A., Golhar, D.Y. and Deshpande, S.P. (2002). Lessons learnt in work teams. Production, Planning and Control. Volume 13 (1), pp. 362-369.

Harrison, D. A., Price, K. H., Gavin, J. H., & Florey, A. T. (2002). Time, teams, and task performance: Changing effects of surface- and deep level diversity on group functioning. Academy of Management Journal, Volume 45, pp. 1029 –1045.

Heller, M.A. (1998). The tragedy of the anticommons: property in the transition from Marx to markets. Harvard Law Review, Volume 111, pp. 621–88.

Henke, J. W., Krachenberg, A. R., and Lyons, T. F. (1993). Perspective - Cross-Functional Teams - Good Concept, Poor Implementation. Journal of Product Innovation Management, Volume 10(3), pp. 216-229. DOI: 10.1016/0737-6782(93)90027-N.

Hitt, M.A., Nixon, R.D., Hoskisson, R.E. and Kochhar, R. (1999) Corporate Entrepreneurship and Cross-Functional Fertilization: Activation, Process and Disintegration of a New Product Design Team. Entrepreneurship - Theory and Practice 145-167.

Holland, J. L. (1973). Making vocational choices: A theory of vocational personalities and work environments. Englewood Cliffs, NJ: Prentice-Hall.

Holland, S., Gaston K. and Gomes J. (2000). Critical success factors for cross-functional teamwork in new product development, International Journal of Management Reviews, Volume 2 (3), pp.231-259.

Horwitz, S. K. (2005). The compositional impact of team diversity on performance: Theoretical considerations. Human Resource Development Review, Volume 4(2), pp. 219-245.

Hsu, J.P. and Yeo, K.T. (1996). A Systemic Approach to Re-engineer a Public Research Institute (PRI) for Commercialization. International Journal of Project Management, Volume 14(6), pp. 387–93.

Hull, F. M. (2003). "Simultaneous involvement in service product development: a strategic contingency approach." International Journal of Innovation Management, Volume 7 (3), pp. 339-370.

Inaba, T. and M. Squicciarini (2017), "ICT: A new taxonomy based on the international patent classification", OECD Science, Technology and Industry Working Papers, 2017/01, OECD Publishing, Paris.

Intarakumnerd, P., Chairatana, P., and Tangchitpibo on, T. (2002). National innovation systems in less successful developing countries: the case of Thailand. Research Policy 31: 1445-1457.

Intarakumnerd, P. and Chairatana, P. (2008), 'Shifting S&T Policy Paradigm. An Experience of an RTO in Thailand,' International Journal of Technology and Globalization, Volume 4 (2), pp. 121-138.

Intarakumnerd, P and Goto, A. (2016). ‘Role of Public Research Institutes in National Innovation Systems in Industrialized Countries: The cases of Fraunhofer, NIST, CSIRO, AIST, and ITRI’ RIETI Discussion Paper Series 16-E-041, Research Institute of Economy, Trade and Industry. http://www.rieti.go.jp/jp/publications/dp/16e041.pdf.

Israsena P., Isaradisaikul S., Noymai A., Boonyanukul S., Hemakom A., Chinnarat C., Navacharoen N., Lekagul S. (2013). Developing an appropriate digital hearing aid for low-resource countries: A case study. The Scientific World Journal, Volume 2013, Article ID 549486, 8 pages.

Ittner, C. D., Larcker, D. F. (1997). The performance effects of process management techniques. Management Science, Volume 43, pp.522–534.

Jaccard, J. (2001). Interaction effects in logistic regression (Sage University Papers Series on Quantitative Applications). Social Sciences, series no. 07-135). Thousand Oaks, CA: Sage.

Jackson, S. E. (1992). Team composition in organizational settings: Issues in managing an increasingly diverse workforce. In S. Worchel, W. Wood, & J. A. Simpson (Eds.), Group processes and productivity (pp.136–180). Newbury Park, CA: Sage.

Jackson, S. E., May, K. E., & Whitney, K. (1995). Understanding the dynamics of diversity in decision-making teams. In R. A. Guzzo & E. Salas (Eds), Team Effectiveness and Decision Making in Organizations (pp. 204-261). San Francisco: Josser-Bass.

Jacobs, L. & Herbig, P. (1998). Japanese Product Development Strategies. Journal of Business and Industrial Marketing, Volume 13(2), pp. 132–154.

Jaffe, A. (1989), 'Real effects of academic research', American Economic Review, Volume 79 (5). pp. 957-70.

Jain, R.K.; Triandis, H.C. (1997). Management of research and development organizations: managing the unmanageable. John Wiley & Sons, New York.

Janvikul, W., Thavornyutikarn, B., Kosorn, W. and Surattanawanich, P. (2013). Clinical study of chitosan-derivative-based hemostat in the treatment of split-thickness donor sites, Maejo International Journal of Science and Technology, 7(03), pp. 385-395.

Jehn, K. A. (1995). A multimethod examination of the benefits and detriments of intragroup conflict. Administrative Science Quarterly, Volume 40, pp. 256-282.

Jehn, K. A., Chadwick, C., & Thatcher, S. (1997). To agree or not to agree: diversity, conflict, and group outcomes. International Journal of Conflict Management, Volume 8, pp. 287-306.

Jehn, K. A., Northcraft, G. B., & Neale, M. A. (1999). Why differences make a difference: A field study of diversity, conflict, and performance in workgroups. Administrative Science Quarterly, Volume 44, pp. 741–763.

Jick, T.D (1979). Mixing qualitative and quantitative methods: triangulation in action. Admin Sci Q Volume 24(4), pp. 602–611.

Johnson, R. B. & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. Educational Researcher, Volume 33(7), pp.14-26.

Joshi, A., & Roh, H. (2009). The role of context in work team diversity research: A meta-analytic review. Academy of Management Journal, Volume 52(3), pp. 599-627.

Ju, B. (2012). An Evaluation of Critical Factors Influencing Product Innovation in the Food Industry—— A Case Study of China Mengniu Dairy Company. International Journal of Business and Management, Vol. 7, 3, pp. 104-110.

Kamei, Shin-ichi and Kobayashi, T (2012). Strategy for new industry creation in the nanotechnology field In TECH MONITOR, Oct-Dec 2012, pp. 34-39.

Kamil, M.H. (2007). "Technology Commercialization In Malaysian Public Universities And. Research Institutions" Dissertation in Institute of Research; Development and Commercialization (IRDC).

Kahn, K.B., 2001, Market orientation, interdepartmental integration and product development performance. Journal of Product Innovation Management, Volume 18, pp. 314-323.

Kandemir, X.U., Neeley, S.M. and Zhao, Y. (2006), “Managing R&D-marketing integration in the new product development process”, Industrial Marketing Management, Volume 24, pp. 540-533.

Kanter, R.M. (1988), “When a thousand flowers bloom: structural, collective, and social conditions for innovation in organizations”, in Staw, B.M. and Cummings, L.L. (Eds), Research in Organizational Behavior, Vol. 10, JAI Press, Greenwich, CT, pp. 97-102.

Katz, R. (1982). The effects of group longevity on project communication and performance. Administrative Science Quarterly, Volume 27, pp, 81-104.

Katz, R. (2003). The human side of managing technological innovation (2nd Ed.). New York: Oxford University Press.

Katz, R. and Tushman, M.R. (1979). Communication patterns, project performance, and task characteristics: An empirical evaluation and integration in an R&D setting. Organizational Behavior and Human Performance, Volume 23, pp. 139-162.

Katzenbach, J., & Smith, D. (1993). The wisdom of teams. New York: Harper Business.

Keller, R. T. (2001). "Cross-Functional Project Groups in Research and New Product Development,
Diversity, Communications, Job Stress, and Outcomes." Academy of Management Journal, Volume 44(3), pp. 547-555.

Kickul, J., & Gundry, L. K. (2001). Breaking through boundaries for organizational innovation: New managerial roles and practices in e-commerce firms. Journal of Management, Volume 27, pp. 347–361.

Kim, L. (1998). Crisis construction and organizational learning: Capability building in catching-up at Hyundai Motor. Organization Science, 9, 506-521.

Kim, P.R. (2013). Characteristics of ICT - Based Converging Technologies. ETRI Journal, Volume 35 (6), pp. 1134-1143.

Kim, B. Y., & Kang, B. K. (2008). Cross-functional cooperation with design teams in new product development. International Journal of Design, Volume 2(3), pp. 43-54.

Kim J. and Marschke G.R. (2005). The Influence of University Research on Industrial Innovation. NBER Working Paper Series. Working Paper 11447.

Knight, D., Pearce, C. L., Smith, K. G., Olian, J. D., Sims, H. P., Smith, K . A., & Flood, P. (1999). Top management team diversity, group process, and strategic consensus. Strategic Management Journal, Volume 20, pp. 445-465.

Kratzer, J., Leenders, T.A.J. and van Engelen, J.M.L. (2004), "Stimulating the potential: creative performance and communication in innovation teams", Creativity and Innovation Management, Vol. 13 No. 1, pp. 63-71.

Krimsky, S. and R. Wrubel (1996). Agricultural Biotechnology and the Environment: Science, Policy and Social Issues. Urbana, Illinois: University of Illinois Press.

Lach, S. and Schankerman, M., (2008). Incentives and invention in universities. RAND Journal of Economics 39(2), pp. 403-433.

Lam, A. (2010). What motivates academic scientists to engage in research commercialization: 'gold', 'ribbon' or 'puzzle'? Research Policy, 40(10), pp. 1354–1368.

Lazzeri, F and Pisano, G. P. (2014). The Organizational and Geographic Drivers of Absorptive Capacity: An Empirical Analysis of Pharmaceutical R&D Laboratories. Working Paper 14-098, Harvard Business School, Boston.

Lee, S. and Teece, D. (2013). 'The functions of middle and top managers in the dynamic capabilities framework'. Kindai Management Review, 1, pp. 28-40.

Lee, Y. J. and Kim, S. U. (2013). Promoting Technology Commercialization of Universities and Government-funded Research Institutes, STEPI Insight, Volume 123.

Leedy, P. & Ormrod, J. (2001). Practical research: Planning and design (7th Ed.). Upper Saddle River, NJ: Merrill Prentice Hall. Thousand Oaks: SAGE Publications.

Leenders, Mark A. A. M., and Wierenga, B. (2002). The effectiveness of different mechanisms for integration marketing and R&D. Journal of Product Innovation Management, Volume 19 (4): pp. 305–317.

Lewin, P. M. E. (2014). Technology Transfer: The Case of Nanotechnology. The European Inter-University Association on Society, Science and Technology, Oslo, Norway.

Link, A. N. & Scott, J. T. (2005). Opening the ivory tower's door: An analysis of the determinants of the formation of U.S. university spin-off companies. Research Policy, Volume34, pp. 1106-1112.

Loden, M., Rosener, J.B. (1991). Workforce America! Managing Employee Diversity as a Vital Resource. Business One Irwin: Homewood, IL.

Love, J. H. et al. (2006), "Organizing Innovation: Complementarities between Cross-Functional Teams," DRUID Working Paper No. 06-27, ISBN 87-7873-219-0.

Macintosh, R. (2003). BPR: alive and well in the public sector. International Journal of Operations & Production Management, Volume 23 (3), pp. 327-344.

Maidique, M.A. and Zirger, B.J. (1984). A study of success and failure in product innovation. IEEE Transactions on Engineering Management, Volume 31 (4), pp. 192-203.

Malsch, I. (2008). Small is beautiful? Nanotechnology solutions for development problems. Retrieved from https://www.nanowerk.com/spotlight/spotid=4618.php

Maltz, E., and Kohli, A. K. (2000). Reducing Marketing's Conflict with Other Functions: The Differential Effects of Integrating Mechanisms. Journal of Academy of Marketing Science, Volume 28(4), pp. 479-92. 10.1177/009207030028400.

Mansfield, E. (1995). 'Academic research underlying industrial innovation', Review of Economics and Statistics, Volume 77, pp. 55-65.

Mcdam, R. and Donaghy, J., (1999). Business process re-engineering in the public sector. Business Process Management Journal, Volume 5 (1), pp. 33-49.

McDonough, E. F. (2000). Investigation of factors contributing to the success of cross-functional
teams. Journal of Product Innovation Management, Volume 17(3). pp. 221-235.

Mehta, S.S. (2008). Commercializing Successful Biomedical Technologies: Basic Principles for the Development of Drugs, Diagnostics and Devices. Cambridge: Cambridge University Press.

Mendibil, K. and Macbryde, J., (2005). Designing effective team-based performance measurement systems: an integrated approach. Production, Planning and Control, Volume 16 (2), pp. 208-225.

Michel, J.G., Hambrick, D.C. (1992). Diversification posture and top management team characteristics. Acad. Manag. J. Volume 35(1), pp. 9–37.

Miller, D., Kets de Vries, M. F. R., & Toulouse, J. M. (1982). Top executive locus of control and its relationship to strategy-making, structure and environment. Academy of Management Journal, Volume 25, pp. 237–253.

Milliken, F., & Martins, L. (1996). Searching for common threads: Understanding the multiple effects of diversity in organizational groups. Academy of Management Review, Volume 21, pp. 402– 433.

Ministry of Education, Culture, Sports, Science and Technology (MEXT) (2013). International Policy Dialogue 2012: Ecosystems for Regional Innovation in Asia. The Takeda Foundation.

Miyazaki, K.; Islam, N. (2007). Nanotechnology systems of innovation – An analysis of industry and academia research activities. Technovation, Volume 27, pp. 661-671.

Moon, K. K. (2016). Examining the relationships between diversity and work behaviors in US federal agencies: Does inclusive management make a difference? Review of Public Personnel Administration: 0734371X16660157.

Morse, J. M. (1991), Approaches to qualitative-quantitative methodological triangulation. Nursing Research, Volume 40, no 1, 48-76.

Nakata, C. and Im, S., 2010, Spurring cross-functional integration for higher new product performance. Journal of Product Innovation Management, Volume 27, pp. 554-571.

Nandagopal, M., Kaushik, G., & Premnath, V. (2011). "Improving technology commercialization at research institutes: practical insights from NCL Innovations". Paper presented at Innovation Educators' Conference (IEC), Indian School of Business, Hyderabad.

Nano4life (2018). Very important notice for consumer awareness over fake nanotechnology products. Retrieved from https://www.nano4life.co/fakeproducts.

Nasta, L. (2016). Team dynamics and technology impact on creative and cultural industries. PHD in management XXVIII Cycle.

National Materials Advisory Board (1993). Commercialization of New Materials for a Global Economy. National Academy Press. USA.

National Science and Technology Development Agency (NSTDA), (2011). Chimeric Dengue Vaccine Licensing Agreement, Press release.

National Science and Technology Development Agency (NSTDA) (2012). Towards Sustainability: 20 years of NSTDA: 1991-2011. Pathum Thani.

National Science and Technology Development Agency (NSTDA) (2013a). BIOTEC-NSTDA and Eco Scientific join hands to bring portable dissolved oxygen test kit to market. Press release.

National Science and Technology Development Agency (NSTDA) (2013b). Annual report 2012: National Metal and Materials Technology Center. Pathum Thani.

National Science and Technology Development Agency (NSTDA) (2014). NSTDA outcome and economic impact assessment guideline. Pathum Thani.

National Science and Technology Development Agency (NSTDA) (2016). Biotechnology & Innovation: Foundation for the Success of Food & Feed Industries. S.R. Printing Massproduct CO., LTD. Nonthaburi.

National Science and Technology Development Agency (NSTDA) (2017). 25 years of NSTDA. Pathum Thani.

Nature (2016). A matter of scale. Nature Nanotechnology, Volume 11. https://doi.org/10.1038/nnano.2016.180.

NCSS (2007). NCSS Statistical System. East Kaysville, Utah, USA.

Norsiah Bt. Mat: Cross-functional New Product Development (NPD) Teams: Characteristics, Dynamics and NPD Performance, 2008, Univeristi Sains Malaysia, Malaysia.

Northcraft, G. B., Polzer, J. T., Neal, M. A., & Kramer, R. M. (1995). Diversity, social identity, and performance: Emergent social dynamics in cross-functional teams. In: S. E. Jackson & M. N. Ruderman (Eds), Diversity in work teams: Research paradigms for a changing workplace (pp. 69–79). Washington, DC: American Psychological Association.

Nwizege1, K. S. and Chukwunons, F. (2011). The Impact of ICT on Computer Application. UKSim 5th European Symposium on Computer Modeling and Simulation.

O'Connell, D., Farine, D., O'Connor, M. and Dunlop, M. (2013). Integration and Implementation Research: Would CSIRO contribute to, and benefit from, a more formalised I2S approach? In Bammer, G. Disciplining Interdisciplinarity: Integration and Implementation Sciences for Researching Complex Real-World Problems, ANUE Press, The Australian National University, Canberra, Australia.

OECD (2003) Turning Science into Business. Patenting and Licensing at Public Research Organizations, OECD, and Paris.

OECD (2004) Patents and Innovation: Trends and Policy Challenges, OECD, Paris.

OECD (2009). Enhancing Public Research Performance through Evaluation, Impact Assessment and Priority Setting, OECD, Paris.

OECD (2013). Commercializing Public Research: New Trends and Strategies, OECD, Paris.

OECD (2016). OECD Science, Technology and Innovation Outlook 2016, OECD Publishing, Paris.

O'shea, R. P., Allen, T. J., Chevalier, A. & Roche, F. (2005). Entrepreneurial orientation, technology transfer and spinoff performance of U.S. universities. Research Policy, Volume 34, pp. 994-1009.

Ojasalo J (2003) Using market information in generating and selecting ideas in new product development – results from an empirical study on innovations management in the software business. Bus Rev Volume 1(1), pp. 71–76.

Olechowski, Alison; Eppinger, Steven D. and Joglekar, Nitin. "Technology Readiness Levels at 40: A Study of State-of-the-Art Use, Challenges, and Opportunities." 2015 Portland International Conference on Management of Engineering and Technology (PICMET), August 2-6 2015, Institute of Electrical and Electronics Engineers (IEEE).

Oliveira, E A., Pimenta, M L., Hilletofth, P. (2015). Characterizing Cross-Functional Teams in Service Companies: A Case Study from Telecom Industri. In: Valerij Dermol (ed.), Managing Intellectual Capital and Innovation for Sustainable and Inclusive Society: Proceedings of the MakeLearn and TIIM Joint International Conference, pp. 2139-2148.

Omninano (2016). What is the difference between BioTechnology and NanoTechnology? Retrieved from http://omninano.slides.com/omninano/nanotech-biotech#/

O'Reilly, C. A., Williams, K., & Barsade, S. (1997). Group demography and innovation: does diversity help? In E. Mannix, & M. Neale (Eds.), Research in the management of groups and teams (Vol. 1, pp. 183–207). Greenwich, CT: JAI Press.

Owen-Smith, J., Powell, W. (2001). To patent or not: faculty decisions and institutional success at technology transfer. Journal of Technology Transfer 26(1-2), pp. 99-114.

Pagell, M. (2004). Understanding the factors that enable and inhibit the integration of operations, purchasing and logistics. Journal of Operations Management, Volume 22, pp. 459–487. DOI:10.1016/j.jom.2004.05.008.

Parker, G.M. (2003), Cross-functional teams, Cross- Functional Teams: Working with Allies, Enemies, and Other Strangers, Wiley Publishers.

Parry, M.E., Ferrin, P.F., Gonzalez, J.A.V. and Song, M. (2010), Cross-functional integration in Spanish firms. Journal of Product Innovation Management, Volume 27, pp. 606-615.

Pavitt, K., (1998). "The social shaping of the national science base," Research Policy, Volume 27 (8), pp.793-806.

Pelled, L. H. (1996). Demographic diversity, conflict, and work group outcomes: An intervening process theory. Organizational Science, Volume 7, pp. 615-631.

Pelled, L. H., Eisenhardt, K. M., & Xin, K. R. (1999). Exploring the black box: An analysis of work group diversity, conflict, and performance. Administrative Science Quarterly, Volume 44(1), pp. 1-28.

Piercy, N., Phillips, W. and Lewis, M. (2012). Change management in the public sector: The use of cross-functional teams. Production, Planning and Control. pp. 1-12.

Pinto, M. B., Pinto, J. K., & Prescott, J. E. (1993). Antecedents and consequences of project team cross-functional cooperation. Management Science, Volume 39(10), pp. 1281–1296.

Pitts, D.W. (2005). Diversity, Representation, and Performance: Evidence about Race and Ethnicity in Public Organizations. Journal of Public Administration Research and Theory, Volume15 (4), pp.615-631.

Poling, T., Woehr, D.J., Arciniega, L.M., & Gorman A. (2006). The impact of personality and value diversity on team performance. Report of Annual Meeting for the Society for Industrial and Organizational Psychology, Dallas, TX.

Rahmat, Bt.N. (2013). A Case Study of Cross-Functional Teamwork Factors in Determining New Product Performance in Mitsubishi Electric (Malaysia) Sendirian Berhad, UNIVERSITI TEKNIKAL MALAYSIA MELAKA.

Rapini, M. S., M., Da Motta e Albuquerque, E., Silva, L. A., Goncalvez, S., Morais, H. and Silva da Cruz, W. M. (2006). Spots of Interaction: An investigation on the relationship between firms and universities in Minas Gerais, Brazil. Discussion Paper (Texto para discussao) No. 286. Belo Horizonte: UFMG/Cedeplar.

Rauniar, R. and Rawski, G. (2011). Organizational Structuring and Project Team Structuring in Integrated Product Development Project. POMS 22nd Annual Conference Reno, Nevada, U.S.A.

Riederer, J.P. et al., (2005). Innovation Management –An Overview and some Best Practices. C-LAB Report, Volume 4 (3).

Rivera, M. A. and Valdez, M. M. (2007): Cross-functional Teams and Informal Social Networks: A Case Study of Project Development and Performance in a Multidisciplinary Science and Technology National Laboratory. Journal of Business and Public Affairs, Volume 1(2).

Roberts, E.B. (1995). Benchmarking the strategic management of technology II. Research Technology Management, Volume 38(2), pp.18–26.

Rosa, N. C. (2006). Principais demandas dos técnicos da extensão e de produtores rurais acerca do processo de inovação tecnológica de uma instituição de pesquisa agropecuária. Série Documentos. Porto Velho: Embrapa Rondônia, 20 p.

Rothwell, R. & W. Zegveld (1985). "Reindustrialization and Technology". Harlow, Longman.

Roucan-Kane, M., et al. (2011). Approaches for Selecting Product Innovation Projects in U.S. Food and Agribusiness Companies, International Food and Agribusiness Management Review, Volume 14 (4).

Roupas, P. (2004). Technology Uptake by the Food Manufacturing Industry. Department of Primary Industries, Australia.

Ruiz, P. P. (2010).Technology & Knowledge Transfer under the Open Innovation Paradigm: A model and tool proposal to understand and enhance collaboration-based innovations integrating C-K Design Theory, TRIZ and Information Technologies. Dissertation for the Master of Science in Innovation and Technology, Management school of Management, University of Bath, UK.

Rujivanarom, P (2016). A Shot in the Arm. Retrieved from https://www.pressreader.com/thailand/the-nation/20160501/281517930317163.

Russell, K.A. (1991). Managing a Biotechnology Business. In V. Moses and R.E. Cape (Eds.). London: Harwood Academic Press.

Rwelamila. P. (2007). Project Management Competence in public sector infrastructure organizations, Construction Management and Economics, Volume 25(1), pp 55-66.

Sabir, R.I., et al. (2014). Cross Functional Teams & Innovation Management. Scholedge International Journal of Management & Development, Volume 1(2).

Sakakura, S. and Kobayashi, M. (1991), "R&D Management in Japanese Research Institutes," Research Policy, Volume 20, pp 531-558.

Sandia National Laboratories (2007). Measuring the Maturity of a Technology: Guidance on Assigning a TRL. Albuquerque, New Mexico 87185 and Livermore, California.

Santa, R., et al. (2011). The role of cross-functional teams on the alignment between technology innovation effectiveness and operational effectiveness. International Journal of Technology Management (IJTM), Volume 55(1/2), pp. 122-137.

Saunders, M., Lewis, P. and Thornhill, A. (2003), Research Methods for Business Students, 3rd Ed.), England: Pearson Education Limited.

Saychum, S., Rugchatjaroen, A., Thatphithakkul, N., Wutiwiwatchai, C., Thangthai, A., (2008). Automatic duration weighting in Thai unit-selection speech synthesis, ECTI-CON 2008.

Schilling, A, & Werr, A. (2009). Managing and Organizing for Innovation in Service Firms, Vinnova Report VR 2009:06.

Schwenk, C. (1984). Devil's advocacy in managerial decision-making. Journal of Management Studies, Volume 21(2), pp. 153–168.

Scott-Kemmis, D., Australian Centre for Innovation Ltd, Jones, A.J., Arnold, E., Chitravas, C., Sardana, D and Technopolis Ltd. (2008). Absorbing Innovation by Australian Enterprises: The Role of Absorptive Capacity. Report on the Project for the Department of Industry, Tourism and Resources.

Second Report to Government of the Co-ordinating Group of Secretaries (1996), Delivering Better Government, Dublin: Government Publications Sekaran, U. (2003), Research Methods for Business: A skill building approach, (4th Ed.), USA: John Wiley & Sons.

Sethi, R., Smith, D.C. & Park, C.W. (2001). "Cross-Functional Product Development Teams, Creativity, and the Innovativeness of New Consumer Products, Journal of Marketing Research, Volume 38 (1), pp. 73-85.

Shane, S., (2004). Academic Entrepreneurship: University Spinoffs and Wealth Creation. Edward Elgar. Cheltenham.

Sharif, N., & Baark, E. (2011). The transformation of research and technology organizations (RTOs) in Asia and Europe. Science, Technology & Society, Volume 16(1), pp. 1–10.

Shen, X. (2002.) Factors Affecting Multifunctional Teams in Innovation Processes. Northern Institute of Technology: Alemania, working paper 13.

Shin, J. C. (2013). The scholarship of teaching, research and service. In J.C. Shin, & U. Teichler, The future of the post-massified university at the crossroads: Restructuring systems and functions. Dordrecht, the Netherlands: Springer.

Shin, S.Y. (2015). Cultural diversity and international trade in cultural products. Thesis Submitted for the Degree of Doctor of Philosophy in Economics. Faculty of Business and Economics Macquarie University.

Simons, T., L. H. Pelled and K. A. Smith (1999). “Making Use of Difference: Diversity, Debate, and Decision Comprehensiveness in Top Management Teams,” Academy of Management Journal, 42 (6): pp. 662―673.

Sosa, M. E. and Mihm, J. (2008). Organization design for new product development. In C. H. Loch and S. Kavadias (eds.) Handbook of new product development and management. Oxford: Elsevier Press.

Stirling, A. (1994). Diversity and ignorance in electricity supply investment: addressing the solution rather than the problem. Energy Policy 22, pp. 195–216.

Stirling, A. (1998). On the economics and analysis of diversity. Working Paper. University of Sussex, Brighton.

Sunberg, H.P. and Sanberg, K. W. (2003). Towards e-government: a survey of problems in organizational processes. Business Process Management, Volume 12 (2), pp. 149-161.

Swink, M. (2003). Completing projects on-time. Journal of Engineering and Technology Management, Volume 20, pp. 319-344.

Tashakkori, A. & Teddlie, C. (Eds.). (2003). Handbook of mixed methods in social & behavioral research. Thousand Oaks, CA: SAGE Publications.

Taylor, A. and Greve, H.R. (2006). Superman or the Fantastic Four? Knowledge Combination and Experience in Innovative Teams. Academy of Management Journal, Volume 49 (4), pp. 723-740.

The US Army Medical Research and Materiel Command (MRMC) (2015). Technology Readiness Levels applied to Medical Device Development. Retrieved from https://reqexperts.com/2015/11/30/technology-readiness-levels-applied-to-medical-device-development/

Thomas, R.R. (1991). Beyond race and gender: Unleashing the power of your total workforce by managing diversity. Amacom.New York.

Thursby, J. G., Jensen, R., Thursby, M. C. (2001). Objectives, characteristics and outcomes of university licensing: A survey of major U.S. universities. Journal of Technology Transfer, Volume 26(1-2), pp. 59-72.

Tidd, J. (2005). Innovation Management in the Pharmaceutical Industry: A Case of Restricted Vision? In Innovation in Phamaceutical Technology. Retrieved from http://www.iptonline.com/articles/public/IPT%2019%202005_p14+nonprintable.pdf.

Trott P (2002). Innovation management and new product development, 2nd edn. Pearson Education, Harlow.

Tsui, A. S., Egan, T. D., & O'Reilly, C. A. (1992). Being different: Relational demography and organizational attachment. Administrative Science Quarterly, 37, 549–579.

Turkulainen, V., and Ketokivi, M. (2012). The real benefits? Cross-functional integration and performance: what are the real benefits? International Journal of Operations and Production Management, Volume 32(4), pp. 447–467. DOI: 10.1108/01443571211223095.

Tushman, M. L. et al. (2003). Innovation Streams and Ambidextrous Organizational Designs: On Building Dynamic Capabilities, Harvard Business School Working Paper (H374 03-106).

Tziner, A. (1985). How team composition affects task performance: Some theoretical insights. Psychological Reports, Volume 57, pp. 1111-1119.

U.S. International Trade Commission (1998). Commercialization of New Manufacturing Processes for Materials. USA.

Van Knippenberg, D., & Schippers, M. C. (2007). Work group diversity. Annual Review of Psychology, Volume 58(1), pp. 515-541.

Vogt, W. P. (1999). Dictionary of Statistics and Methodology: A Nontechnical Guide for the Social Sciences (2nd Ed.). Thousand Oaks, CA: Sage Publications.

Voica, A. (2015). MIPS in space: Inside NASA’s New Horizons mission to Pluto. Retrieved from https://www.mips.com/blog/mips-in-space-inside-nasa-new-horizons-mission-to-pluto/

Voss, C.A. (1985). Determinants of success in the development of application software. Journal of Product Innovation Management, Volume 2, pp. 122-129.

Webber, S. S., & Donahue, L. M. (2001). Impact of highly and less job-related diversity on work group cohesion and performance. Journal of Management, Volume 27, pp. 141-162.

Weingart, P. (2005), Impact of bibliometrics upon the science system: Inadvertent consequences?, Scientometrics, Volume 62, pp. 117–131.

Wiersema, M. F. and K. A. Bantel (1992): 'Top management team demography and corporate strategic change', Academy of Management Journal, Volume 35, pp. 91 - 121.

Williams, C. (2007) Research Methods. Journal of Business & Economic Research, Volume 5, pp. 65-72.

Williams, K.Y. & O’Reilly, C.A. (1998). Demography and diversity in organizations: A review of 40 years of research. Research in Organizational Behavior, Volume 20, pp. 77-140.

Wilson, T. (1997). Diversity at Work: The Business Case for Equity. John Wiley & Sons: Toronto.

Wintjes, R. (2016). Systems and Modes of ICT Innovation; Joint Research Centre. JRC Science for Policy Report EUR 28005 EN; doi: 10.2791/58656.

Woehr, D. J., Arciniega, L.M. & Poling, T.L. (2013). Exploring the effects of value diversity on team effectiveness. Journal of Business & Psychology, Volume 28, pp. 107-121.

Woodman, R. W., Sawyer, J. E., & Griffin, R. W. (1993). Toward a theory of organizational creativity. Academy of Management Review, Volume 18: pp. 293-321.

World Intellectual Property Organization (WIPO), (2011). World Intellectual Property Report 2011, the Changing Face of Innovation, WIPO, Geneva, Switzerland.

Wutiwiwatchai, C., Furui, S. (2007a). Thai speech processing technology: A review. Speech Communication, Volume 49, pp.8–27.

Wutiwiwatchai, C., Supnithi, T., Kosawat, K. (2007b): Speech-to-speech translation activities in Thailand. In: Workshop on Technologies and Corpora for Asia-Pacific Speech Translation (TCAST).

Xie, J., Song, M, and Stringfellow, A. (2003). Antecedents and consequences of goal incongruity on new product development in five countries: A Marketing View: Journal of Product Innovation Management, Volume 20, pp. 233-250.

Yang, C.F., Wu, C. S. Huang, Y. H., Sung, T. J. (2015). Beyond the Innovation: An Exploratory Study of Designing Web-based Self-services. Procedia Manufacturing 3, pp. 3391-3398

Zajac, E. B., Golden, R., & Shortell, S. (1991). New organizational forms for enhancing innovation: The case of internal corporate joint ventures. Management Science, Volume 37, pp.170–184.

Zenger, T.R. and Lawrence, B.S. (1989). Organizational demography: The differential effects of age and tenure distributions on technical communication. Academy of Management Journal, Volume 32: pp. 353-376.

Zucker, Lynne G., Michael R. Darby, and Marilynn B. Brewer (1998). "Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises," American Economic Review, Volume 88 (1), pp. 290-306.

Zuniga, P., and Correa, P., (2013). Technology Transfer from Public Research Organizations: concepts and market and institutional failures, World Bank Policy Brief.