Investigation of Research Commercialization at a University: A Case Study

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Abstract

With the increase of awareness and focus on university research commercialization, much research had been conducted to investigate this subject. It was revealed that because universities were not traditionally built to serve the purpose of commercialization, many obstacles existed in the path of university research commercialization. Historically, research had largely focused on identifying critical factors that impacted the performance of commercialization. However, it was not clear how those findings could be systematically incorporated into the commercialization improvement plan of individual cases. This research intended to fill this gap and provide a framework that could be used by most universities to access and improve their research commercialization process.

A case study of a U.S. land-grant university was conducted and a narrative approach was mainly used as the method of data analysis. Under the scope of a single-case study, four sub-studies were conducted to address the goals of this research. First, a framework was developed that incorporated theories of existing research and the value stream map of lean management. Interviews with the intellectual property office and faculty were conducted to determine if the theoretical framework was applicable. It was found that the framework fitted well with the current process of university research commercialization. After that, a survey that covered a sample size of 1110 researchers at the targeted university was conducted to investigate the importance of different resources at different stages of the process. Resources that were under investigation were grouped into four categories: technical, human, social, and financial resources. This research identified the most important resources for research commercialization were industrial connections (social resource) and assistance from the intellectual property (IP) office (human resource), with industrial connections playing a more importance role at the beginning of the process and the IP office from the stage of patent application. To assess organizational characteristics of the targeted university, interviews were conducted with 22 faculty, three representatives from the administration, one representative from the intellectual property office, and one representative from an external organization. Six criteria derived from previous research were used to guide the assessment: (1) expenditures on research and development (R&D), (2) intellectual property policy, (3) research field, (4) key individuals, (5) commitment to innovation, and (6) networking with external relations. It was found that the targeted university had strong evidence of the advantages of expenditures on R&D and research field, however, it was relatively weak in the other four characteristics. The last part of the research involved interviews with two companies for the purpose of developing a best practice for research commercialization with the examples from the industry. Recommendations to improve targeted university's research commercialization were developed based on findings of the research.

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Chapter 1: Introduction and Literature Review

Introduction

Commercialization of university research is an important activity in the research environment of the U.S. (Siegel *et al.*, 2003). Many universities have adjusted their policy and opened the door to welcome business activities, which has not been the traditional routine. However, due to the nature of universities being academic institutions, there are several challenges within the commercialization process. These difficulties provide universities opportunities to change and to achieve a better transition from academic to business.

A close review of previous studies on university research commercialization reveals that both a university's resources and organizational characteristics play important roles in influencing research commercialization in the universities (Grandi *et al.*, 2005; Lockett *et al.*, 2005; Rasmussen, 2011). From the resource point of view, universities generally lack resources such as business assistance, financial support, and industrial connections, to conduct commercialization activities (Lockett *et al.*, 2005); and from the organizational characteristics point of view, a university's academic systems have traditionally focused on publication, but not commercialization. Therefore, there may not be clear policies, processes, and routines for transferring university inventions to industry ((Lockett *et al.*, 2005). To explore how universities can improve their capabilities in facilitating research commercialization, it is then important to understand what are the critical resources and organizational characteristics, and how far they are away from the best condition for research commercialization.

Literature Review

Overview of U.S. University Research Commercialization

University research commercialization is not uncommon in today's literature. Its problems and benefits have been discussed extensively. With regard to the type of commercialization, there are formal or informal types. As to key factors that affect the commercialization outcomes, there are different focuses, ranging from individual level to institutional level. In addition to those topics, numerous frameworks have been developed to study the commercialization process, such as resource-based theory, capability theory, and process-based view, etc. The theoretical framework of this research was developed based on existing findings, incorporating resource-based theory, organizational characteristic theory, and process-based view, to measure the commercialization performance and to provide insights on resources allocation in the commercialization process.

Growth of university knowledge commercialization in the US

Commercialization of university knowledge started to grow exponentially in the late 90's after the passage of the 1980 Bayh-Dole Act (Sher *et al.*, 2011), which allowed universities or other organizations to retain titles to inventions made under federally funded research programs (Managers, 2010). It is widely known that commercialization of university knowledge plays an important role in supporting economic growth in the U.S. (Grandi *et al.*, 2005; Lockett *et al.*, 2008). On one hand, it enhances the development of innovation in the universities (Grandi *et al.*, 2005), while on the other hand, it provides resources and new business opportunities for both current and new businesses, facilitates job creation, and promotes the business of communities (Lockett *et al.*, 2003). Reports show that the number of companies formed as a result of university research commercialization has been increasing steadily, even during the economic downturn that started in 2008. The reported number of published patents has almost doubled since 2001 (Managers, 2002). Increased involvement of universities in commercial activities is not only reflected by the number of start-up companies, but also by the actions universities have recently taken. Currently, most universities have established technology transfer offices to assist the commercialization process. And some universities have also developed business incubators or research parks next to the universities to facilitate research commercialization (Markman *et al.*, 2005b).

Different types of university knowledge commercialization

There are multiple ways universities can commercialize their knowledge. In general, the main approach has been in the form of technology licensing (Lockett *et al.*, 2003). In a licensing agreement, the university licenses a patented technology to the industry and allows it to commercialize the technology. In exchange, the industry gives the university research funding, equity in a company, or payment in cash (Markman *et al.*, 2005b). Many universities take this form of commercialization because it eases professors and researchers from the burden of conducting the business activities that are out of the realm of normal academic routine (Markman *et al.*, 2005b). Despite the advantages listed above, there are also issues associated with the licensing approach. First, the value of a new technology cannot be estimated easily (Lockett *et al.*, 2005). In most cases, technologies developed from a university are very novel and their future performance in the market is unknown. This uncertainty makes it difficult to capture the real value of the technology. Therefore, settlement of royalty or payments between industries and the universities is hard to be agreed upon. Secondly, licensees are not easy to find (Rasmussen, 2011). Most developed or mature companies have their own product development plans. Unless a research idea or product fits the strategic plan of the company, the possibility that the company will adopt the patent from a university is low. Additionally, adoption of university technology has the challenge that current industry infrastructure is not always sufficient to produce the invention (Sher *et al.*, 2011). Especially when a technology is developed with new materials or cutting edge equipment, universities find it difficult to attract industries to commercialize the technology.

Because of the issues mentioned above, many researchers from the university choose another approach, research spinning-out, in which inventors of a technology start a company of their own and share the ownership of the company with interested parties (Mustar *et al.*, 2006). In general, these parties can be universities, management teams invited from the industry, and investors (Rasmussen *et al.*, 2010). In the case of spinning-out, inventors either leave their positions in the university to run the company full time or work on academic and business ventures at the same time (Clarysse *et al.*, 2004). This approach has its advantages that the technology is commercialized by the individuals that are most familiar with the invention, and all business activities are tailored to fit with the technology (Lockett *et al.*, 2003). However, there are downsides to this approach too. First, the inherent nature of the university limits its ability to manage a business. It is widely known that the academic is more technically driven than business driven (Rasmussen *et al.*, 2010). Therefore, while a researcher can solve technical problems easily, he or she may lack the business skills required to run a company. To overcome this shortcoming, in most cases, someone with business experience from the industry is invited to manage the company (Clarysse *et al.*, 2004). Another drawback is the schedule of researchers. This problem comes up when the researcher decides to keep his or her position in the university at the same time when he or she also wants to be involved fully in the business. Conflicts between the research and the university may emerge in this case. Because when a researcher devotes a large proportion of his or her time to the business, it is very unlikely that he or she will be capable of fulfilling his or her academic responsibilities (Rasmussen, 2011).

Barriers to the university knowledge commercialization

Commercialization of university research represents potential opportunities to stimulate economy growth (Siegel *et al.*, 2003), however, there are also difficulties in achieving successful performance in the market place (Mustar *et al.*, 2006). As previous studies indicate, universities face two major challenges to commercialize research. The first challenge is attributed to the culture of university being a non-commercial organization. Traditionally, the university acts as an education agent that carries the additional mission of conducting research and disseminating knowledge (Santoro, 2000). Therefore, universities lack resources and business skills to manage commercial activities. Specifically, researchers could be too occupied by academic routines to contribute their time to the development of a new product and launching a business; in addition, the reward system in the university does not create enough incentives for researchers to fully engage in commercial activities. Generally, researchers are evaluated with regard to the number of quality publications they have instead of the number of commercial products they create. As a result, researchers might lack the motivation to devote efforts to refining a potential product for the purpose of commercializing it; finally, in general, researchers in the universities are well trained to be professional scientists or engineers but not businessmen or business women. So, even when a researcher happens to create a good product and is motivated to commercialize it, he may still face challenges as to how to define the market and how to develop a business plan for the product.

The other barrier is related to balancing conflicted interests from different parties. University research commercialization involves dynamic interactions between individuals including academic entrepreneurs, managers from industries, university administration, and financial investors. These parties have distinctly different objectives. Between the academic entrepreneur and the manager of a start-up company, they there may be conflicts for the ownership of decision-making or the leadership role; between the academic entrepreneur and the university administration, there would be counter interests in the priorities of research activities or resources utilization.

Therefore, to ensure that a university's commercialization efforts are successful, universities should pay attention not only to bring in resources to develop business essentials in the academic field, but also to enhance the capability of managing the commercialization activities.

University characteristics impacting the performance of university knowledge commercialization

As indicated above, the nature of universities being academic institutes creates challenges for university research commercialization. To have a deeper understanding of this process, previous literature extensively studied the relationship between university characteristics and their impacts on the performance of university knowledge commercialization and identified two types of organizational characteristics that had the most influence.

The first type of organizational characteristics focus on institutional factors such as a university's intellectual properties and human resources policies (Kenney, 1986), expenditures on R&D (Rasmussen *et al.*, 2010), research fields (O'Shea *et al.*, 2005), and the availability of venture capital (Grandi *et al.*, 2005). The other type places more emphasis on the social aspects. Different from institutional factors, which are static, social factors provide more information about the dynamic aspects of commercialization activities. For example, Grandi *et al.* (2005) summarized four main factors that reflect the social aspects of organizational characteristics, including commitment to innovation, key individuals, networking with external relations, and market focus attitude. The first factor, *commitment to innovation*, refers to the extent to which involved individuals commit to the commercialization process. As suggested by Grandi *et al.*, to overcome the difficulties on the way of research commercialization, a strong commitment to the process is necessary. The factor *of key individuals* emphasizes the roles different figures play in supporting the commercialization process. In Grandi *et al.'s* argument, they claim five critical roles: idea generator, internal entrepreneur, leader of the project, technological gatekeeper, and project sponsor. *Networking with external relations*, as the name indicates, relates to the effort universities make to bring in external resources to support their commercialization process. As addressed above, one of the major problems universities have is the lack of business competency. While individuals from the industries are more familiar with the business aspects of knowledge transformation, universities should be more open to look for and accept external help. Having a *market focus attitude* is generally not new to organizations whose main activities are commercialization and their product development strategic is usually customer-oriented (Rothwell, 1992). However, since universities have traditionally not focused on market applications of their research, it becomes critical for them to learn and understand business aspects of the research if they have put research commercialization on the agenda.

Existing Theoretical Framework for University Research Commercialization

There are mainly two theoretical approaches in studying university knowledge commercialization (Mustar *et al.*, 2006). The first one is resources-based and focuses on explaining the importance of different resources and their relations with the outcomes of knowledge commercialization (Rasmussen, 2011). Developed from the resource-based approach, there is also the capability-based perspective, which looks at how well an organization can utilize different resources in its process of commercialization (Lockett *et al.*, 2005). Different from resource-based perspective, the second theoretical approach places more emphasis on the process and illustrates the phases the commercialization would go through (Bhave, 1994; Clarysse *et al.*, 2004; Perrini *et al.*, 2010). In the text below, details of the two approaches are shown and discussed.

The resource-based perspective

In the field of strategic management, resources-based theory has been studied extensively since it provides insight into which resources are most valuable in transferring knowledge within or between organizations (Rasmussen, 2011). As Wernerfelt (1984) indicated, a firm should put most attention on its internal workings since its resource base is positively related to its success of research commercialization. Resource-based studies on university research commercialization have developed into different categories. For example, Barney (1991) summarizes resources as physical capital, human capital and organizational capital resources. *Physical capital resources* include the physical items used in the organization, such as equipment and materials. *Human capital resources* regard both the individuals involved and their interactions in an organization. *Organizational capital resources* refer to an organization's internal structure, including business structure, planning system, and relationship with external institutions.

O'Shea *et al*. (2005) categorize resources as: institutional resources, human capital, financial resources, and commercial resources. *Institutional resources* relate to a university's historical or social assets. It is stated that if a university has engaged in commercialization in the past, it is more likely the university will succeed in the future. *Human capital* includes individuals that are equipped with cutting-edge knowledge of the products. *Financial resources* refer to the funding a university receives from the industry to support its commercialization activities. Finally, *commercial resources,* in specific, relate to the intermediate between universities and industries, such as a technology transfer office, which provides other necessary resources to facilitate commercialization.

In addition to the categories used by Barney (1991) and O'Shea et al. (2005), there are also other approaches adopted by different researchers. Those approaches either address more general definitions, such as tangible, intangible and personnel-based resources (Grant, 1991), or focus on more specific cases. For example, Lichtenstein and Brush (2001) targets small business and suggests that capital, organizational systems, management know-how, employees, owner's expertise and reputation, technology, physical resources, leadership, organizational structure and culture or informal systems are the most important resources for an organization to achieve commercialization success.

Built on that literature, Mustar *et al.* (2006) conceptualized the heterogeneity of research-based spin-offs and summarized four categories of all resources necessary for the commercialization of university research. In this study, we used their classification. In Mustar *et al.*'s view, one of the four types of resources is *technological resource*, which refers to the technical aspects of the research. This category covers all technical elements of the knowledge, including the specific type of research, scope of the research, and the stage of the product development cycle. The second category, *human resource*, includes all personnel involved in the commercialization activities. Normally, it refers to inventors of the research, management team in the company and other supportive personnel. *Social resource* relates to the two main relationships an organization needs to keep with its external environment. One is networking with the industries and the other is connection with financial contacts. The last category, *financial resource*, refers to all types of funding needed to commercialize the knowledge. As Lockett & Wright (2005) claim, the availability of financial support is a critical element an organization should take into consideration at all times when conducting knowledge commercialization.

Capability-based perspective

Resource-based studies on university research commercialization provide a good foundation to understand the relationship between different resources and commercialization outcomes. However, as recent studies point out, though the resource-based approach is useful in giving insight into favorable conditions (Rasmussen *et al.*, 2010), it is static and does not reflect how an organization can strategically utilize resources discussed above in its commercialization process. Clarysee *et al.* (2005) indicates different commercialization processes require different types of resources. Rasmusen *et al.* (2010) also find that the importance of resources varies at different stages. Therefore, an organization's capability of fully integrating needed resources into its business development plan plays an important role in determining the organization's commercialization outcomes (Lockett *et al.*, 2005). In response to the need to better understand the routines or processes through which different resources are used, some scholars propose another approach, the capability-based perspective, to study how universities manage to utilize their resources to secure the strategic position (Bhave, 1994; Lockett *et al.*, 2005; Rasmussen, 2011).

University capabilities, as Rasmussen (2011) defines, are routines or internal procedures coordinated in a university that utilize organizational resources to support the research commercialization process. Lockett *et al.* (2005) provide a detailed description of university capabilities. They state that first a university should have policies or processes in place for the decision making between licensing and spinning-out. This step is critical for future business development because it is at this stage that the performance of the product be analyzed and estimated. If the analysis indicates a research product has no market potential (e.g. current infrastructure is not ready to produce the new product; the market size is too small and the marginal profit is too low; or there is regulation prohibiting the commercialization of the product), future development is not needed and continuous investment would be wasted. Secondly, there should also be clear procedures describing how to start a company and bring a product to the market. Though managerial and marketing skills are intangible and are developed over time, an available generic business procedure is still helpful for the commercialization team in guiding their daily business activities.

Similarly, Rasmussen *et al.* (2010) also suggest that the capabilities of universities to identify and analyze new business opportunities and to transform these new ideas into commercial products are important. Further than that, they also discuss specific capabilities including universities' capabilities to accept new paths of action, capabilities to balance academic and commercial interests, and capabilities to look for and integrate new resources. At the end of the study, a positive relationship is identified between these capabilities and the outcomes of commercialization. The remaining research on university capabilities reveals similar results (Grandi *et al.*, 2005; Mustar *et al.*, 2006). Therefore, capability-based perspectives enrich the existing studies on university resources. It goes beyond resource-based approach and provides deeper investigations to identify how resources should be utilized.

Despite its merits, the capability-based approach also has shortcomings. It is found that though past research provided general concepts of university capabilities, detailed routines a university should take to develop its capabilities in managing knowledge transfer are still missing.

Process-based perspective

Universities need not only the resources but also developed internal procedures to support their knowledge transfer process (Grandi *et al.*, 2005). As stated above, the need to better understand a university's capabilities of managing its resources and activities in commercialization calls for detailed analysis of the university knowledge transfer process (Rasmussen *et al.*, 2010). While current studies addressing both the topics of resources and process are still sporadic, there are many studies that target only the process and provide a good foundation to understand the university knowledge transfer process (Bhave, 1994; Clarysse *et al.*, 2004; Perrini *et al.*, 2010).

Ven *et al.* (1995) provide four basic theoretical frameworks to explain the process of organizational change. As university research commercialization can be included as one form of organizational changes, these frameworks can also be applied to analyze the process of commercialization. The first framework is *stage or life-cycle theory*, which assumes that there are defined stages of business development and the process will go through the stages in sequence. The second framework is *teleological theory*. This approach emphasizes the importance of purposeful actions of individuals and suggests it is people's will that takes the development process to the next level. The third framework, *dialectic theory*, mainly studies how to balance the objectives of parties with different backgrounds. In the case of university knowledge transfer, there will be conflicts between universities and industries and also conflicts between different units in the university. Therefore, universities should have available routines or guidelines to manage those relationships. The last framework is *evolutionary theory*, which explains how external factors influence the outcomes of a process (Rasmussen, 2011).

Among all the frameworks, the stage-based model is the most discussed and available in the literature (Hermann *et al.*, 1997; Rasmussen, 2011; Steyaert, 2007). Vohora *et al*. (2004) give a detailed summarization of the stage-based model. Basically there are five phases university knowledge transfer will undergo, as **Figure 1** shows, including research phase, opportunity framing phase, pre-organization phase, re-orientation phase and sustainable returns phase.

Figure 1 A Stage-based Model of Knowledge Transfer Process.

In the *research phase*, the main activity is conducting the research. Time needed for this period varies depending on the field and specific area. It extends until the creation of an intellectual property becomes available and a plan to commercialize the patented research is put on schedule. After a decision is made to commercialize the research, the *opportunity framing phase* starts. During this period, the business idea is evaluated and the technology transfer office or a similar unit normally gets involved and helps to identify potential markets for the knowledge. This stage can also last from months to years depending on the commercial experience of the team and market potential of the technology. The *pre-organization phase* starts when the market opportunity is framed and the team is committed to develop the business. What, when, where, and how to commercialize the knowledge are the most encountered questions at this stage. Answers to those questions are critical to the success of commercialization because it is at this stage that the business direction is determined and the business plan as to resources allocation is laid out. Once decisions are made, future modifications that cause strategic changes could be detrimental to the success of the business venture. If a venture can pass the pre-organization phase, it normally means a business or a company is officially established and it moves to the *re-orientation phase*, where the team needs to continuously adjust the market size, operation, and company structure. A business reaches the phase of *sustainable returns* when it achieves stable cash flow and human resources. At this stage, the team either keeps modifying the operation or starts to expand the business to different areas.

Due to the simplicity of the stage-based model, it has been criticized for being too static and rigid to explain the heterogeneous nature of the commercialization process (Rasmussen *et al.*, 2010). However, it still has a number of advantages. First, it gives a holistic view of the research commercialization process from the time an idea is generated to the time the idea reaches the market. Secondly, the illustrated layout of the commercialization process is simple and generic, which makes it easy for other researchers to build their process models on it. Therefore, even when scholars claim the stage-based model is not sufficient and does not cover the dynamic aspects of the commercialization process, many of them still use the stage-based model as a foundation or reference for their model developments. For example, Bhave (1994) developed subprocesses under the stage-based model to differentiate two conditions where opportunities are recognized externally and internally (**Figure 2**). In the study of team formation during a knowledge transfer venture, Clarysse *et al.* (2004) integrate the pattern of the stage-based model to describe how the venture team is formed at each phase. As **Figure 3** shows, the author also divides the whole process into idea phase, pre start-up phase, start-up phase, and post-start-up phase. Under each phase, they then discuss in detail the roles of all members and critical events that have changed the formation of venture team.

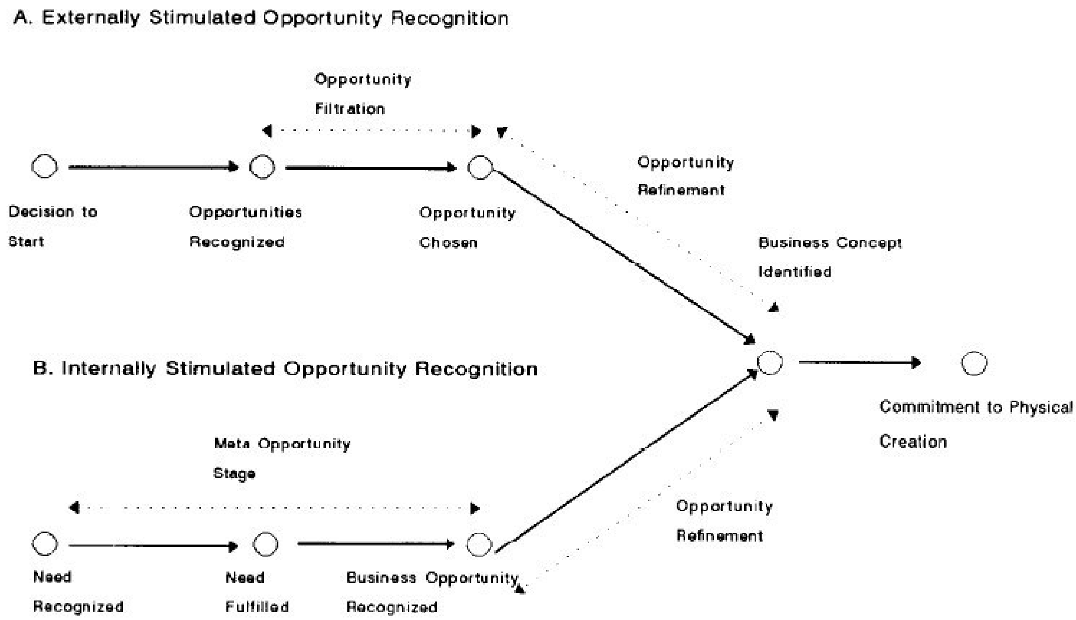

Figure 2 Process of Venture Creation when Opportunities are Recognized Externally and Internally (Bhave, 1994).

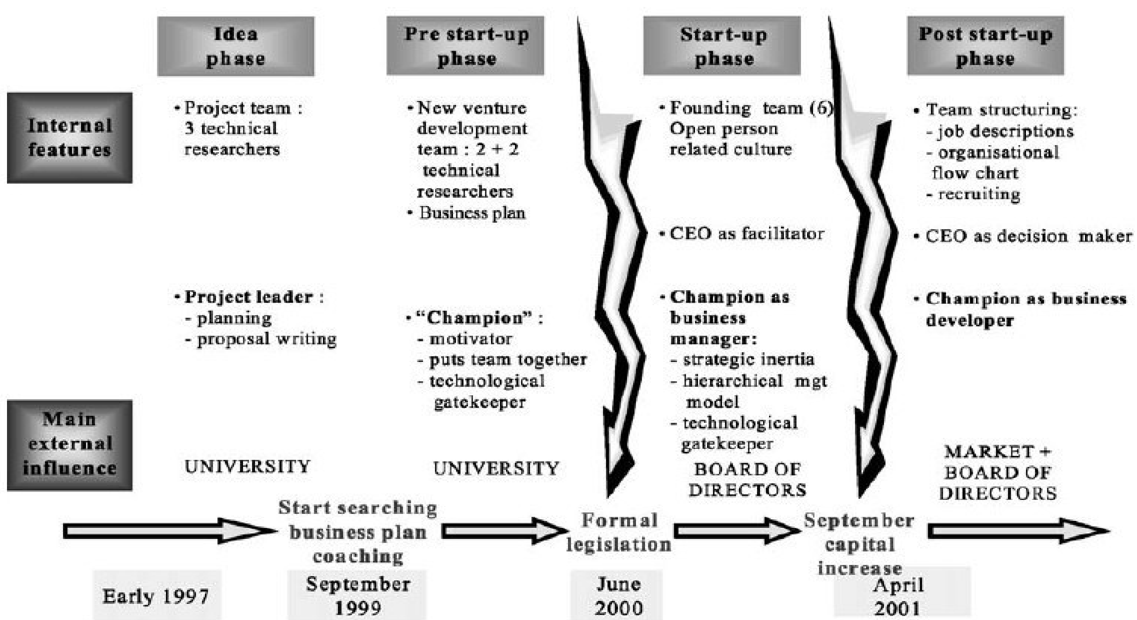

Figure 3 Development of the Venture Team along the Organizational Life Cycle (Clarysse *et al*., 2004).

Perrini *et al*. (2010), on the other hand, extends the stage-based model by adding sociocultural perspectives (**Figure 4**). They claim the stage-based model gives people a misconception that commercialization of knowledge will move from one stage to the next naturally, however, it is the entrepreneurial characteristics of individuals embedded in the process that carry the process to overcome difficulties and move forward. As shown in Figure 4, if an individual dimension is connected to a stage, it means this specific dimension has the most impact on the outcome of this stage.

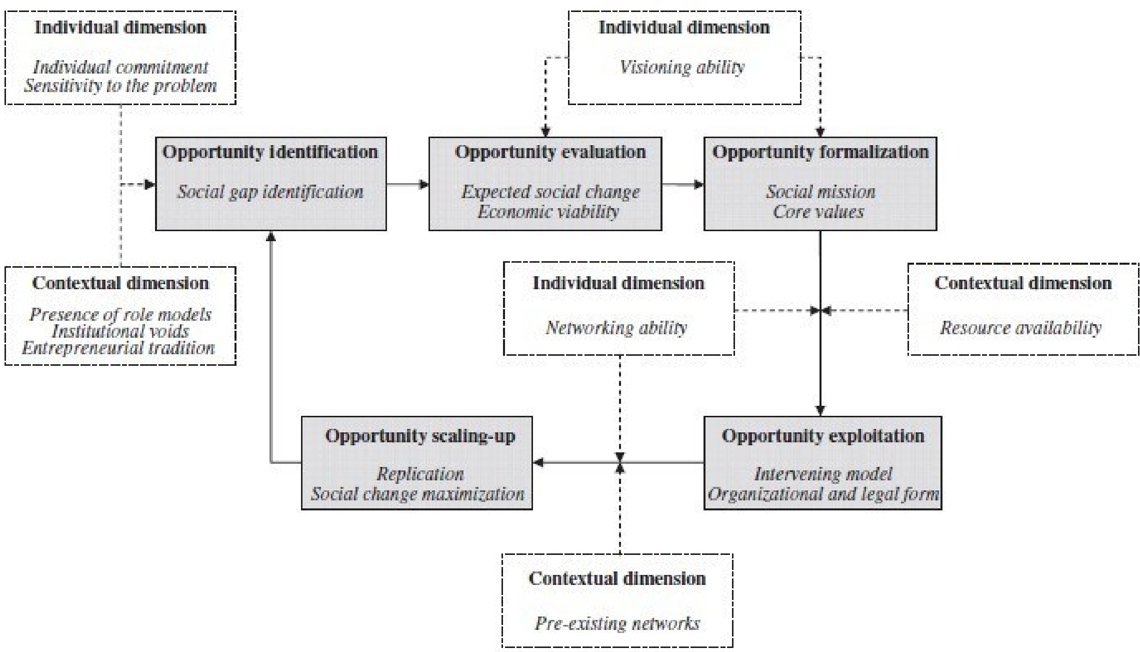

Figure 4 A Process-based View of Social Entrepreneurship (Perrini et al., 2010).

Therefore, it is not hard to conclude that the stage-based model serves as a good foundation for theory development. Researchers can use it as a starting point to build another model by adding or integrating the needed factors for a specific research question. In our case, we want to look at the efficiency of resource utilization for all participating parties in university research commercialization from a process point of view. It is proposed that we can embed resource factors into the stage-based model to analyze resources utilization within the commercialization process. To add other elements, such as participating parties and their activities, into the framework, we are going to borrow models from other disciplines, because they are not found in the present management literature.

Lean Management

What is Lean?

Lean is one of the most well-known terms in the industry. Throughout its development, Lean has been interpreted in different ways and referred to by the industry interchangeably with other phases, such as process improvement, continuous improvement, just-in-time, and Kaizen, etc. However, as corrected by Rachna Shah and Peter T. Ward (Shah *et al.*, 2007), Lean should be understood as more of a production system as a whole instead of individual process improvement tools. Derived from the Toyota Production System (TPS), the term "lean" was first fixed to name Toyota's production system by Jim Womack, in 1988. As described by Womack, Lean is a management philosophy that guides the way of thinking for an organization’s process improvement effort. It focuses on the customer value and improves processes throughout the entire value stream. The main goal of Lean is to deliver to customers what they need with shorter lead time, lower costs, less human resources, and fewer defects, etc. Simply put, Lean means creating the maximum value to the customer when utilizing the minimum resources (LEI., 2013b).

The Development of Lean

Lean was developed through an accumulation of decades of industry development. While the earliest recorded Lean concept could be traced back to centuries ago, the most recognized emergence of Lean is around 1927, when "Henry Ford published its production philosophy and the basic principles underlying the revolutionary Ford Production System (Shah *et al.*, 2007)." The Ford Production System (FPS) describes concepts and the manufacturing system Ford used to produce its "Model T", a modular car that offered only one color and one specification. In its manufacturing system, Ford fabricated the "Model T" with standardized and interchangeable parts and delivered those parts on a moving conveyance. Also, Ford placed the machine that produced the parts in a sequence along the assembly line, so needed parts could be fed into the assembly line in a flow. In addition, Ford also broke the entire production of the "Model T" into many simple tasks and distributed them to different workers. Those workers usually stayed by the conveyance and received parts that were supplied to them. As workers received the parts from the conveyance, they required few movements and only stayed at one location and conducted assigned tasks repeatedly. Ford's production system had proven numerous advantages over the traditional "craft production system". It resulted in higher productivity, lower cost, shorter cycle time and higher inventory turnover rate. It demonstrated a breakthrough in the automobile industry back in its time and the introduction of standard work, interchangeable parts, and continuous flow opened the door to more adoption and development of Lean in the automobile industry (LEI., 2013a).

The Ford Production System, to some extent, had satisfied the needs of U.S. customers to own an affordable personal automobile. However, when the demands extended to variety, instead of sole color and specification, Ford seemed to lose its edge. The use of identical parts throughout the production no longer worked because fabricating varieties of models required the supplies and assembly of different parts. Continuous flow was interrupted as the assembly processes differed from one model to another. Workers had to move around to search for and get supplies, and their tasks became more complex than before. Around the 1930s, when Ford's competitors were struggling with the chaos brought by introducing awide variety of automobiles, Toyoda cousins Kiichiro and Eiji, and Taiichi Ohno started their journey to study and apply FPS in their firm, the Toyoda Motor Company. The initial plan was to stabilize the company's production processes and realize just-in-time delivery with FPS, however, in Japan, as the total market demand of cars was low and the demand of variety was high, Eiji Toyoda and Taiichi Ohno found the mass production system introduced by FPS did not fit well into their production reality. Adjustments were made to develop their own production system (Toyota Production System) to achieve continuous flow when producing cars with various specifications. Gradually, Toyoda developed "kanbans" and "supermarkets", and integrated quality management principles from Deming, Ishikawa, and Juran and made the Toyota Production System more adaptable to the company culture. Then in 1978, Taiichi Ohno published the first edition of "Toyoda Production System" in Japan.

Around 1970s, the oil crisis hit North America and competition from overseas became very severe. Given those challenges, U.S. automakers started to innovate and improve their manufacturing processes. At that time, both the industry and academia showed interests in the Japanese manufacturing and management methods (Shah *et al.*, 2007). In 1977, Sugimori *et al.* (1977) published the first academic article in the U.S. discussing Kanban and just in time. After that, other publications appeared and expanded the topic to production smoothing and level loading (Monden, 1981). In 1988, Ohno's Toyota Production System: Beyond large-scale production was published in English (Shah *et al.*, 2007). In the 1980s, one of the most well-known research events for studying Lean, a five-year and five-million dollar worldwide research project was initiated by the international Motor Vehicle Program (IMVP) in 1984. This research aimed to search for the factors and production methods that led to success in the automotive industry. It resulted in a report, *The Future of the Automobile* (Altshuler, 1984), which summarized the state, development, and future of the global automotive industry. In 1988, Krafcik from IMVP coined the term "Lean" to describe the Toyota Production System. In 1990, the same group from IMVP, James Womack, Daniel Jones, and Daniel Roos, published the book, "*The Machine that Changed the World: How Japan's Secret Weapon in the Global Auto Wars will Revolutionize Western Industries*". In this book, they provided an in depth discussion of the difference between the traditional mass production that was generally used by the U.S. auto makers and Lean production adopted by the Japanese counterparts (Womack *et al.*, 1991). Since then, Lean became more well-known and disseminated, with publications including both books and academic articles flourishing (Flynn *et al.*, 1995; Hopp *et al.*, 2004; Lasa *et al.*, 2009; Rother *et al.*, 1999; Sakakibara *et al.*, 1993; Womack *et al.*, 1996). Presently numerous companies across different industries have practiced Lean. The application scope of Lean has also expanded from manufacturing to administrative offices, accounting, and product development, etc.

Key Concept of Lean: The Toyota Production System (TPS)

Lean and the Toyota Production System (TPS) are frequently used interchangeably in the industry. Generally speaking, as Lean descended from the TPS, these two terms can be the proxy for each other (Shah *et al.*, 2007). As previously stated, TPS was developed at the Toyoda Company back in the 1960s and 1970s. It consisted of many pieces of innovation enlightened by three key persons in the company, Taiichi Ohno, Sakichi Toyoda, and Kiichiro Toyoda.

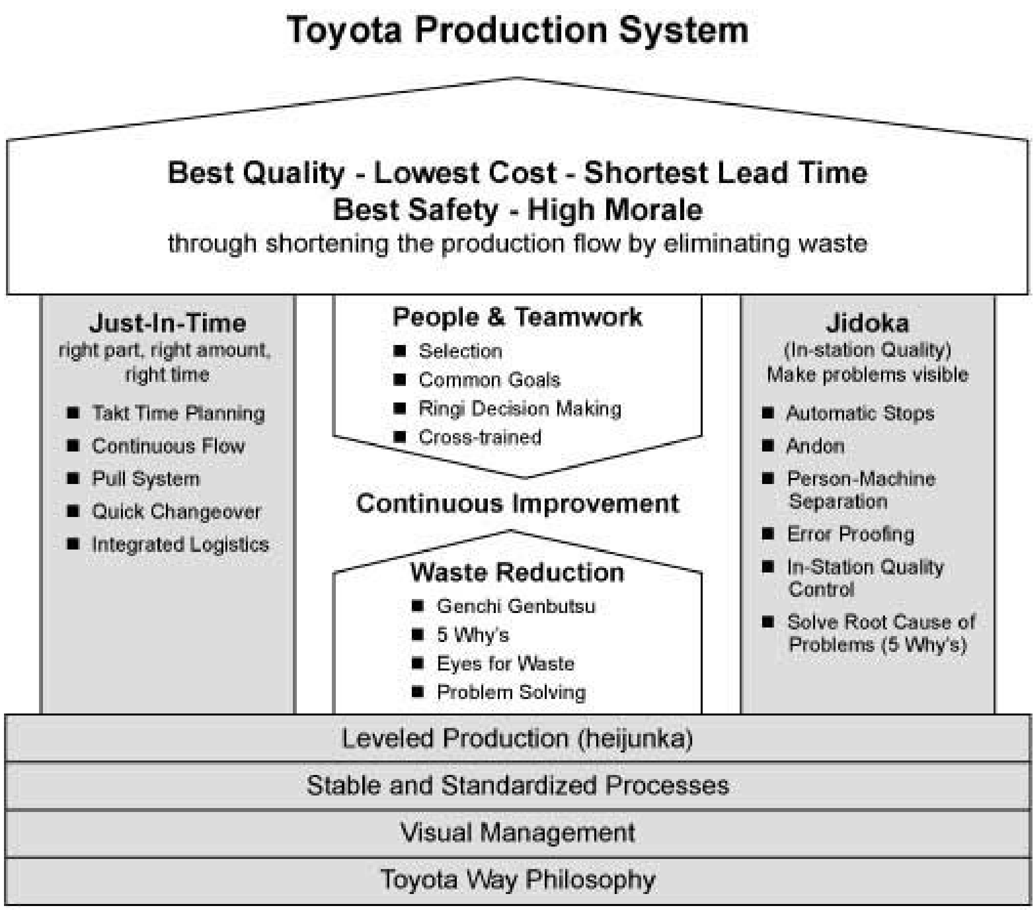

Figure 5 The Toyota Production System House (Liker, 2003).

TPS includes several key elements which are usually presented as different components within a house structure. As **Figure 5** shows, those elements respectively represent the foundation, the supporting pillars, the middle section, and the roof of a house. As Liker explained, the intention of creating the TPS house is to indicate that the success of adoption of TPS requires building and developing all elements as a whole instead of focusing on individual ones (Liker, 2003).

Interpretation of the house can start from the roof, which contains the goal of TPS: Deliver to customers the best quality product with the lowest cost and the shortest lead time, while maintaining the best safety and high morale within the company. This goal is supported by two pillars: a) Just-in-time (JIT), and b) Jidoka. JIT means delivering to customers the right part and the right amount at a right time. The objective of JIT has been a very important philosophy that guides the production at Toyota, even before the TPS was created (Womack *et al.*, 1996). At an ideal JIT scenario, Toyota will only start to produce once the customer places the order. In that case, Toyota does not need to carry excessive inventory so as to avoid generating extra costs. However, the ideal state is nearly impossible to achieve. And simply maintaining a system that is close to the ideal situation has proven to be very difficult and challenging (Liker, 2003). To achieve the goal of JIT, throughout years of innovations Toyota has developed an integrated manufacturing system that will respond to any changes in the production plan and make adjustments simultaneously. Production planning methods that support the system take time planning, creation a production flow, application of a pull system, realization of quick changeover, and development of integrated logistics, etc. (Liker, 2003).

The second pillar, Jidoka, stands for autonomation, meaning creating an on-site quality inspection system that will stop the production and send a warning whenever defects are detected.

With autonomation, only parts with acceptable quality can be passed to the next step, and defects or problems will be identified and solved in a timely manner. Therefore, the final defect rate can be largely reduced or eliminated. This method derives from a loom Sakishi Toyoda invented to detect broken threads back in 1920 (Ohno, 1988). So, in most cases, autonomation is realized by setting up a machine that functions autonomously, while in some cases, human help is also added (Ohno, 1988).

The center of the TPS house includes two main components: people and waste reduction. Derived from the Japanese culture, people development is a very crucial part in the TPS at Toyota (Womack *et al.*, 1996). Toyota only selects and recruits people that share the company's culture and goals. It also provides training and encourages people to work together as a team for any decision making or problem solving. As Taiichi Ohno explained (1988), "managing the employees in the company is like leading a sport team. Having individual excellent players does not lead to success. However, it is the teamwork of the players that brings the team to the top of any contest." As important as "people development", "waste reduction" is another effort that requires continuous improvement as described in the TPS. As the words indicate, waste is the item or activity that is unnecessary and does not create value. Managed properly, waste reduction can help a company not only save tremendously on costs, but also bring other benefits, such as improved quality, safety, and employee morale, etc. (Womack *et al.*, 1996). According to Ohno (1988), in a manufacturing environment, there are mainly seven types of waste:

1) **Overproduction:** producing more than needed. Most companies forecast customer demand and produce in advance to ensure future needs. However, early production

results in building-up of inventory. In most cases, the inventory largely exceeds customer demand and is wasted.

2) **Unnecessary transport or conveyance:** unnecessary movement or transport of materials, such as work-in-process (WIP), raw materials, parts, and finished goods.

3) **Excess inventory:** inventory that is not needed to fulfill customer demand and unnecessary WIP and raw materials. Inventory requires additional space and handling. It hides problems such as defects and unleveled production. And it causes longer lead time as needed parts have to wait in the queue to be processed until the unnecessary ones ahead are finished.

4) **Unnecessary movement:** insignificant steps taken by employees or equipment. Usually, those steps happen because of inefficient process layout, defects, reprocessing, overproduction or excess inventory. Non-value-added motion like this should be eliminated.

5) **Over-processing or incorrect processing:** unnecessary and inefficient operations such as rework, reprocessing, handling or storage that occurs due to poor design, use of inappropriate tool, or defects.

6) **Waiting:** inactivity period of a worker or a machine. This normally happens when there are missing or broken parts, late supply of materials, machine downtime, or capacity bottlenecks.

7) **Defects:** finished products or parts that do not meet the specification of the customer order and need reworking or to be discarded.

The foundation of the TPS house contains four elements: 1) leveled production (heijunka), 2) stable and standardized processes, 3) visual management, and 4) the Toyota way philosophy. At the bottom of the TPS house is the "Toyota way philosophy", the main principle and guidance that underlies the company's managerial approach and production system. It stresses the long-term goal of the company and is the most important element in the TPS (Ohno, 1988). The second element of the TPS's foundation is "visual management". As the name implies, it means making everything visual, including inventory, instructions, measurements, and other items and activities, etc. Visual management makes it easier for people to observe, communicate and share information. As Tezel *et al*.(2009) stated, "*visual management helps performance through connecting and aligning organizational vision, core values, goals and culture with other management systems, work processes, workplace elements, and stakeholders, by means of stimuli, which directly address one or more of the five human senses (sight, hearing, feeling, smell and taste).*" The third element, "stable and standardized process", specifies that all processes and instructions should be standardized. Ohnn (1988) claimed, "*without standard there can be no improvement*". To illustrate that, people normally use a scheme, as **Figure 6** shows, explaining how standardization helps to prevent the process improvement effort from sliding back to the beginning state. "Leveled production" is the last element of TPS foundation. It refers to constantly leveling of production and inventory according to the demand. Achievement of leveled production enables the company to achieve full utilization of resources, reduction of inventory costs, and quick response to changing demands (Womack, 2006). The last three elements do not have a strict order of importance. They are equally important in the TPS.

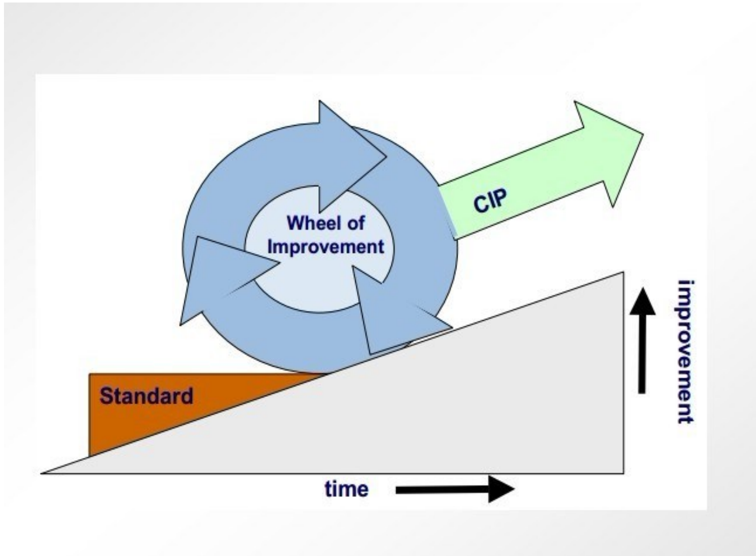

Figure 6 The Role of Standardization.

The principles of Lean/Toyota Production System (TPS)

As explained above, TPS is more than a combination of tools but an integrated system comprising Toyota's company culture, managerial strategies, employees, and improvement methods. Lots of followers have simply adopted different tools introduced by the Toyota Production System, but did not understand the essentials. After numerous attempts and failures, those people then concluded Lean did not work in their organizations. However, tools were not the reason that Toyota thrived. It was the philosophy behind TPS, the understanding of people and human motivation, that keep Toyota evolving and prospering (Liker, 2003). Once the core of TPS is grasped, application of tools will naturally follow. With that being said, it does not mean that there is no principle or guideline to follow when applying Lean. Drawing on comprehensive research on Toyota, previous researchers have induced and outlined sets of principles for industries to guide their Lean transformation projects (Womack *et al.*, 1996).

Womack and Jones (1996) indicated that the application of Lean mainly follows five principles, as listed below. And these five principles were linked to each other in a sequence and formed a cycle, as shown in **Figure 7**.

1) **Identify and specify value from the customer's perspective**. An organization first needs to understand who the customer is and what the customer wants. Producing only what the customer orders enables a company to better allocate resources to the activities that create value to the customer.

2) **Map value stream**. Once the value is determined, all the steps involved to create a specific type of product in the value stream should be identified and mapped out. Value Stream Mapping is generally used to serve this purpose. A detailed description of value stream mapping can be found in the following section.

3) **Creating continuous flow**. This principle refers to making all identified steps in a sequence so that the product will flow through the production from order to delivery without stopping. Creating flow requires not only laying out equipment and materials in proper order, but also eliminating obstacles, such as work-in-process (WIP), waiting, unnecessary motion or transportation, incorrect processing, etc., in the process. These setups ensure that materials will move from one step to the next without waiting in between, so the lead time can be largely reduced.

4) **Establish pull**. With continuous flow created and lead time shortened, the production needs to be scheduled based on customer demand. Different from a traditional "push" system, in which a company will produce in advanced and wait to push the products to the market, a "pull" system allows the customers to pull products from the next upstream activity. In an ideal state, production will only be triggered by a customer order and no inventory is held at the end of the process.

5) **Strive for perfection**. Lean is a long term effort. Improvements from the previous four principles come from aligned and empowered people making small changes every day. Even when perfection is achieved, there would always be areas for improvements as the market changes and customers' preferences shift. In this case, start from the first principle and continue until another state of perfection is reached.

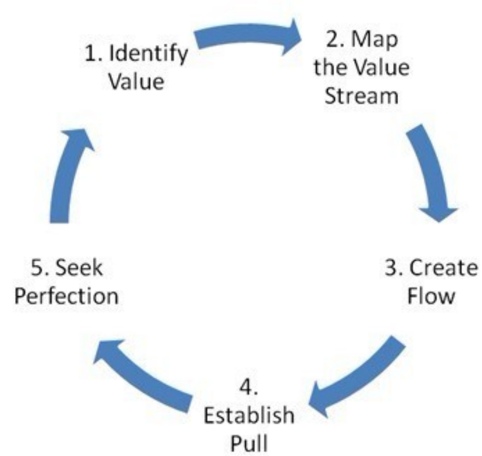

Figure 7 Womack and Jones's Five Principles of Lean (Womack et al., 1996).

According to another researcher, Dr. Jeffrey Liker, who has spent about 20 years studying Toyota, interpreted the Toyota Production System from a different angel and implied that the Toyota Production System is based on 14 principles (Liker, 2003). In Dr. Liker's explanation, the 14 principles were organized into four categories: philosophy, process, people, and problem solving, as illustrated in **Figure 8** below.

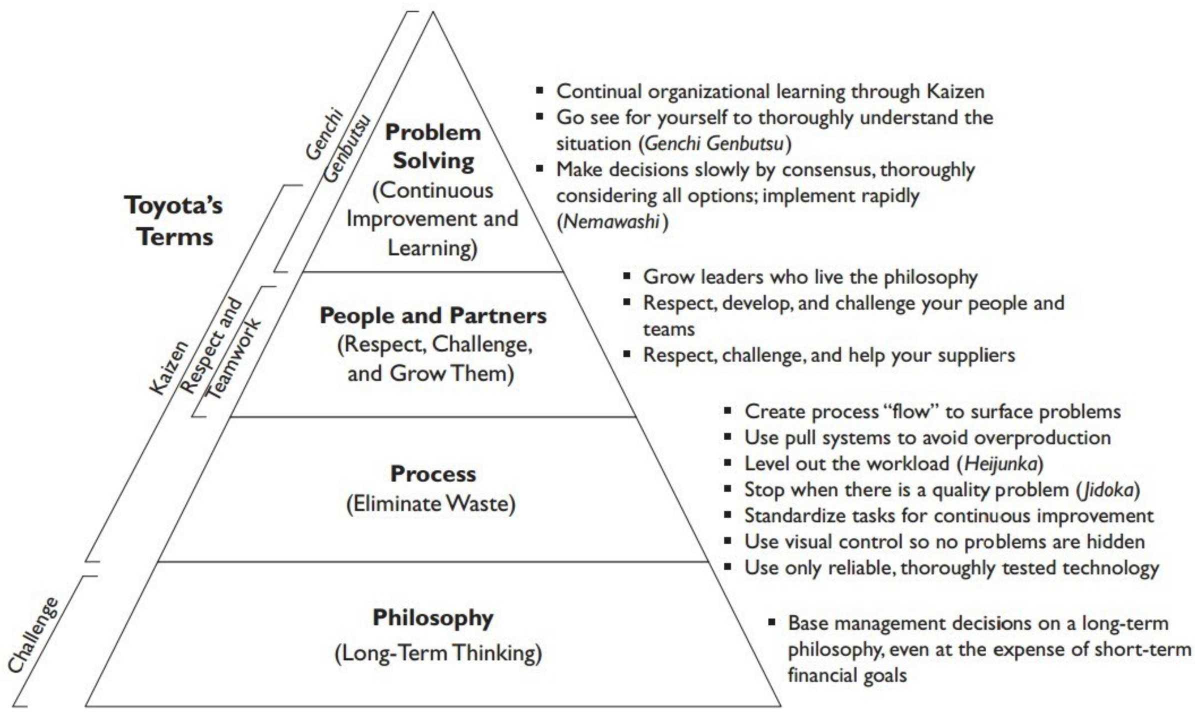

Figure 8 The "4P" Model of TPS Principles (Liker, 2003).

The first category, ***long-term philosophy***, stresses the importance of creating and focusing on a long-term goal for an organization. As Dr. Liker indicated, this is the principle that most Lean practitioners missed. Even for many companies that claim to have practiced Lean for years and are at the advanced level, few of them have truly integrated Lean with their long-term strategic planning. Without a long-term goal, any improvement will be short-term and not sustainable. The second category, ***process***, emphasizes having the right process to produce the right results.

From principle two to eight, it covers all the improvement methods and tools to use for the development of ideal processes, including creating a process flow, adopting a pull system, leveling out the production, timely problem solving, standardization, visualization, and using reliable technology (Liker, 2003), as show in **Figure 8.** The process part has been the focus of the majority of companies, probably because tools are more straightforward and they are mentioned more frequently by Lean practitioners or consultants. "***People and partners***" is the third category, including principle nine to eleven. This category underlines the importance of educating people not only inside the company, but also outside, such as partners and suppliers. Dr. Liker (2003) addressed repeatedly in his book that people were always treated as the greatest assets in Toyota. Most companies fail to implement Lean largely because they did not get the buy-in of their employees. For people development, as principle nine points out, a company should first grow a leader from within. This person should embrace the company's culture, understand the work, and be willing and able to coach others, because he or she will play a critical role in developing teams that can add value to the company. In addition to that, partners and suppliers are also key players in the value stream. Building collaborative relationships with external parties is also equally important. From principle twelve to fourteen is the last category, "***problem solving***". Problem solving requires people go to the worksite in order to thoroughly understand the situation. By checking the site themselves, people can learn more about the situation to make better judgment of root causes and provide appropriate solutions. In many organizations, top managers only read the problem reports instead of visiting the places where problems are identified. This can largely reduce the effects of problem solving. In additional to that, when solving a problem, people need to think thoroughly of all options and discuss with everyone that has been affected by the problem. Once a decision is made, it should be implemented quickly. The last principle stresses to make continuous improvements and become a learning organization. The success of Lean implementation is built on relentless reflections, daily corrections, and endless refinements of the process. Stable process should be created and stable personnel developed. Once those improvements have been accomplished, the organization should have a careful succession plan to continue and sustain the effort.

Value Stream Mapping (VSM)

As discussed above, value stream mapping is one of the process improvement tools under the umbrella of Lean management (Womack *et al.*, 2003). It is a process map that depicts a holistic view of manufacturing processes, from the time raw materials are purchased to the time finished products are delivered (Chen *et al.*, 2010; Shah *et al.*, 2003; Singh *et al.*, 2011; Womack, 2006). In addition to that, a value stream map also provides detailed information such as resources usage (i.e. labor, materials, and time), productivity at each stage, material and information flows between different stages, problems and bottlenecks at each stage, and a timeline of the whole process (Rother *et al.*, 1999). Therefore, compared to other historically used process maps in the industry, such as flow charts, BPMN diagrams, IDEF diagrams, and work flow diagrams, etc., value stream mapping has advantages as it contributes to the root cause analysis and helps to identify bottlenecks by presenting all main processes in a map with detailed deployment of key resources (e.g., number of people, process time, quality of the work, and inventory, etc.).

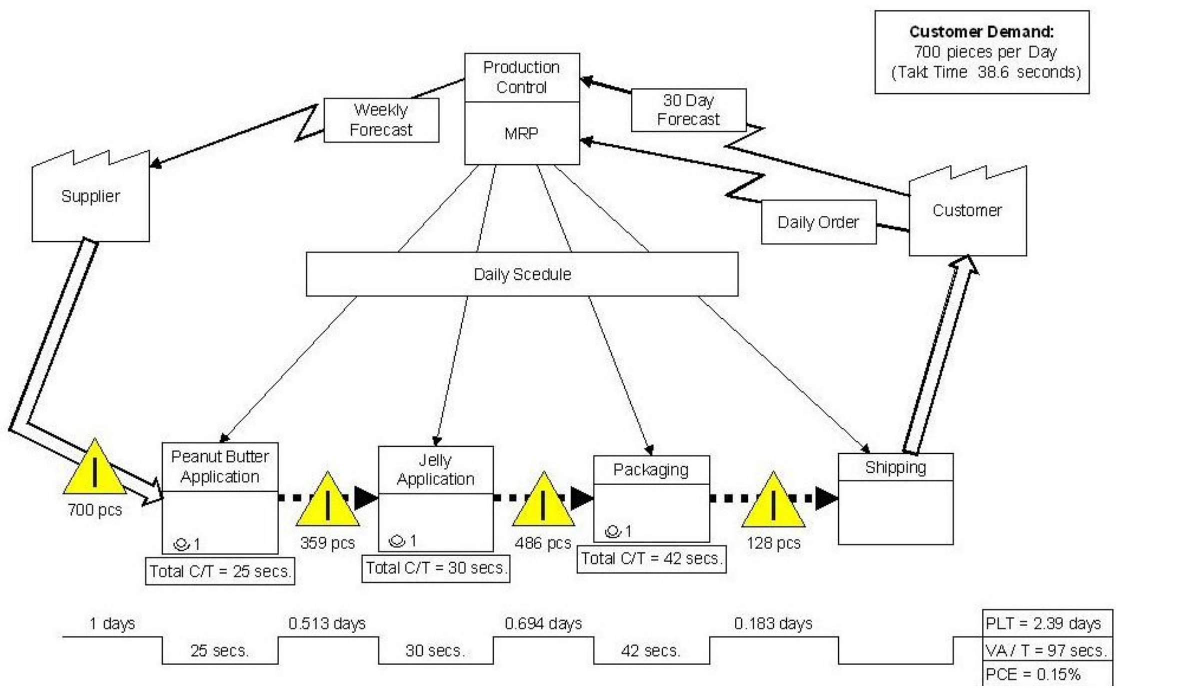

Figure 9 Example of a Value Stream Map (Pereira, 2014).

The first step of preparing a value stream map is to select a product or product family for investigation. Generally, selection criteria are based on the business need. It can be a product, the manufacturing process of which is representative for the company's most other products. It can be a group of products that share similar manufacturing process. Or it is one product or a group of products that represent the most profitable/troubled product category of a company. Therefore, in most cases, product selection is based on business need. As to the content of a value stream map, it contains mainly three parts, as shown in **Figure 9**. The top section of the map represents the information flow from the time an order is sent to the controlling center to the time a production signal is sent to the manufacturing floor. The boxes in the center demonstrate all the value-added activities in the process. Value-added means the conducted activity is what customers are willing to pay for (take the assembly of a door as an example: putting parts together is a value-added activity, while searching for parts is not value-added). At the bottom of the map, is the timeline that contains cycle time of each activity and the total lead time to produce one product. Except for the information mentioned above, the value stream map also displays other details of the production, such as inventories (i.e. raw materials, finished products, and work-in-process (WIP)), product defect rate from each activity, efficiency of each activity, and required number of operators, etc. In a general conduct of value stream mapping, a current state value stream map that reveals the most recent status of a process is drawn first. Based on analysis of production details provided by the VSM, process improvement plans are then created. For example, WIP is displayed in the VSM to provide an overview of the inventory situation within a manufacturing process (Womack *et al.*, 2003). A high WIP usually indicates a bottleneck, and it is one of the reasons that cause long lead time of a process. Hence, if a high WIP is seen next to a process, it indicates an opportunity for improvement and a sign of "kaizen burst" will be placed next to this process. "Kaizen" was a Japanese word that means making improvement (Rother *et al.*, 1999). When a "kaizen burst" is placed next to a task or an activity in the VSM, it gives a signal that this task needs attention and should be the focus for future improvements. Similar to the study of WIP, if analysis of other production data also reveals potential problems of certain tasks, kaizen bursts are given to these tasks.

Once all "kaizen bursts" are listed in the current state VSM, the process improvement project then proceed to creating a process improvement plan that aims to eliminate all kaizen bursts. At this point, an ideal state VSM is usually first prepared. As the word "ideal" indicates, an ideal state VSM represents the "best practice", in which all conflicts have been removed and kaizen bursts eliminated. The ideal state VSM serves as a long-term goal that guides the process improvement projects. To achieve the ideal state, multiple small-step improvements are to be done. These short-term process improvement projects are represented by future state VSMs. Similar to the ideal state VSM, a future state VSM is also used as guidance for a company's process improvement effort; while different from the ideal state VSM, future state VSM is a short-term goal. It is created based on the results of gap analysis between a current state and ideal state VSM, together with an evaluation of status quo. And it demonstrates the best a company can achieve in the current condition. Once all areas that are addressed on the first future state VSM have been improved, a new future state VSM is then drawn. This process is repeated many times until the ideal state is achieved.

Once the first future state VSM is drafted, one or multiple "kaizen events" are launched to deal with the kaizen bursts that are listed in the current state VSM. "Kaizen event" meant process improvement projects, which targeted a specific "kaizen burst" and aimed to solve the associated problem (Rother *et al.*, 1999). Therefore, one "kaizen event" was usually planned for one "kaizen burst". Expectation of "kaizen events" was to eliminate addressed kaizen bursts and accomplish the goal set by the future state VSM upon completion of process improvement projects.

When the "kaizen" concept was applied to this study, modifications were also made. In this study, making more research ideas commercialized with less time was the goal, therefore, low research outputs or long lead time would be the indicator for 'kaizen burst". In addition, "kaizen burst" also came from investigation of the most influential resources and organizational characteristics for research commercialization.

The value stream map described above is commonly used in manufacturing and is the original form from the Toyota Production System. When Lean is applied to other sectors of a company, such as the office environment, in order to serve special needs, the format of a value stream map evolves into a different form, as shown in **Figure 10** below.

The VSM in **Figure 10** is called a swim-lane VSM, because it contains horizontal lines that look like the swimming lanes in a pool. Except for the previously mentioned three main sections included in an original VSM, the swim-lane VSM has a new section on the left to provide information of key individuals or groups involved in the process. Similar to the activity layout in the original VSM, all main activities are arranged on the swim-lane VSM in sequence from the left to the right. However, the new layout is different from the original one in that each activity is placed in a different lane depending on which individual or group it belongs to.

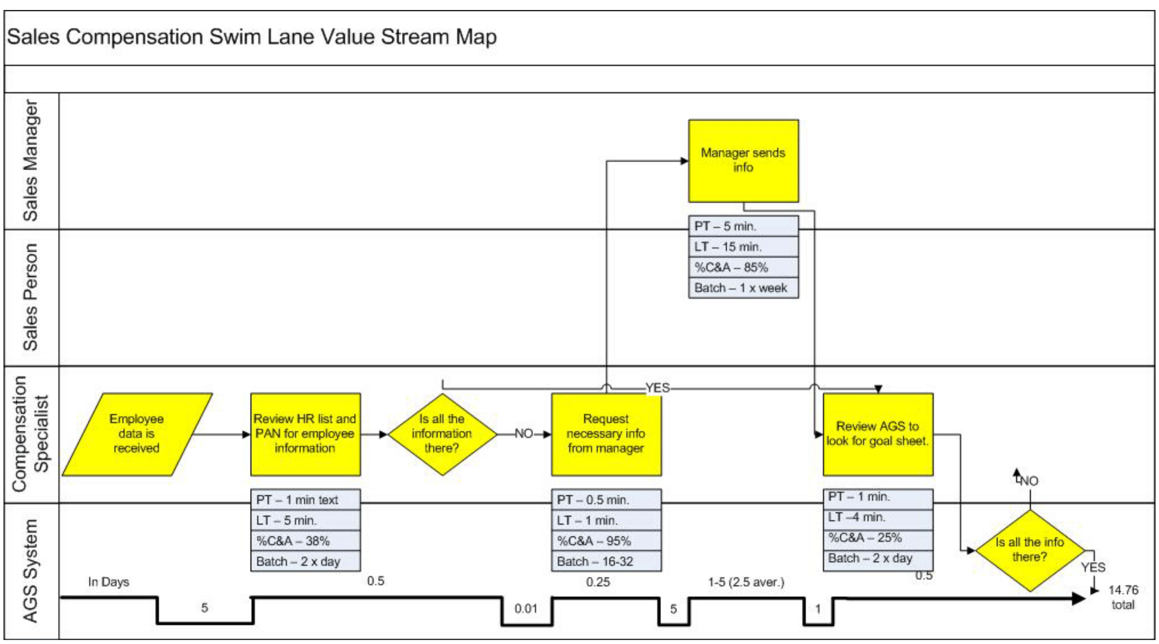

Figure 10 Example of a Swim Lane Value Stream Map (Sweet, 2014).

Application of Lean across different sectors

Manufacturing

Ingersoll Rand (IR) is a U.S. $14 billion global provider of diversified products ranging from indoor comfort systems, engine starting systems, pneumatic tools and motors, fluid handling systems, and refrigeration systems, etc. (Bell *et al.*, 2011). As a company in the industry adjacent to construction and housing, when the recession hit in 2008, IR was impacted dramatically and sales plummeted about 70 percent (Madison, 2013). Compared with its competitors, IR almost ranked at the bottom for every metric evaluated, including revenue growth, operating margins, return on invested capital, and working capital as a percent of revenue. When Keith Sultana, now vice president of Global Integrated Supply Chain for Ingersoll Rand Climate Solutions Sector, was hired to assist re-stabilization of the company, he worked together with two other leaders and decided to "Lean" their organization and achieve operational excellence. They started from the CEO of IR and gained his commitment to Lean transformation. The reform was then rolled out to IR's 18 pilot sites over the world (Madison, 2013). Each site of the company took the initiative and hired a consultant or a Lean specialist to facilitate the process (IES, 2012). In 2010, IR set the goal of achieving the top quartile performance among its competitors. Since then, with the lead of top management, IR has conducted numerous kaizen events and completed numerous process improvement projects across the company. To date, it has successfully built a Lean culture within the company. And most of the key metrics have increased by about 25%.

Research and Development

DJO Global, Inc. (DJO) is a global provider of medical devices, products, and services, with headquarters in Vista, CA (DJO Global, 2012). DJO Global began its "lean" journey in 2000 (DJO Global, 2014b). During its Lean implementation, DJO did not simply adopt the tools introduced by Lean. Instead, it integrated Lean principles into the company's culture and developed its own "The DJO Way". With more than a decade of experience in Lean, DJO has received numerous awards regarding its excellent operational performance, including Industry Week's Top Ten Best Plants in North America (2005), Outstanding Corporate Innovator (OCI) (2005), the Shingo prize for operational excellence (2006), and AME's Manufacturing Excellence award (2010) (AREADEVELOPMENT, 2014). Among all of the Lean projects, DJO's R&D departments has provided a good example of showing how Lean worked in a company.

In 2003, before DJO introduced Lean to its R&D lab, it faced the challenges of low new product release rate and long lead time to take new products to the market. To solve those problems and encouraged by the positive outcomes of Lean application at the company's manufacturing sites, DJO decided to also try Lean in its R&D lab. However, at that time, Lean research and development was not widely practiced in the industry (Radeka, 2012). Lacking guidance of how to use Lean in research and development, DJO chose to align all improvements to the two fundamentals of Lean: creating value and eliminating waste. During the search for non-value-added activities, DJO found its engineers spent less than 50% of their time on research, instead, they were buried by unnecessary activities, such us filing endless complicated paperwork, trying to figure out how to use project management tools, and conducting tedious routine testing. In an effort to solve these problems, DJO built a Lean culture at its R&D lab and continuously conducted kaizen events to eliminate waste. Inspired by the rapid prototyping processes reported in the industry, DJO launched a protostorming program to accelerate the process of creating working prototypes. In a protostorming process, people from different functional areas were invited to provide possible solutions to a design challenge. Once the group chose the most promising idea, they made and tested the prototype right away. If the prototype did not work, the team will discard the idea and move on to the other one. If it works, the team will repeat the brainstorming process and suggested adjustment of the design. With the changes made in the R&D lab, DJO released more than triple the number of products and reduced the product-to-market time by 60% (Radeka, 2012). As addressed in the company's website, DJO also used A3, a problem solving tool developed by Toyota, for the management of R&D projects extensively (DJO Global, 2014a). The tool got the name A3 because the report just fit on an A3 size of paper. With limited space, people had to be concise and brief when describing the problem, analysis, solution, and action plan. People can grasp the situation of a problem quickly using an A3. Therefore, managers can run a project at a faster pace and become free from preparing trumpery PowerPoint slides, writing tedious reports, and keeping check of long chains of emails (Radeka, 2012). In one project that aimed to reduce the approval lead time for start of production at DJO's Surgical R&D department, using A3, the process improvement team spent only four days and achieved 58% reduction of the number of forms needed and a 61% drop of signatures required (Radeka, 2012).

Education

Success stories of Lean implementation can be found in the university as well. The University of Central Oklahoma (UCO), a regional institution located in Edmond, Oklahoma, is one of the pioneers that have tried to use Lean to improve the process of different offices across campus

(Moore *et al.*, 2007). Before the Lean implementation in 2002, UCO faced the challenges of dramatic reduction of financial support from the state (about 15%) and increase of mandatory personnel costs. It became very urgent for UCO to look for ways to better use limited funds to maintain the normal running of current programs. A campus wide problem-searching survey, initiated by the Executive Vice President, identified that non-value added activities were the problems at most offices. Spending the majority of time on non-value added activities had created many delays in order processing and employee dissatisfaction. Noticing that those identified problem were very similar to what had been mentioned in other private sectors, the Executive Vice President made a bold move and decided to introduce Lean to lead the process improvement effort. Aided by Argent Global Service and Francis Tuttle Technology Center, both of which had gained extensive experience in applying Lean in non-manufacturing sectors, UCO completed Lean training for all administrative staff and developed a "4-step model" that would guide all its Lean venture. This model included:

> *"Step 1: Identify the Opportunities - Complete an organization-wide diagnostic search for issues, problems, and opportunities.*
> *Step 2: Solution Design - Create a blueprint for success that involves all employees: training, mapping, and planning.*
> *Step 3: Implementation – Use kaizen events, core teams, and metrics to implement and illustrate change.*
> *Step 4: Continuous Improvement – Monitor performance after projects are completed. (Moore et al., 2007)"*

Following their "4-step model", UCO first identified and selected the Facilities Management department as a pilot study and developed a process improvement team with staff from the department. The Facilities Management department was selected because it received the highest amount of complaints and its improvement would make the greatest impact on the campus. After that, value stream maps were drawn based on a two-week study of the process. When preparing value stream maps, the improvement team identified bottlenecks in the process and created a list of areas to improve. The following kaizen events were then designed and planned according to those areas. At the end of a five-day kaizen event, the improvement team achieved an 88.4% increase of pieces of paper generated, 80% increase of travel path of work order, 91.9% reduction of annual paper cost, and 89.2% reduction of average work order waiting time, etc. (Moore *et al.*, 2007).

With the success of Lean implementation at the Facilities Management department, UCO extended the effort to the rest of the departments on campus. As its report later concluded, Lean helped the university to accomplish more outcomes with limited staff, funding, and other resources. The overall customer satisfaction and employee morale had also largely increased. And because the Lean application went so well, UCO established "Lean University", a consulting group, that offered certification and process improvement consultation for those in higher education and government agencies (UCO, 2014).

Measures of university research commercialization performance

Measures of effectiveness

Due to the heterogeneous nature of research spin-outs, there is no developed benchmark for measuring the effectiveness of research commercialization among existing literature. The majority of the researchers have used the number of patents filed and issued as their dependent variables, taking advantage of easy accessibility of this information (Agrawal, 2001; Grimaldi *et* *al.*, 2011). However, as other scientists point out (Phan *et al.*, 2006), the applications and approvals of patents do not necessary lead to the success of research commercialization, because not all patents can finally be utilized by industries or be developed into a commercialized product. Therefore, some different metrics, such as the number of start-up companies (Rogers *et al.*, 2000), revenues (Markman *et al.*, 2005a), the number of products in the market (Phan *et al.*, 2006), and firm growth (Wennberg *et al.*, 2011), which are more related to the market performance of university innovation are used to test the effectiveness of research spin-outs.

Rogers *et al*., (2000) suggest that effectiveness of knowledge transfer can be better understood if all the steps within the process are considered. Instead of taking only the final outcomes of knowledge transfer as the evaluation metrics, they propose to develop individual variables to measure the effectiveness of each step. Steps within a commercialization process are shown in **Figure 11**. Following the flow of the steps, the number of invention disclosures is used to measure the success rates of research coming out of laboratories with commercial opportunities. The number of patent applications is a variable that measures the approval rates of patent applications for research. The number of technology licenses executed and the number of start-up companies launched is the metric for the step where universities start to look for companies to commercialize the research. The last variable, license income, is an indicator of financial performance of the company. Because the six variables are expressed in different units, to keep measurement consistent Rogers *et al.* (2000) convert each of the six variables to standard scores and average them. The average of all scores represents the level of effectiveness of the knowledge transfer process.

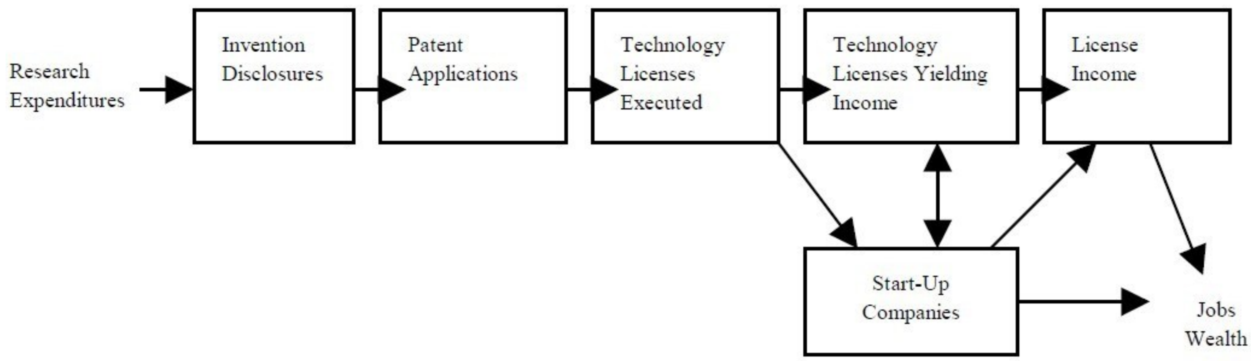

Figure 11 Variables to Measure Effectiveness of Each Step within a Technology Transfer Process (Rogers et al., 2000).

Rogers *et al*.'s (2000) evaluation model has advantages over other general approaches as it takes all stages within the commercialization process into consideration. The development and evolution of knowledge transfer is not simply a process with two ends, but with heterogeneous activities in between. These activities would influence the ultimate outcomes. When all of these activities are equally evaluated, a more comprehensive assessment of the effectiveness of knowledge transfer can be established. This research adopted the multi-stage evaluation model to test the effectiveness of research spin-offs.

Measurement of efficiency

In the past, when researchers mentioned the performance of university research commercialization, they usually referred to the effectiveness of the process as described above. Few people had addressed the speed of knowledge transfer. In fact, the ability to transfer knowledge to the market at a fast rate can be converted to a competitive advantage (Kessler *et al.*, 1996). As shorter cycle time of knowledge transfer allows an organization to fully relocate its resources to more successful products so as to maximum profit (McEvily *et al.*, 2004). Similarly, within a period of time, accelerated process time leads to more ideas being tried out and more research coming into the market (Markman *et al.*, 2005a). In an attempt to investigate the factors that impact the knowledge transfer time, Markman *et al.* (2005a) select individual-related factors (i.e. faculty and company), university technology transfer office, and resource-related factors as the main determinants and conclude the following: at the discovery stage, individual-related factors, such as faculty motivation and cooperation, have more impact on the commercialization time than resource-related factors do. At the research disclosure stage, faculty's familiarity with the research and involvement has greater impact on the process time than a company does; and at the stage of seeking for licensees, the commercialization time is negatively related with the level of experience of the university technology transfer office.

Impacts of different factors on research commercialization cycle time will be analyzed following Markman *et al.*'s stage model, aligned with the process-model we previously selected. Also, in addition to taking the overall cycle time of research commercialization as the dependent variable, we will also measure the cycle time of each step along the process and analyze how the efficiency of every step is affected by different factors.

Case Study

Rationales of a Case Study Approach

A case study is one of many other ways of conducting social science research, including surveys, experiments, histories, and archival analysis, etc. Depending on the research purpose, different methods are selected to serve the research's specific goals (Yin, 2009). The case study is very useful for understanding complex social phenomena, as it allows investigation of different characteristics of events and provides many types of evidence to support the research proposition (Yin, 2009). Same as other research methods, the case study method has been found commonly used in psychology, political science, business, anthropology, and economic, etc. (Yin, 2009).

Regardless of its common use in social science, the case study method is still generally viewed as a research method mainly for exploratory research by most scientists, while surveys and experiments are for descriptive and explanatory. In addition to that, it is said that the case study is weak in generalization. However, as Yin (2009) explained in his book, *Case Study Research: Design and Methods*, with proper design and different research propositions, the case study method was also suitable for descriptive and explanatory research. And to overcome the disadvantage of not generalizable, researchers could conduct multiple case studies like what they usually did for experiments, though not with the purpose to postulate but to expand and generalize theories. To some extent, selection of the case study as a research method is not restrained by the named limitation of not able to provide descriptive or explanatory analysis, but the initial research propositions and research environment (Yin, 2009). As guidance for research method selection, **Table 1** below provides the relationship between four types of frequently used research methods and types of questions, illustrating the condition under which certain methods are more appropriate.

Table 1 Conditions for Different Research Methods (Yin, 2009).

Method	**Form of Research Question**	**Requires Control of Behavioral Events**	**Focuses on Contemporary Events**
Experiment	what? how, why?	yes	yes
Survey	who, what, where, how many, how much?	no	yes
Case Study	what? how, why?	no	yes
History	what? how, why?	no	no

As shown in **Table 1**, the first factor a researcher should consider is the form of his or her researcher questions. Most research questions fall into a categorization of questions types like "who", "what", "where", "how", and "why". In general, a "what" question can be addressed by any of the three research methods listed, depending on the content of "what" is asking for. Take topics related to this study as examples, a question that focuses on the benefits of different school policies on the research commercialization outcomes can be addressed by either surveys or experiments. On the other hand, a question that intends to know the importance of establishing certain policy over the other can be accomplished by case studies. As to questions that involve "how many" or "how much" related inquiries, they can be better answered by conducting surveys. For example, if a study aims to identify all existing school policies on research commercialization, surveying all representative schools will better serve this purpose. A "who" and "where" question is somehow similar to a "how many" or "how much" question, to the extent that the intent is to describe the incidence or prevalence of a phenomenon, or to predict the happening of certain outcomes. For example, an investigation of the relationship between key persons or geographic locations and commercialization outcomes will find a survey the most suitable research method. At last, there are also "how" and "why" questions, which place more emphasis on understanding an event through a period of time or a series of stages. For example, how does a researcher commercialize his or her research? Or, why does a researcher make a choice to commercialize the research? For these types of questions, it is important to trace the operational details within the process. While it is out of the realm of a survey's capability to identify those details, however, case studies or histories can better address those issues.

After research questions are defined, choices of research methods may have been narrowed down to a few. To pick one or a few methods as the final research method, what a researcher can consider is the degree of focus on contemporary in contrast to a historical event and the extent of control over an event. Take the question that has more choice of research methods as examples, when a “how” or “why” question is asked, it leads to the options of three research questions: experiment, case study, and history. At this point, a researcher can start the selection process by first asking if he or she has current access to the event being studied. If it is a past event, meaning the event has ended and no living people exist to be interviewed, the history method will be a good choice. If the event is current, or not current but accessible, the researcher will still have the options of the above three research methods. At this stage, the researcher can evaluate the three research methods by considering the extent of control over the event, meaning if he or she can manipulate certain factors of the event so as to alter the resulting outcomes. Experiments will be the choice if the researcher can have direct interruption, on the other hand, histories or case studies are the choice if manipulation is merely possible or desirable. Histories and case studies are similar and have overlaps of techniques to the extent that they both use documents and physical artifacts as sources of evidence. However, case studies have a boarder selection of sources of evidence. The two sources that differentiate case studies from histories are direct observation and interviews of the persons that are involved or knowledgeable of the event. Due to those additional sources of facts, case studies deal with more detailed information and provide a more holistic view of an issue.

Because the main focus of this study is to understand the current university research commercialization process and investigate how this process can be improved for greater outcomes, following Yin's logic of method selection, the case study method is most appropriate for this study. First, this study is addressing a "how" question, intending to explore what has actually happened within a research commercialization process and investigate operational links over a period of time. Additionally, because research commercialization is generally heterogeneous and cases vary from each other (Rasmussen, 2011), it makes it difficult to collect a big sample size for result particularization. With the above consideration, this study chooses to take the approach of expanding and generalizing theories, so the options of research methods can be narrowed down to experiment, history, and case study. With regard to the extent of control over the studied event, the investigator played the role of an observer more than an executor. Commercialization is a complex and lengthy process. Though past research has identified key elements of the process and proposed generalizable paths, how influential factors impact the progression of commercialization is still not clearly known. Therefore, if research covers an end-to-end process of commercialization, the control of numerous factors is barely manageable. Alteration of a minor unknown factor can lead the progress of commercialization to a totally different direction. In this case, justification of proposed research proposition will become less possible. Therefore, this research chose not to take the approach of experiment. At last, in comparison of history and case study, as explained above, the history method largely focuses on analysis of existing documents or physical artifacts. While a research commercialization process usually goes far beyond what is written on the paper, the history method has its limitation and is not capable of capturing the dynamic characteristics of commercialization. The case study method, on the other hand, can use a wide range of data collection techniques. With the combination of various evidence, the case study can provide very insightful information about the studied event. As this study requires a method that helps to give a comprehensive view of the commercialization process and to detect operational links and potential causal relationship, the case study method is selected to serve this purpose.

Case Study Design

There are four basic designs for case studies, as shown in **Figure 12**. Single- and multiple-case studies are two design situations that a researcher can consider at the onset of case study design (Yin, 2009). A multiple-case study is usually preferred for a sound case study design as it produces multiple and comparable results to verify the validity of research findings. Like conducting experiments, a significant finding is more convincing if additional experiments replicate the same finding. With that being said, it does not mean that a single-case study is not appropriate. A single-case study is also justifiable under certain circumstances (Yin, 2009)

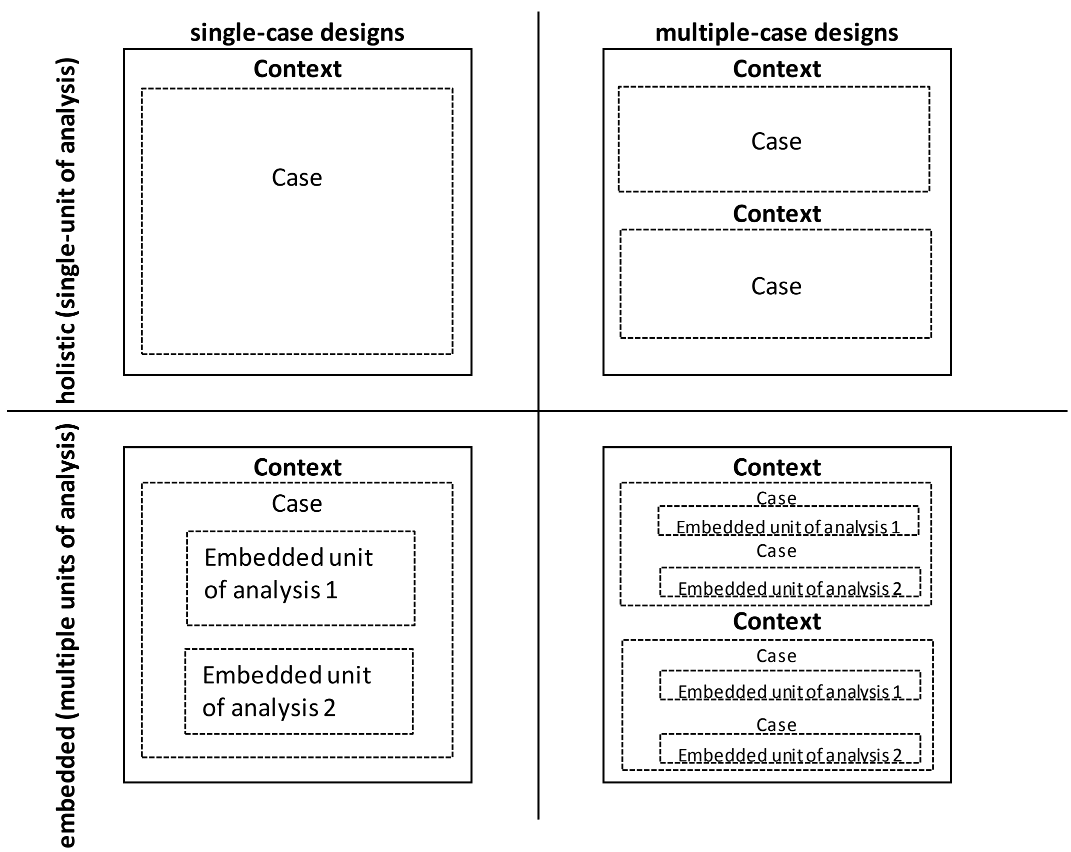

Figure 12 Four Basic Types of Case Studies (Yin, 2009).

- If a single case represents the critical case in *testing a well-formulated theory*: In this case, a theory has been clearly defined. A single case meeting all requirements of this theory is selected to test the research proposition.
- If a single case represents an *extreme case* of a *unique case*: In some circumstances, there can be a situation that happens suddenly or people have never met before. Fox example, an unusual disease. There may be only one patient found carrying this disease. An investigation of this disease then finds it hard to relate it to other cases that demonstrate the same symptoms. A single-case study design will be the only choice in this case.
- If a single case is a *representative* or *typical case*: There is also situations that a case is one typical unit of a group or population in which each unit shares similar characteristics, for example, a typical school among a group of other schools, a representative project among many other projects in a company, or a typical person of a society, etc. In a situation like this, a single-case study of those typical units is usually sufficient enough to generate results that are applicable and transferable to other units with similar characteristics.
- If a single case is a *revelatory case*: Here, an investigator is granted access to a case that was never accessible to researchers for specific reasons. Generally, a situation like this is related to politics, a business secret, a prohibited place or a sensitive topic, etc. An opportunity to study and analyze those cases is very limited and valuable. A single-case study then becomes the only choice.
- If a single case is a *longitudinal case*. The last situation exists when a study is about a case at different points in time. The goal of the study is to identify how a case changes over time and the focus is this specific case only.

It is very important for a researcher to make a decision between a single-case or multiple-case study. As explained above, it is not a rule of thumb that a multiple-case study is better. No matter which one to choose, it is the researcher's job to have all opportunities and limitations considered and make a choice that is not only theoretically but also empirically justifiable.

Except for the selection between a single-case study or a multiple-case study, as **Figure 12** demonstrates, for each case (under a single-case study or a multiple-case study) that is studied, there are also choices of unitary and multiple units of analysis (also called holistic and embedded case studies). Unitary unit of analysis, as the name indicates, involves investigation of only one unit under a case study. This approach takes a holistic view and analyzes the case as a whole. Multiple units of analysis, on the other hand, include a study of subunits. For example, a case study of a company may include the company's employees as subunits; a case study of a learning program may generate results related to the program's students; and a case study of an organization can involve investigation of numerous projects. Subunits are important elements of a case, like bricks of a house, constituting the case. Therefore, including studies of subunits helps to enrich the content of research findings and capture significant details that may be overlooked at the case level.

Chapter 2: Research Questions and Conceptual Framework

Research Questions

Past studies identified critical resources and organizational characteristics that impacted the performance of university research commercialization. However, it was not clear what actions a university could take to implement changes for improvement of its commercialization performance, and how it could realize full utilization of critical resources to maximize commercialization outcomes. This research aimed to fill this gap by conducting a case study of one university, investigating its current state of research commercialization, identifying potential areas for improvement, and providing recommendations of process improvement. To fulfill this goal, four research questions were developed to guide this research:

1. Can process improvement principles be adopted to develop a systematic framework that evaluates the university research commercialization's effectiveness and efficiency?
2. How can a university allocate its resources to maximum the effectiveness and efficiency of research commercialization outcomes?
3. Were the organizational characteristics of the targeted university favorable to research commercialization?
4. What are actions a university can conduct to improve its commercialization performance?

The Conceptual Framework

Introduction

To answer these questions, an existing theory of university research commercialization and operation management model (value stream map from Lean management) were integrated to study the process. In specific, as indicated in chapter one, a stage model was chosen as the foundation to frame the end-to-end process. Different from the phases initially suggested by a stage model, phases in our model were defined according to the critical points from a patent management point of view, as listed below:

- **Stage 1:** Conducting research - Invention Disclosure
- **Stage 2:** Invention Disclosure - Patent Application
- **Stage 3:** Patent Application - Patent Issued
- **Stage 4:** Patent Issued - Patent Licensed/Company formed
- **Stage 5:** Company formed - Sustainable Growth

This classification took the patent into consideration because the patent application process was consistent across different research fields and individuals. In a university almost all commercialization projects went through the stage of filling invention disclosures and patent applications. Therefore, while the commercialization process took a heterogeneous form, having a standard process that was applicable to most cases enabled a more reliable measurement and comparison of outputs within the process among different research projects. Additionally, the university generally used the numbers of patents published as key performance indicators to evaluate its commercialization performance. Hence, when this research analyzed the commercialization process according to the path of patent application, the chance of getting relevant data was more secure.

Once the structure of stages was determined, a value stream map (VSM) from Lean management was incorporated into the framework, as shown in **Figure 13**. As introduced in chapter one, this study adopted the format of a swim-lane-VSM. Listed on the top of the map, proceeding from the left to the right, were the five main stages within a commercialization process. Key individuals or groups that were involved in the process were listed on the left of the map. For demonstration purposes, "*person 1, person 2, person 3, and person …*" was used. In the middle section of the map, was the process flow that included all core activities involved in the commercialization process. Elements related to performance measurements were placed at the bottom of the map. In this study, evaluation of the commercialization process focused on measures of effectiveness and efficiency. In the map, these two elements were represented as "*outputs*" and "*process time*" respectively. "Outputs" referred to the research outcomes at each stage, and "process time" represented the total time consumed to complete one stage. The yellow "explode shape" demonstrated one of many kaizen bursts that could possibly be found during our investigation. As introduced in chapter one, kaizen bursts were Japanese words and they referred to areas that had potential for improvement. Kaizen bursts are very important elements in a VSM, as they provide a summary of main problems that exist in a process. Within the process of research commercialization, many kinds of problems can exist. While covering all issues that impacted research commercialization was beyond the scope of a dissertation, this study selectively focused on two factors that had been commonly investigated by other researchers, resource-related factors and organizational characteristic-related factors. Once identification of kaizen burst was completed, recommendations were developed with the goal to remove all kaizen bursts.

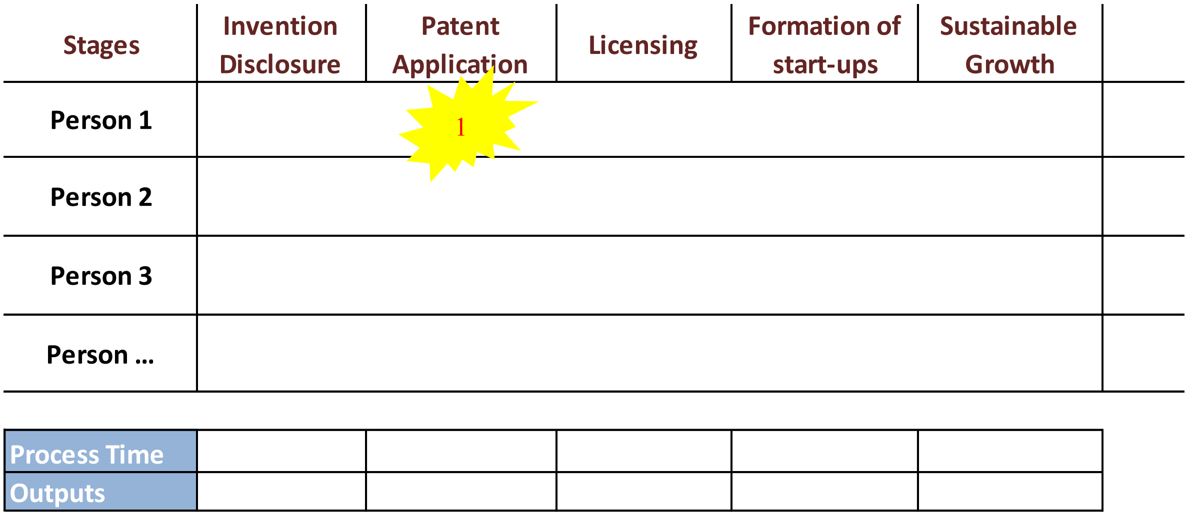

Figure 13 A Preliminary Value Stream Map (conceptual framework) for Study of University Research Commercialization Process.

From the description above, at the first glance, VSM would not been seen as a theoretical framework, but simply a tool that helped to organize important elements of a process. However, the map was just one reflection of this research. Behind the map, was the approach of value stream mapping and Lean principles that guided the analysis of data. Value stream mapping provided a different way of problem solving and it led the investigator to think about the whole process first before tackling any problems. Also, it helped to prevent myopia during investigation. For example, the investigator would have missed an important problem at the stage of invention disclosure without understanding the disclosure evaluation process at the targeted university. It had been found that there were not enough staff at the targeted university to review all disclosures in time and having sufficient staff was seen as critical to the performance of research commercialization. Based on the correlation provided, a possible conclusion to this problem would be to hire more staff. However, by studying the disclosure review process, it was found that because most invention disclosures were not prepared with complete or correct content, much time was spent on interacting with inventors for missing information. Most of the disclosures might have been reviewed and processed in time if there was not this excess work involved. Therefore, recommendation to this staff shortage problem turned out to be very different from suggested above.

Justification

In the field of operation management, cases conducted in manufacturing companies have proven that value steam mapping was beneficial for companies in improving production efficiency, as it provided many details of a process and the way a value stream map was created enabled identification of numerous problems (Chen *et al.*, 2010; Shah *et al.*, 2003; Singh *et al.*, 2011; Womack, 2006). Those advantages made value stream mapping a potential process study approach in this research, however, there had been concerns that value stream mapping might not fit well because a research commercialization process was not as linear as a manufacturing process and individual activities within the process were not visibly displayed. It would be a challenge to depict all commercialization-related activities in a map. However, as described in chapter one, there had been many successful implementations of Lean and VSM in the service industry, which had cases that presented very similar process situations as this research faced. Additionally, university research commercialization did follow a generic process that contained iterative activities, from the time a research idea was created to the time a product was made (Rasmussen, 2011), (Lockett *et al.*, 2005). For example, all commercialization projects needed approvals from the department; all patent applications should be processed by the university's office of intellectual properties, and there was usually a meeting among the inventor, the university's office of intellectual property, and industrial representatives for clauses on the licensing agreement, etc. If linked together, these commonly occurring situations could serve as the critical activities within a research commercialization process and a process flow could then be developed. Given the evidence above, investigators of this research decided to adopt value stream mapping to analyze the process of research commercialization at targeted university.

How were Research Questions Addressed?

To achieve the goal of improving current university research commercialization process, this research developed four research questions, as introduced above. From a holistic view, it could be seen that the first three research questions were all prepared to answer the fourth one, "what actions a university can conduct to improve its commercialization performance". In this research, these questions were answered in sequence, with studies conducted for the first three taken as part of the investigation of the last one. From a value stream mapping point of view, answering research question one was the first step of value stream mapping: identify the process flow. Research questions two and three then addressed the "kaizen bursts" that exited in the process. Research question four worked on creating plans that could be used to eliminate the identified kaizen bursts and developing an ideal research commercialization process.

During the investigation of the research commercialization process at the targeted university, the first step was to answer research question one and see if the actual research commercialization process at the targeted university fit with the theoretical framework as the map shown in **Figure 13**. If the answer was positive, a process flow could be drawn in the middle section of the current state VSM. Research question two looked for a resource allocation plan that could maximum commercialization outcomes with the least resources. In order to address that, it was important to first understand the current state of resource utilization within the process and how each type of resource impacted the performance of commercialization at each stage. With regard to resources, the four resource categories suggested by Mustar et al.(2006) were used as the guidance for this study: 1) technical resources, 2) human resources, 3) social resources, and 4) financial resources. Once the two questions above were answered, problems related to resources were identified and a resource allocation plan developed. As part of the value stream mapping process, these identified problems should be marked as kaizen bursts in the current state VSM. Research question three aimed to assess the current organizational characteristics of the targeted university. Because this research involved only one university, it was not possible to analyze impact of different organizational characteristics on the performance of commercialization on a "case-to-case" basis. Hence, findings from previous research were used as reference. If findings showed the targeted university was not favorable to commercialization in certain areas, these issues were built into the current state VSM as kaizen bursts. It was expected that problems beyond resource and organizational characteristic related issues could also be revealed during investigation. If any of these types of problems were found, they were listed in the VSM as well. The last step of this research was to address research question four, developing recommendations to improve research commercialization process at the targeted university. Under the scope of this research, recommendations covered issues related to resources, organizational characteristics, and other potentially critical issues. Following the approach of value stream mapping, an ideal state VSM of research commercialization process was first developed. An idea state represented a status in which all problems related to commercialization had been eliminated. To develop an ideal state, in addition to adopting findings from the studies of research question two and three, studies of research commercialization at existing companies were also conducted. Then, with a completed ideal state VSM, a gap analysis between the current state and the ideal state VSM was conducted to generate recommendations for the targeted university's research commercialization process. Under the terms of Lean management, recommendations that were developed at the end of this research were the future state VSM, which represented the short-term goals that could be achieved under current conditions.

Goal and Objectives

The primary goal of this research was to assess and improve the performance of a university research commercialization process. According to the research questions and the way these questions were addressed, five objectives were developed:

1. Investigate and determine the process flow of research commercialization;
2. Evaluate the impacts of difference resources on the research commercialization process at different stages, with regard to effectiveness and efficiency;
3. Access the organizational characteristics of the targeted university;
4. Identify other problems within the research commercialization process;
5. Develop recommendations to help the targeted university improve its research commercialization process.

Expected Outcomes

Two major outcomes were expected from this research.

1. A process model/framework that captures all the critical elements and activities within a university research commercialization process.
2. Systematic recommendations on how to improve the university research commercialization process.

Significance of the study

Adopting a process model to analyze the performance of university research commercialization was no longer novel in the field of management (McAdam *et al.*, 2006; McAdam *et al.*, 2005). However, integrating models from other disciplines to analyze the process, as proposed in this study, could be regarded as unique and innovative. This research took the first step to utilize a commonly used industrial operation management approach to study the processes of university research commercialization. Also, as this study was built on the merits of previous process studies of knowledge transfer, by introducing a new process-based methodology, findings from this research would contribute to the literature of university research commercialization. With completion of this research, university administration should have a better understanding as to how a university invention was commercialized, and how the process could be improved systematically.

Chapter 3: Methods

Overview of Research Methodologies

This research took a case study approach to analyze the research commercialization process in the university and to identify potential impediments or accelerators within the process. Virginia Tech (Virginia Polytechnic Institute and State University), Blacksburg VA, a leading land-grant universities and a top 40 research university in the U.S., was selected as the case for this research. Within a single case study, a literature review, a survey, and interviews were completed to address the four research questions of this study. For each research question, different methods were used, as described below:

For research question 1, "can process improvement principles be adopted to develop a systematic framework that evaluates the university research commercialization's effectiveness and efficiency", literature review and interviews were selected as the main research methods.

For research question 2, "how can a university allocate its resources to maximum the effectiveness and efficiency of research commercialization outcomes", survey was selected as the main research method.

For research question 3, "were the organizational characteristics of the targeted university favorable to research commercialization", interviews were selected as the main research method.

For research question 4, **"**what are actions a university can conduct to improve its commercialization performance", recommendations were developed based upon the findings for the previous three research questions.

Methodologies

Case Study Design

A single case study with embedded sub-units of analysis was designed to investigate the process of university research commercialization. A single case study approach provided investigators the opportunity to gain a deep understanding of how research ideas passed through different phases and eventually turned into a product. Sub-units of this study are research projects in a university.

Case Selection

As research commercialization usually occurred in the field of life science, engineering, chemistry, and related science or engineering-based disciplines, and mostly, U.S. land-grant universities provided degrees and research programs for such disciplines, the population under this study was the U.S. land-grant university. Virginia Tech (VT), located at Blacksburg, VA, was selected as the unit of analysis. The reason for selecting Virginia Tech for this case study relied on the fact that it had a rich research environment and it had tried to increase efforts to facilitate research commercialization the past few years (VirginiaTech, 2012). Virginia Tech provides research programs across many different disciplines, enabling selections of subunits from various research fields so as to avoid having bias from a specific area (Bhave, 1994). Also, Virginia Tech is associated with a research park where over 150 research, technology, and support companies are located. With regard to commercialization, numerous efforts and improvements had been made by the Virginia Tech Intellectual Properties Inc. (VTIP) to facilitate the handling of commercialization at Virginia Tech (VTIP, 2011). As the annual reports of VTIP indicated, the numbers of patents, license and option agreements, and startup companies licensed had seen steady growth for the past few years (VTIP, 2011). Also, as subunits covered by this study were all in Virginia Tech, identified relationship or correlation between resource-related factors and commercialization outcomes could be explained without interference of other factors such as geographic location, universities' relationship with industry, universities' experience with commercialization, and university policy (Di Gregorio *et al.*, 2003).

Case Study Execution

As introduced at the beginning of this chapter, multiple research methods were adopted to address the four research questions. For the first research question, to investigate if process improvement principles could be used to improve university research commercialization, a literature review was conducted to gain full understanding of established concepts and theoretical frameworks of studied topic (**chapter one**). After analysis of existing research, a new framework that served to assess the performance of university research commercialization was developed (**chapter two**). Once the theoretical framework was established, empirical evidence was ascertained through narrative interviews with a representative from the Virginia Tech Intellectual Properties Office (VTIP) and a professor that had rich research commercialization experience at Virginia Tech (**chapter four**). Answers obtained from the interview were used to verify the framework developed from literature.

The second research question, to identify the critical resources for research commercialization, was accessed by a combination of literature review and survey of subunits of the case (**chapter four**). Previous studies had provided a foundation with a list of resources that could be essential to the commercialization process. This study aimed to extend those findings and to provide elaborated assessment of how different resources were important to commercialization at different stages of the process. The questionnaire was structured into the five stages this study previous defined. The same set of questions was developed for each stage asking respondents their current state of resources availability, outcomes at each stage, and lead time of each stage. The questionnaire was designed in a way that respondents only need to answer questions suiting their experience. For each stage, at the end of the question list there was a "yes or no" question inquiring if the respondent had experience of the next stage. If the answer was yes, questions of the following stage would be displayed; if the answer was no, respondents would be led to the end of the questionnaire for general questions. At the end of the questionnaire, respondents were also asked if they were willing to participate in a one hour-long face-to-face interview. Respondents that answered yes to this question were selected as the samples for personal interviews. The population of the survey included all researchers from the College of Agriculture and Life Science, College of Engineering, College of Natural Resources and Environment, and College of Science. The ideal sampling of the selected population was to distinguish researchers with commercialization experience from researchers without. However, at this stage, because information with regard to faculty's commercialization experience was not accessible, no further sampling was conducted. The questionnaire was sent to the entire population electronically through Qualtrics.com. Completed and submitted questionnaires were also stored at the same website.

Following the survey, face-to-face interviews with selected respondents were conducted. This study was prepared for answering research question three (**chapter five**). As indicated above, the initial sample for interview was selected by participants' answers to the question at the end of the questionnaire during the survey study. Twelve respondents implied their willingness to participate in the interview. To increase the sample size, this study adopted the "snowball sampling" technique and asked referrals from the initial sample to generate additional samples. An invitation email was sent to each referee and only respondents that agreed to participate in the interview were included in the sample. The interview adopted a narrative and semi-structured approach. A list of questions, including both quantitative and qualitative questions, was prepared beforehand and used to lead the conversation. Quantitative questions were very similar to the ones that were asked in the survey study. Qualitative questions included but were not limited to:

a) What is your commercialization experience at Virginia Tech?
b) Is research commercialization common in your field?
c) What do you think are the most important resources to commercialize your research?
d) How were your commercialization efforts awarded?
e) And what recommendations do you have for other researchers and for the university, with regard to research commercialization?

During the interview, not all prepared questions were asked, as respondents might have answered some questions indirectly when responding to another question. Also, additional questions were asked if the answer was not clear, or the respondent brought up an unexpected finding that needed further investigation. Answers of interviewees were recorded by both hand notes and audio recording. While hand notes were used mainly to capture key words, audio recording was used to keep details of the answers.

The last section of the case study involved interviews with companies for development of answers for research questions four (**chapter six**). The commercialization process, or the product development process in a company was studied and compared with that of university. Two companies were selected for interviews. One was a small size company that originated from a start-up, which was formed by a Virginia Tech alumnus. Another company was a large corporation in the coating industry, referred by a Virginia Tech alumnus. Both interviews followed a narrative and semi-structured approach. The same set of questions with slight modifications was used for each interview.

At the end of this research, all information collected from the above three data collection phases was integrated to generate recommendations to improve research commercialization at Virginia Tech, following the value stream mapping approach (**chapter seven**).

Chapter 4: University Research Commercialization Framework Validation

Overview

This phase involved interviews with the Office of Intellectual Properties at Virginia Tech (VTIP) and a representative professor at Virginia Tech to gain a view of the commercialization activity at Virginia Tech and to verify the feasibility of the theoretical framework developed. Information received from the interview was also used to extend the information obtained from the literature review (i.e. Break the commercialization main stages into detailed activities in the process).

Objectives

Developed from the previous literature, a conceptual framework had been created at the beginning of this study. Because it was not clear if this framework could be adopted to analyze the current research commercialization process, the first objective of this research was to test and verify the feasibility of this framework.

Data Sources

To study the current commercialization activities at Virginia Tech, the Office of Intellectual Properties at Virginia Tech (VTIP) was first interviewed. An affiliated organization of Virginia Tech, VTIP was formed in 1985 to assist Virginia Tech with technology commercialization, including protecting the intellectual property rights of technology, marketing technology, and conducting technology commercialization. As stated in the organization's homepage, the goal of VTIP is "*to pursue innovative strategies to help translate scientific progress into tangible products, while returning income to the inventor and Virginia Tech to support further research* *and education*". VTIP is familiar with the research commercialization activities at Virginia Tech and it meets the requirements to be the initial data source of this research.

Another data source was VT faculty that had research commercialization experience. Information collected from the faculty provided an overview of the research commercialization from a different prospective. One VT professor from the investigator's department was selected. This faculty was considered because he had rich experience in patenting and had been active in commercializing his research outcomes.

Data Collection

An invitation letter was sent to an "info" email address found at VTIP's homepage. The invitation email included a brief introduction of the research, main researchers, purpose of the email, and a request to be referred to someone at VTIP that could provide relevant information of research commercialization at Virginia Tech. This inquiry email was replied to by a licensing manager from VTIP and an interview was arranged. A similar invitation email was also sent to the faculty member. The email included a brief introduction of the research, main researcher, purpose of the email, and a request to interview the faculty member. After the faculty member replied and agreed to have an interview, a meeting was arranged.

For both meetings, semi-structured interviews were designed and administered. A list of pre-prepared interview questions, designed based on the conceptual framework, was used to guide the interviews. Expected outcomes of the interviews were an overview of the current state of research commercialization activities at Virginia Tech, the general process flow or path of research commercialization, identified key individuals and resources involved in the process, and the role of VTIP throughout the process. The important questions to be addressed during the interview included:

1) What are the research areas that have active research commercialization at Virginia Tech? What is the current commercialization status at Virginia Tech?
2) What phases or steps will a researcher go through if he or she wants to commercialize his or her research?
3) How many people are involved in the commercialization process, and who are they?
4) What are the important resources that facilitate the commercialization?
5) What are the impediments that hinder the commercialization?
6) Does a researcher need help or support from the university, such as human resources, technical supports, funding, etc.?
7) What is the average lead time of commercialize a research idea?

Results

Similar to what was found in the literature, the university research commercialization process involved different stages. Typically, if the faculty or researcher decided to commercialize research results towards completion of experiments, he or she would contact the VTIP and submit a business proposal for invention disclosure and patent application. From here, VTIP started to play more roles in the commercialization process. First, VTIP would review the business proposal and communicate with the faculty for changes that needed to be made. When both sides felt the business proposal was ready for a patent application, VTIP would file an IP application with the U.S. Patent Office. After receiving a patent, the faculty could either start a company with the patent or license it to existing companies. No matter which approach was taken, VTIP would assist with marketing or with searching for investors throughout the process.

From VTIP's perspective, the most important resource for commercialization was inventors' industrial connections. It was indicated that involvement of faculty and faculty's social network played an important role in the process of commercialization. For the cases in which research commercialization was processed faster and had higher success rates, faculty either knew in advance the market opportunities of the research or they had developed industrial connections to promote the inventions. Due to the limited human resources at VTIP, research commercialization would take longer if the faculty did not have experience and relied solely on the performance of VTIP. As to financial resources, it was rated of high importance. However, as the representative from VTIP implied, financial support usually came from the industry or investors. If the faculty already had industrial connections and industrial involvement at the beginning, financial resource were less likely a problem. Interviews with the faculty revealed similar answers. It was said that faculty should be more proactive and search for industrial connections at the early stage. While faculty usually had little business experience, frequent interaction with industry helped them to refine the research and tailor it to be more applicable to the market.

While both VTIP and the faculty indicated the importance of financial support for research commercialization, it should be noted that there was distinct differences between the funding for conducting research and that for promoting research to the market. Generally, financial support for research could only be used for conducting the research as described in the grant proposal. For activities that were beyond the scope of the proposal, such as commercializing research outcomes to the market, additional funds should be acquired. Interviews with faculty revealed a general path of research grants application process. Usually, once faculty completed the grant proposal, he/she would submit it to the department head and college dean for signatures. After that, the proposal was sent to the Office of Sponsored Program (OSP). At Virginia Tech, OSP was responsible for reviewing the proposal and getting in touch with institutes that provided research funding. Once the institutes approved the proposal, OSP would notify the professor. Research grants were generally applied for at the very early stage of the process, close to the time when invention disclosure was filed. Therefore, the interviewee was also asked about the sequence of grant application and invention disclosure. It was indicated that there was no clear separation between these two steps. Invention disclosure was filed whenever there were enough data after some preliminary experiments, which could happen before or after the application of the research grant. When asked about the funding sources for conducting the preliminary experiments, the interviewee responded that the funding could come from either department or research grants from other projects. In all, getting research funding was also hard for faculty. Most research ideas could not be realized in the lab because a research grant was not available.

Out of the scope of the interview questions, the licensing manager from VTIP brought up an important factor that could also impact the success of research commercialization, university policy of licensing royalty. As the policy indicated, licensees should pay an agreed upon royalty (around 30%) to the university for any licensing of Virginia Tech owned patents. While this policy helped the university to create economic benefits, it might also impede the commercialization process in many ways. First, most companies did not want to pay the royalty. It was very common that they tried to negotiate with VTIP for a waiver and discontinue the interests if a waiver became not possible. This hesitation could largely reduce the chance of getting research outcomes into the market. Secondly, even if the company was willing to pay for the royalty, it was difficult to reach an agreed upon royalty fee between the company and VTIP. Royalty fee was positively related to the commercial value of an invention, calculated as the product of a fixed rate and estimated market value of the invention. Therefore, if an invention had an estimated high market value, the royalty fee would be high, and vice versa. Generally, it was less difficult to estimate the value of an existing product or new products that have comparable counterparts in the market. For novel research or products coming out of university, however, making an estimate was challenging. It was close to a pure guess to project the revenue a new product could bring in for the long term. Therefore, while the estimated market value of a new product was questionable, making a decision of royalty fee became hard accordingly. Endless discussion and negotiation of the royalty fee could not only delay the progress of research commercialization, but also end the commercialization project.

After the preliminary interviews, a preliminary value stream map was created based on the information gained from the interviewees, as shown in **Figure 14**. In this case, as the actual commercialization process matched the framework developed, it could be concluded that the conceptual framework was compatible with the empirical process of research commercialization. The top section of the map illustrated the process flow within the whole commercialization process. As seen in the map, the process was divided into five main stages, including invention disclosure, patent application, licensing, formation of start-ups, and growth of start-ups, as described in the literature (Rogers *et al.*, 2000). Under each stage, sub-stages that indicated the activities and related parties were depicted. The bottom section of the map provided key measurements at each stage, including value-added time, cycle time, and research conversion rate. As indicated above, these measures were the dependent variables to be analyzed in this study.

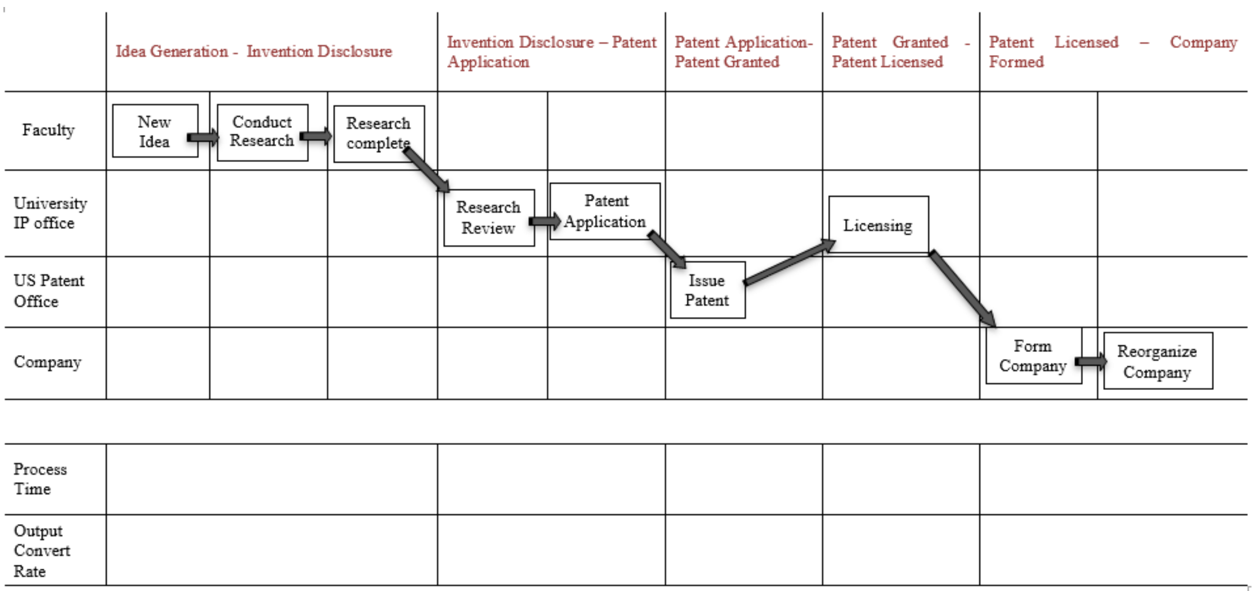

Figure 14 Preliminary VSM of Research Commercialization Process at Virginia Tech.

Chapter 5: Identify the Most Important Resources for Research Commercialization

Overview

At this stage, to identify the most important resources, a campus-wide survey was conducted targeting Virginia Tech faculty and researchers that had experience with research disclosure, patent application, patent licensing, or establishing a company from research outcomes. Data collected from the survey was the main source for analysis. The importance of different resources on research commercialization was analyzed according to the defined five stages within a commercialization process:

Stage 1 conducting research - invention disclosure,

Stage 2 invention disclosure - patent application,

Stage 3 patent application - patent issued,

Stage 4 patent issued - patent licensed/company formed,

Stage 5 company formed - sustainable growth.

Objective

According to research question two, the goal was to identify the most influential resources at each stage of the commercialization process.

Methods

Sample

Population of this study consisted of all Virginia Tech faculty and researchers that had experience with research disclosure, patent application, patent licensing, or establishing a company from his/her research outcome, from the College of Engineering, College of Agriculture & Life Science, College of Natural Resources and Environment, and College of Science. This group was considered because the study focused on research that created tangible products and the above selected colleges were viewed as the most relevant. Virginia Tech has more than 3300 faculty members and researchers (Lovegrove, 2013). Considering this number also includes a population from the research areas that do not involve working on tangible research (e.g. College of Architecture & Urban Studies, College of Business, College of Liberal Arts & Human Sciences), our sample frame would be less than 3300. After a manual search at each targeted department's webpage, a dataset of email addresses of 1110 researchers was identified, including faculty, research scientists, and post-doctoral students. This research had intended to conduct sampling by separating the 1110 based on their experience in research commercialization. However, as there was no public information available indicating the experience level of the contacts, no further sampling was conducted, resulting in a sample size of 1110.

This research conducted an online survey with Qualitrics.com. A questionnaire was first developed in Microsoft Word. Contents of the questionnaire were then transferred to a pre-setup questionnaire account at Qualtrics.com. Once content transfer was completed, the email addresses of 1110 contacts were also entered into the online administration system. With the aid of questionnaire administration system at Qualtrics.com, the questionnaire was sent to the email address of all 1110 contacts.

Questionnaire

Independent variable: Independent variables were resource-related factors: technical, human, social, and financial resources factors. For technical related resources, we mainly referred to the materials and equipment needed to conduct research and the technology. Human resources included quantitative and qualitative aspects of faculty, professionals, and staff at VTIP. Social resources referred to individuals' social networks. Financial resources included the funding for both research and commercialization. **Table 2** below provides a summary of the factors for independent variables.

Dependent variables: Multiple dependent variables were used in this study to measure the effectiveness and efficiency of university research commercialization. As **Table 3** shows, the measures of variables related to effectiveness focused on tangible outcomes at each stage, and variables related to efficiency on the time consumed for each activity.

Table 2 Resource-related Factors that Influence the Performance of University Research Commercialization.

Resource-related Factors	
Technical	• Technology • Research materials • Research equipment
Human	• Research staff/assistant • Research experience of research staff/assistant • Assistance from the IP Office • Business experience of the IP Office • Leadership of the entrepreneur
Social	• Connections with the industry
Financial	• Governmental funding faculty receive for research • Industrial funding faculty receive for research

Table 3 Variables to Measure the Effectiveness and Efficiency of Research Commercialization.

Stages		Invention Disclosure	Patent Application	Patent Approval	Licensing	Formation of Start-ups
Effectiveness	Variables	No. of research disclosures	No. of patent applications	No. of patents	No. of licenses	No. of established start-ups
Efficiency	Variables	Process time	Process time	Process time	Process time	Process time

The questionnaire used both closed-ended and open-ended questions. For closed ended questions, a Likert-type-scale was used. The final questionnaire consisted of three sections. The first section included a pre-screen question that asked respondents if they had experience in either of two activities that were related to commercialization experience, i.e. applying for an invention disclosure and applying for a patent. As both researchers with or without commercialization experiences were included in our sample, this pre-screen question helped to select only respondents that were relevant to this research to answers the rest of the questions in the questionnaire. The second section consisted of questions that were the core of the questionnaire. This section was divided into five categories, with each category covering one of the five stages within the research commercialization process. The same sets of questions were asked in each category. Data collected from this section included respondents' perception of availability of different types of resources, research outputs at each stage, and lead time of each stage. **Table 4** provides a list of the main information collected in this section. The last section of the questionnaire included questions that described background information about the respondents (e.g. position, associated department, and research area), rating of quality of different resources, and their willingness to participate in a face-to-face interview.

Table 4 Detailed Content Information in the Questionnaire.

Category	Contents	Units	Type of data
Resources Type	Availability of this type of resource at defined stage of commercialization	5 point Likert scale	Numerical
Effectiveness	The outcome at each stage	Number	Numerical
Efficiency	The lead time for each activity	Day	Numerical

The web-based questionnaire was stored and managed through Quatrics.com. A complete copy of the questionnaire can be found in **Appendix D**. Prior to sending the questionnaire, approvals from Virginia Tech's Institutional Review Board (IRB) for the questionnaire, the invitation letter, and the thank you letter were obtained (**Appendix G**).

Questionnaire Pretest

The first draft of the questionnaire was reviewed by two faculty members for verification of the questionnaire's thoroughness and clarity. After adjustments, a pretest was executed among five randomly selected faculty members and an invitation email was sent to each (invitation letter for pretest can be found in **(Appendix B)**. After that, a two-week time frame was given for responses and one reminder email was sent in between (reminder letter for pretest could be found in **(Appendix B)**. At the end of the pretest, three questionnaires were submitted and feedback was received from one faculty member. Modifications were then made according to faculty's feedback on the premise that the recommendations did not alter the intent of the survey.

Questionnaire Administration

The survey was sent to respondents through the automatic email delivering system of Qualtrics. The first invitation email was sent to 1,110 respondents on September 2, 2013. The invitation email included a brief introduction of the research, a request to fill out the questionnaire, a link to access the online questionnaire, and a noted deadline for participation (invitation letter can be found in (**Appendix C**). After that, three reminder emails were sent on September 16, October 7, and October 21, 2013 (reminder letter can be found in (**Appendix C**). All responses received were recorded and stored in Qualtrics.com. An overview of distribution of responses received over the two month period is found in **Figure 15**.

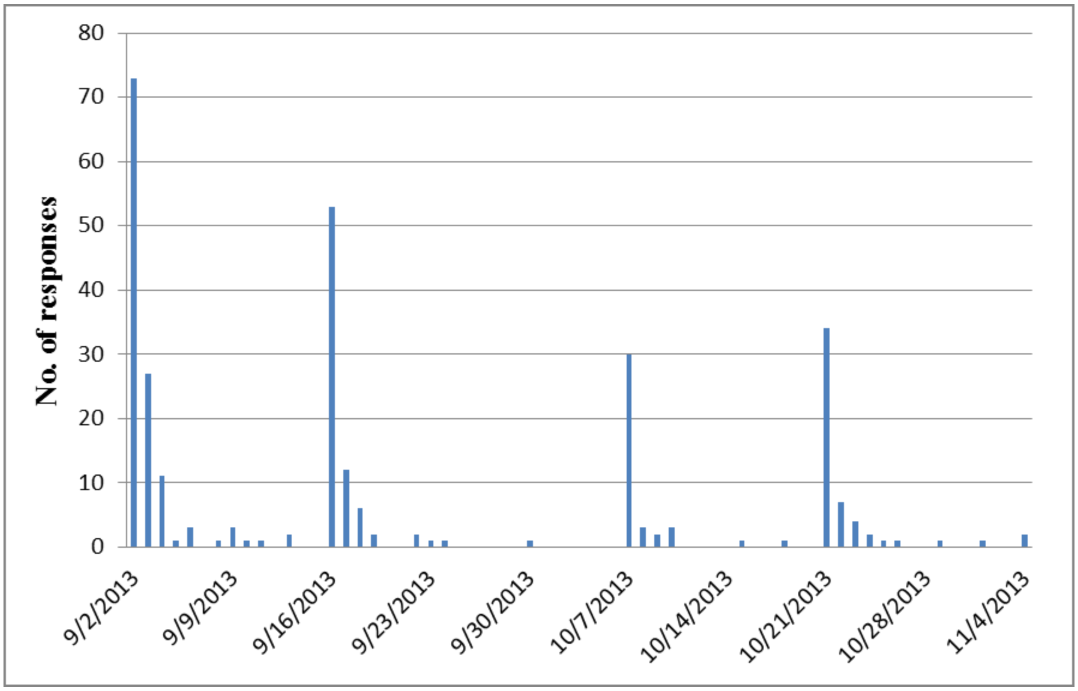

Figure 15 Responses of Questionnaire per Day.

Hypotheses

To address the objective of identifying the most important resources for commercialization, hypotheses below were developed to guide the investigation. As this study aimed to evaluate different types of resources specifically at each stage of commercialization, hypotheses on the relationship between resources and output were established according to the five stages developed.

Stage one: *Period between conducting research and invention disclosure*

It was not uncommon that faculty or researchers did not have the intention of commercialization. Most of their time was spent on refining the research towards scientific perfection and academic accomplishment (Vohora *et al.*, 2004). The moment of recognition of commercial opportunity normally came unplanned. Even so, Vohora *et al.* (2004) found that commercialization champions were normally the ones that were also top researchers in their field, regardless of their business experience. Therefore, academic accomplishment of the researcher could be a key factor in determining the outcomes of commercialization. Previous studies also indicated that the initial phase of the research commercialization was critical for the future development (Rasmussen *et al.*, 2010). Early market proposition of the potential product provided direction for product development and avoided late product modifications. Therefore, decisions were to be made in terms of the direction of future business. To make sound decisions, either the inventor should have market-driven perception or the professional from the IP office should be able to help and identify commercialization opportunities (Grimaldi *et al.*, 2011). In general, faculty or researchers in science or engineering were not familiar with commercialization. Even if they were, there were time constraints between conducting research and running a business at the same time. Therefore, the assistance of experienced professionals from the IP office became very critical. Financial condition was also important at this stage since conducting a research project requires sufficient research funding to hire research technicians and to purchase supplies. Technical resources, including raw materials and equipment, were of little impact on the effectiveness of commercialization because the availability of research funding had more or less determined the availability of technical resources. However, technical factors could play an important role in determining the time to complete the research. While conducting research, researchers might find the suppliers of research materials out of stock or the equipment in need was occupied by others. Any one of these conditions could prolong the research time. Finally, the role of social resources in the role of the commercialization process had also been discussed in existing literature (Markman *et al.*, 2008; Perrinia *et al.*, 2010). Early interaction with industry people helped researchers to shape the business ideas and make the new product more favorable to the market (Lockett *et al.*, 2003). Hence, we proposed:

- **Hypothesis 1a**: Between the period of conducting research and invention disclosure, *researchers' academic proficiency*, *research funding,* and *experienced professionals from the IP office* were more important than other resources in determining the effectiveness of research commercialization.
- **Hypothesis 1b**: Between the period of conducting research and invention disclosure, *researchers' academic proficiency*, *research funding*, *experienced professionals from the IP office*, and *research materials and equipment* were more important than other resources in determining the efficiency of research commercialization.

Stage two: *Period between invention disclosure and patent application*

In most cases, the research was not complete upon application of invention disclosure. More work was needed before the research outcomes qualified for patent application. Therefore, in this period, the main activities involved research refinement and patent application preparation. A researcher's technical proficiency played an important role in taking the research further to the phase of completion. Meanwhile, preparation of patent application required the person that handles it being familiar with the application process. However, not all of the researchers were fully knowledgeable of patent application. Professionals from the IP office were better candidates that could facilitate the process. We proposed:

- **Hypothesis 2:** Between the period of invention disclosure and patent application, *researchers' academic proficiency* and *professional competency of the personnel from the IP office* was more important than other resources in determining the effectiveness and efficiency of research commercialization.

Stage three: *Period between patent application and patent issued*

At this stage, a patent application had been submitted to the U.S. Patent and Trademark Office (U.S. Patent Office). Not many activities were required from researchers or the university IP office unless a request was made by U.S. Patent Office for more information. In the case that changes were needed, as long as the researcher can revise and re-submit the application promptly, the time needed to obtain the patent largely depends on the process time of the U.S. Patent Office. In terms of the application outcome, soundness and novelty of the research was the main factor with high impact. For this period, we propose

- **Hypothesis 3b:** Between the period of patent application and patent issued, *soundness and novelty* of the research was more important than other resources in determining the effectiveness of research commercialization.

- **Hypothesis 3a:** Between the period of patent application and patent issued, *researchers' academic proficiency* is more important than other resources in determining the efficiency of research commercialization.

Stage four: *Period between patent issued and patent licensed/company formed*

At this stage, the main agenda for commercialization has largely departed from the academic research and involved more business-related activities, such as marketing the research, accessing and acquiring resources, managing the operation, and developing social networks. However, as many studies point out, lacking such business skills was one big drawback of academia (Clarysse *et al.*, 2004; Lockett *et al.*, 2003; Rasmussen, 2011). Many patents could not be licensed and lots of research ideas failed to be turned into companies because the inventor was not able to translate the technical merits of the new product into commercial values. Therefore, to license a patent or form a company, a person with rich business experience was needed (Vohora *et al.*, 2004). Licensing would not require more financial support. Forming a company, on the other hand, was in great need of capital. With insufficient capital, the required resources, such as employees, may not be available; and ongoing projects would be postponed or cancelled. Pursuing seed money or venture capital was almost one of the daily activities for every entrepreneur. In this regard, social networks became another critical factor in the success of commercialization. Being acquainted with industrial people or investors provided entrepreneurs the opportunities to present the business idea to a variety of investors for potential venture capital. Therefore, we propose here:

- **Hypothesis 4:** Between the period of patent issued and patent licensed, *inventors' business experience* and *relationship with the industry* is more important than other resources in determining the effectiveness and efficiency of research commercialization.

- **Hypothesis 5:** Between the period of patent issued and forming a company, *entrepreneurs' business experience*, *financial support*, and *relationship with the industry* is more important than other resources in determining the <u>effectiveness</u> and <u>efficiency</u> of research commercialization.

Data Analysis

Missing Responses

All responses of the questionnaire were automatically stored and organized in Qualtrics. After the survey was terminated, data were transferred into a Microsoft Excel file for analysis. A thorough review of the data revealed that not all of the responses satisfied the need for analysis. As **Table 5** shows, out of the 294 responses, 1 was reported as spam, 85 were submitted blank, and 132 indicated having no experience, leaving 74 questionnaires with commercialization related inputs, a useful response rate of 6.67%.

Table 5 Summary of Responses from Submitted Questionnaires.

Questionnaire Category	No.
Total received submitted questionnaires	294
Spam	1
Blank questionnaire	85
Indication of no experience	134
Questionnaires with inputs	74

In addition to the online submission, the investigator also received private emails from 73 respondents indicating their unavailability of participation. Their reasons were summarized and displayed in **Table 6**. It could be seen that the most common reason of not filling out the survey was "*having no experience*". This category included respondents that indicated they do not have commercialization experience also ones that said the questionnaire did not apply to them. The rest of the reasons included "*Don't do survey*", "*Busy*", "*Retired*", and "*Left VT*", etc. In general, if a private rejection email was received from a respondent, his/her contact information would be removed from the distribution list and no more reminder emails sent to them. It is noted that among those respondents, some of them mentioned they did try to fill out the survey but later on found their situation did not apply.

Table 6 Summary of Reasons of No Response Received by Email.

Reasons of no response	No. of respondents
No experience	48
Don't want to do survey	3
Busy	6
Retired	7
Don't think the questionnaire made sense	1
Left VT	2
No reason was provided	6

A reasoning process was conducted to understand why blank questionnaires were received. At the technical side, the Qualtrics system had been set up in a way that any questionnaire would be submitted automatically after a period of time if it had been opened once. Therefore, it was at least certain that those questionnaires had been accessed by the respondents. As to the reason why respondents did not continue to fill out the questionnaire, it was suspected that most of the respondents did not have related experience and they realized that while reading the introduction at the first page. Because respondents with no commercialization experience were not the target of this study, the 85 blank questionnaires, together with another 134 that contained "*no experience*" as inputs, were deleted from the dataset. This removal resulted in 74 analyzable responses.

Missing Data

Except for questionnaires with no input, the investigator also found missing inputs in few of the final 73 questionnaires. In summary, four types of missing data were identified among the responses. Depending on the nature of missing data, different treatments were used following Howell (2007) 's methods.

<u>**Type I:** Single missing data among independent variables</u>

Independent variables in this study involved various resource-related factors. Respondents were asked to provide their perception of availability of each type of resource by clicking a bubble related to the availability level. It was found that a few respondents had missed one variable when all other variables were addressed. With regard to this type of missing data, it was assumed that they were missing completely at random (MCAR) (Howell, 2007). **Regression imputation** was used to replace missing values with predicted ones. For example, if an answer for research materials was missing, and correlation was found between variable of research materials and research equipment, a value could be estimated based on the regression between these two variables. In total, **6** missing data of this type were identified and solved with regression imputation.

<u>**Type II:** Single missing data among dependent variables</u>

Dependent variables in the questionnaire included outputs and lead time of each stage of the commercialization process (e.g. the no. of proposals, the no. of invention disclosures, and the no. of patents, etc.). Based on comments the investigators later received from interviews with faculty, the most possible reasons that respondents skipped these questions was that they were not sure of the answers. Therefore, the data was missing not at random (NMAR) (Howell, 2007). In this case, each type of missing data was treated individually as discussed below:

No. of grant proposals: 2 missing data were found for this variable. It is very likely that respondents skipped this question because they had too many grant proposals that they had lost count. If data were normally distributed, their responses should lie on the upper tail of distribution. Therefore, calculated mean would be higher if this type of data was not missed. However, as there were only two missing data, their impact would not be significant. A method of **listwise deletion** was adopted to handle this type of missing data (Howell, 2007), meaning ignoring the missed data and analyzing all cases with available values.

No. of invention disclosures: No missing data of **Type II** was found for this variable.

No. of provisional patents: 1 missing data was identified. A review of the whole dataset revealed that the respondent belonged to category 2 and he or she also indicated having zero invention disclosure in previous question. Therefore, an estimate was made that this respondent might have applied for a patent directly skipping invention disclosure and provisional patent. **Listwise deletion** was then used to treat this missing data.

No. of patents: No missing data of **Type II** was found for this variable.

No. of licenses: No missing data of **Type II** was found for this variable.

No. of companies: No missing data of **Type II** was found for this variable.

Type III: Complete missing data for continuous sections

This type of missing data referred to the situation where respondents had answered questions in one or more sections, but completely skipped the questions in the following sections. For example, one respondent had indicated having experience in applying for a patent. In the questionnaire, questions related to both invention disclosure and patent application would be displayed. However, this respondent only answered the question related to invention disclosure and missed the rest for patent application. 5 responses with this pattern were identified and grouped into type III missing data. Except for the pattern above, it was found that these five responses also shared another common characteristic. While the questionnaire's middle section was skipped, the last section including questions of respondent's background was addressed. Therefore, it was assumed that this data was NMAR (Howell, 2007). Respondents had answered the questions selectively and intentionally omitted several. Because those respondents had the intention to complete the questionnaire, the best explanation of missing data was that not all of the questions apply to their experience. In this regard, those respondents' inputs were unrelated to the outcomes of this study. The missing data was then removed from future analysis, following the method of **listwise deletion** (Howell, 2007).

Type IV: Missing data due to questionnaire design

As the description of Type IV missing data implied, in this case, data were missing because respondents were advised to skip some questions. This type of missing data was all identified in the last section, where respondents were asked to answer only questions that applied. Therefore, the missing data would not impact the results of our analysis, **listwise deletion** was adopted to handle Type IV missing data (Howell, 2007).

Non-response Bias

For non-response bias, respondents after the last reminder were treated as non-respondents. Specifically, a comparison of the commercialization experience of non-respondents with the respondents was conducted. A summary of non-respondents' commercialization experience is shown in **Table 7** below. Results indicated that non-respondents were greatly biased towards researchers with no experience and ones with only experience in invention disclosure. This result implied that researchers with commercialization were more than likely to respond to the questionnaire. And more experience a researcher had, the higher chance that he or she would answer the questionnaire. This bias also would not impact our extrapolation of the data, because responses of researchers with different levels of experience were treated separately. However, when data were analyzed and discussed together, extrapolation of the data would be more applicable to researchers with more commercialization experience.

Table 7 Summary of Commercialization Characteristics of Non-Respondents.

Experience Level	No experience	Invention Disclosure	Provisional Patent	Patent	License	Start-up
Percent of non-respondents	47%	27%	8%	11%	8%	5%

Data Organization

Design of the questionnaire determined that not all respondents needed to answer every question. As introduced before, the questionnaire had been divided into five categories. Depending on the respondents' experience or their progress in the commercialization journey, some might need to answer only questions in one or few of the five categories. For example, if the respondent had only applied for invention disclosures and never proceeded to the next step, applying for a patent, this respondent would only need to answer questions in the first category. Similarly, if a respondent had moved to the stage of applying for a patent but was never approved one, he or she would only see questions of the first and second category. According to respondents' answers to the question asking their experience in research commercialization, the remaining 74 responses were grouped into five categories, as shown in **Table 8**.

Table 8 List of Respondents Categories and Number of Responses in each Category.

Respondent Category No.	Category Description	No. of responses	Percentage
1	Having at most experience with "invention disclosure"	28	37.84%
2	Having at most experience with "patent application"	16	21.62%
3	Having at most experience with "granted patent"	15	20.2%
4	Having at most experience with "patent licensed"	9	12.2%
5	Having at most experience with "forming a company"	6	8.1%

As shown in **Table 8**, when the 74 responses were distributed to different categories, the number of responses for each category became very small. While multiple regressions would be ideal for testing the hierarchical relationship between different resources and commercialization performance, due to the small sample size, other statistic tools were adopted to interpret the data, as explained below.

Data Analysis

Modification of Dependent Variables during Research

As mentioned before, the research commercialization process is different from a manufacturing process or a business process in the service industry. Format of the VSM and measurements of key factors needed to be adjusted when it was applied to research commercialization. At the beginning of this study, measurements of performance indicators (dependent variables) had been defined as efficiency and effectiveness of commercialization. While efficiency was calculated as dividing cycle time by process time of each activity, effectiveness was calculated as dividing research outputs of targeted activities by research outputs of previous activity. This definition was adjusted after the first interview with VTIP and two faculty, because feedback from the interviews indicated that accomplishing the initial plan would be barely possible. First, listing detailed activities of research commercialization was very challenging considering that commercialization was not a routine for faculty. Many details might have been forgotten. Additionally, assigning time for each activity was also very hard as the time faculty spent on commercialization was very limited and irregular. Estimate of such time would not be accurate. Therefore, taking these comments in consideration, the investigator adjusted the plan and made the following changes to performance indicators:

1) efficiency and effectiveness was measured as the lead time and output of each stage respectively;
2) time measurement was simplified to the total time frame of each stage, named lead time.

For data analysis, first, frequency analysis was conducted to study respondent demographics. While understanding the demographics of respondents was not directly related to the objective in this chapter, results from this analysis provided valuable insight as to inventions from which research fields showed more promising outcomes and researchers in which fields had a higher tendency to pursue research commercialization. When developing recommendations, these findings became very important and could be used to guide the selection of areas for improvement, as described in chapter eight.

Before testing the hypotheses proposed in this chapter, this study first conducted descriptive analysis of responses on outputs and lead time for all stages. This analysis was a different approach of identifying kaizen bursts in the commercialization process. If relatively low outputs were identified at one or few of the five stages, it meant that problems might exist at these stages and there should be kaizen bursts. Likewise, if some stages were related to long lead time, those stages also needed attention.

To test hypotheses, multiple regression was initially planned as the main statistical tool to evaluate the relationship between resources and commercialization performance at each stage. For example, to test the two hypotheses at stage one (period between idea generation and invention disclosure), answers of respondents with invention disclosure experience would be used for two multiple regression analysis. Those respondents' answers on the availabilities of resources were independent variables and answers on research outputs and lead time were dependent variables. For the rest of the hypotheses at other stages, the same pattern of analysis would be applied. However, as indicated above, when respondents were grouped into different categories according to their level of experience on research commercialization, sample size became too small and was not sufficient for multiple regression.

In order to identify important resources that impacted the performance of research commercialization, the investigator decided to take a different approach and adopt a combination of descriptive analysis, ANOVA, and T-test to serve the purpose. Importance of each type of resource at each stage was evaluated by comparing the means of responses from different categories for this resource (categorization of respondents could be found in **Table 8)**. To illustrate the analysis in an example, to identify whether research materials were the most important resources at stage one, means of respondents from category 1, 2, 3, 4 and 5 on availability of research materials were first calculated and then compared with ANOVA analysis.

If ANOVA showed no significant difference among all categories, it implied that research materials were not the most important resource that impacted the transition of research from stage one to stage two. However, if ANOVA indicated there is at least one variable was significantly different from others, a t-test was then run to compare the mean of category 1 to category 2, 3, 4 and 5 respectively. If any of the comparisons showed significant differences, it meant that research materials were one of the most important resources that affected the success of taking invention to stage two. On the other hand, research materials were very critical resources at stage one. The design of what data were compared for ANOVA and t-test analysis can be found in **Table 9**.

Table 9 Design of Data Categories for ANOVA and T-test.

	1st ANOVA	2nd T-test
Stage 1	Category 1, 2, 3, 4, and 5	Category 1&2, 1&3, 1&4, 1&5
Stage 2	Category 2, 3, 4, and 5	Category 2&3, 2&4, 2&5
Stage 3	Category 3, 4, and 5	Category 3&4, 3&5
Stage 4		Category 4&5

Because of the modification above, previously proposed hypotheses were no longer feasible and needed adjustments accordingly. In the original statements, performance of research commercialization focused on the two indicators, output and lead-time. As the new method of data analysis showed, criteria to determine the performance of research commercialization had changed. Whether or not the invention was carried forward to the next stage in the commercialization process became the new indicator of successfulness. Therefore, hypotheses were modified:

Hypothesis 1: Between the period of conducting research and invention disclosure, *research funding*, *experienced professionals from the IP office*, and *research materials and equipment* were more important than other resources in facilitating the transition of invention from stage one to stage two.

Hypothesis 2: Between the period of invention disclosure and patent application, *professional competency of the personnel from the IP office* was more important than other resources in facilitating the transition of invention from stage two to stage three.

Hypothesis 3b: Between the period of patent application and patent issued, *there is no resource more important than others* in facilitating the transition of invention from stage two to stage three.

Hypothesis 4: Between the period of patent issued and patent licensed, *inventors' business experience* and *relationship with the industry* is more important than other resources in facilitating the transition of invention from stage three to stage four.

Hypothesis 5: Between the period of patent issued and forming a company, *financial support*, and *relationship with the industry* is more important than other resources in facilitating the transition of invention from stage four to stage five.

Results and Discussions

Respondent Demographic

A demographic analysis of 73 respondents (1 respondent did not answer) with commercialization experience was conducted based on their answers to the question about their associated department. A frequency analysis was used to describe respondents' demographic background. As responses to the questionnaire had been organized into five categories according to the level of respondents' commercialization experience, frequency analysis was also conducted at five levels to investigate the demographic change along the progress of research commercialization. Detailed frequency analysis outputs can be found in **Table 10**. For easy demonstration, these results have also been transferred into a pie chart, as shown in **Figure 16**.

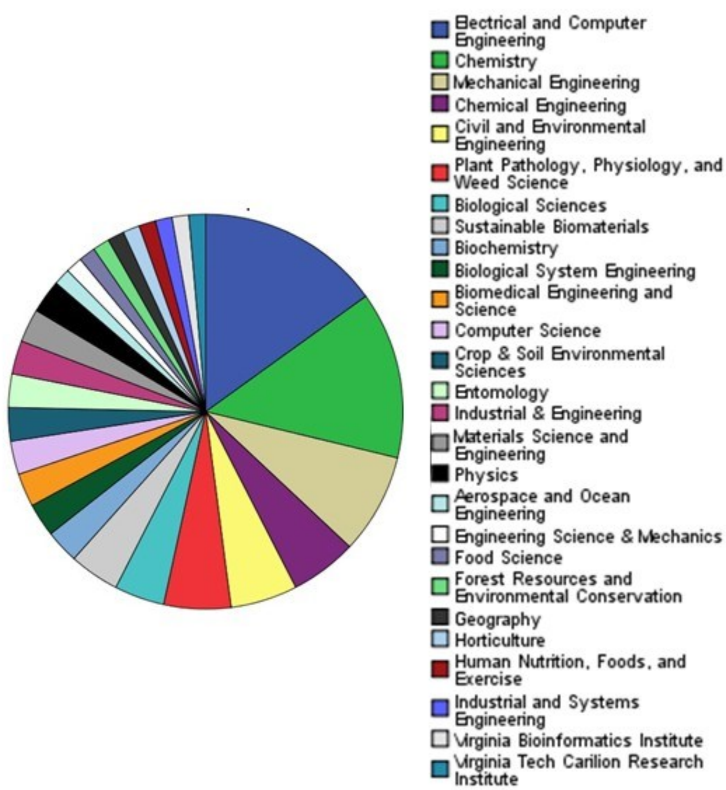

Figure 16 Demographic Distributions of Respondents at **Stage One**.

Table 10 Frequency of Respondents' Associated Departments at **Stage One**.

Departments

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Electrical and Computer Engineering	11	15.1	15.1	15.1
	Chemistry	10	13.7	13.7	28.8
	Mechanical Engineering	6	8.2	8.2	37.0
	Chemical Engineering	4	5.5	5.5	42.5
	Civil and Environmental Engineering	4	5.5	5.5	47.9
	Plant Pathology, Physiology, and Weed Science	4	5.5	5.5	53.4
	Biological Sciences	3	4.1	4.1	57.5
	Sustainable Biomaterials	3	4.1	4.1	61.6
	Biochemistry	2	2.7	2.7	64.4
	Biological System Engineering	2	2.7	2.7	67.1
	Biomedical Engineering and Science	2	2.7	2.7	69.9
	Computer Science	2	2.7	2.7	72.6
	Crop & Soil Environmental Sciences	2	2.7	2.7	75.3
	Entomology	2	2.7	2.7	78.1
	Industrial & Engineering	2	2.7	2.7	80.8
	Materials Science and Engineering	2	2.7	2.7	83.6
	Physics	2	2.7	2.7	86.3
	Aerospace and Ocean Engineering	1	1.4	1.4	87.7
	Engineering Science & Mechanics	1	1.4	1.4	89.0
	Food Science	1	1.4	1.4	90.4
	Forest Resources and Environmental Conservation	1	1.4	1.4	91.8
	Geography	1	1.4	1.4	93.2
	Horticulture	1	1.4	1.4	94.5
	Human Nutrition, Foods, and Exercise	1	1.4	1.4	95.9
	Industrial and Systems Engineering	1	1.4	1.4	97.3
	Virginia Bioinformatics Institute	1	1.4	1.4	98.6
	Virginia Tech Carillion Research Institute	1	1.4	1.4	100.0
	Total	73	100.0	100.0	

Figure 16 and **Table 10** demonstrated the distribution of associated departments of all 73 respondents. It was noticed that at this level respondents came from a variety of departments of Virginia Tech, with two departments, Electrical Computer Engineering (11) and Chemistry (10), accounting for more than one quarter of the population. Following that, the counts of Department of Mechanical Engineering (6), Chemical Engineering (4), Civil and Environmental Engineering (4), and Plant Pathology, Physiology, and Weed Science (4), were on top of the list. This result indicated, at the early stage, there was not only a wide reception of invention disclosures from researchers of different fields, but also active commercialization activities in limited fields.

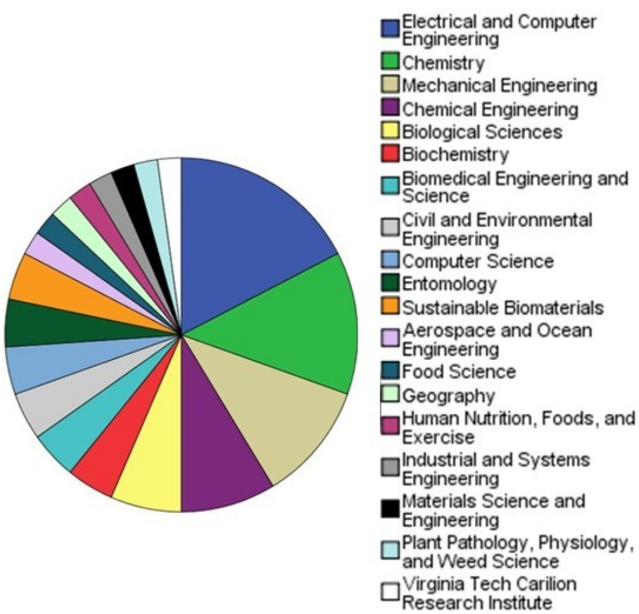

Figure 17 Demographic Distributions of Respondents at **Stage Two**.

Table 11 Frequency of Respondents' Associated Departments at **Stage Two**.

Departments

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Electrical and Computer Engineering	8	17.4	17.4	17.4
	Chemistry	6	13.0	13.0	30.4
	Mechanical Engineering	5	10.9	10.9	41.3
	Chemical Engineering	4	8.7	8.7	50.0
	Biological Sciences	3	6.5	6.5	56.5
	Biochemistry	2	4.3	4.3	60.9
	Biomedical Engineering and Science	2	4.3	4.3	65.2
	Civil and Environmental Engineering	2	4.3	4.3	69.6
	Computer Science	2	4.3	4.3	73.9
	Entomology	2	4.3	4.3	78.3
	Sustainable Biomaterials	2	4.3	4.3	82.6
	Aerospace and Ocean Engineering	1	2.2	2.2	84.8
	Food Science	1	2.2	2.2	87.0
	Geography	1	2.2	2.2	89.1
	Human Nutrition, Foods, and Exercise	1	2.2	2.2	91.3
	Industrial and Systems Engineering	1	2.2	2.2	93.5
	Materials Science and Engineering	1	2.2	2.2	95.7
	Plant Pathology, Physiology, and Weed Science	1	2.2	2.2	97.8
	Virginia Tech Carilion Research Institute	1	2.2	2.2	100.0
	Total	46	100.0	100.0	

At stage two, the total number of respondents was reduced to 46. As demonstrated in **Figure 17** and **Table 11**, many departments that had only one or two invention disclosures were no longer in the list. The highest number was in the Department of Electrical and Computer Engineering (8), followed by the Department of Chemistry (6), Mechanical Engineering (5), Chemical Engineering (4), and Biological Sciences (3). Recalling the interview with VTIP, not all of the invention disclosures were selected for patent application after submission. VTIP would review each application and select only proposals that indicated sound commercialization potentials (A detailed VTIP review process is discussed in **chapter six**). Combing the demographic data and based on VTIP's review, we concluded that research from the fields of electrical and computer engineering, chemistry, mechanical engineering, chemical engineering, and biology had more commercialization opportunities. However, at this point, we also did not exclude the possibility that there were bias from VTIP and agents from VTIP might have preferences for a few research fields. Further investigate of this issue can be found in **chapter six**.

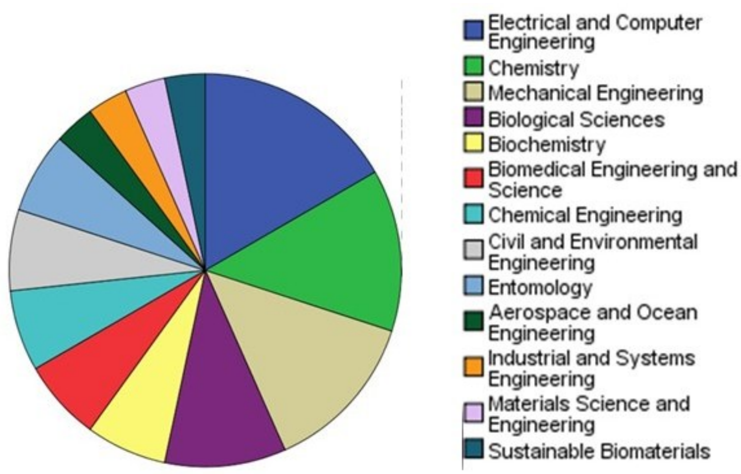

Figure 18 Demographic Distributions of Respondents at **Stage Three**.

Table 12 Frequency of Respondents' Associated Departments at **Stage Three**.

Departments

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Electrical and Computer Engineering	5	16.7	16.7	16.7
	Chemistry	4	13.3	13.3	30.0
	Mechanical Engineering	4	13.3	13.3	43.3
	Biological Sciences	3	10.0	10.0	53.3
	Biochemistry	2	6.7	6.7	60.0
	Biomedical Engineering and Science	2	6.7	6.7	66.7
	Chemical Engineering	2	6.7	6.7	73.3
	Civil and Environmental Engineering	2	6.7	6.7	80.0
	Entomology	2	6.7	6.7	86.7
	Aerospace and Ocean Engineering	1	3.3	3.3	90.0
	Industrial and Systems Engineering	1	3.3	3.3	93.3
	Materials Science and Engineering	1	3.3	3.3	96.7
	Sustainable Biomaterials	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

Stage three included a total of 30 respondents. **Figure 18** and **Table 12** provide an overview of the distribution of their associated departments. While the top departments remained unchanged, fewer other departments were observed. A closer look at the list of departments revealed that despite the difference of names, most departments on the list were related and belonged to one college, the College of Engineering. Therefore, research from the fields of engineering might demonstrate more opportunities to gain patents.

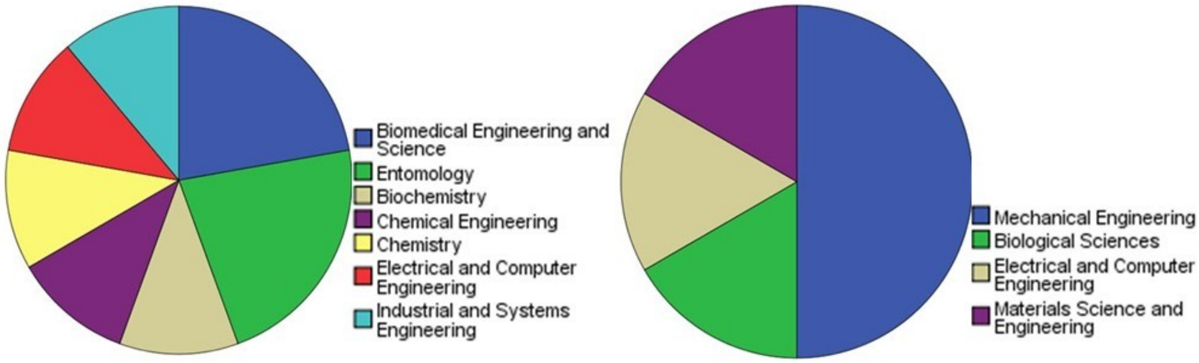

Figure 19 Demographic Distributions of Respondents at Stage Four and Five.

The last two stages represented the time when a patent was licensed to an existing company or licensed by the inventor to create a new company. In this study, while either case was viewed as the start of successful commercialization, demographic data were displayed together as shown in **Figure 19** and discussed jointly. Outputs can be found in **Table 13** and **Table 14**.

Table 13 Frequency of Respondents' Associated Departments at Stage Four.

Department

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Biomedical Engineering and Science	2	22.2	22.2	22.2
	Entomology	2	22.2	22.2	44.4
	Biochemistry	1	11.1	11.1	55.6
	Chemical Engineering	1	11.1	11.1	66.7
	Chemistry	1	11.1	11.1	77.8
	Electrical and Computer Engineering	1	11.1	11.1	88.9
	Industrial and Systems Engineering	1	11.1	11.1	100.0
	Total	9	100.0	100.0	

Table 14 Frequency of Respondents' Associated Departments at Stage Five.

Department

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Mechanical Engineering	3	50.0	50.0	50.0
	Biological Sciences	1	16.7	16.7	66.7
	Electrical and Computer Engineering	1	16.7	16.7	83.3
	Materials Science and Engineering	1	16.7	16.7	100.0
	Total	6	100.0	100.0	

At this stage, the numbers of respondents for each case were nine and six respectively. While the sample size was small, the difference between the number of respondents of licensing group and start-ups group did correspond with the fact indicated by VTIP that licensing was still the main form of commercialization at Virginia Tech. In the case of licensing, respondents were spread among different departments; while in the case of start-ups, respondents from the Department of Mechanical Engineering played a dominant role. Respondents' answers to the question of their research fields were also reviewed to identify possible linkages among research that had been indicated commercialized. It was found that all research that had reached the stage of commercialization did not share similarities. Similar to the conclusion made at stage three, demographic data at stage four and five indicated that most of commercialization activities concentrated in the field of engineering. However, this kind of concentration was not found if the investigation went down to the level of specific research field.

Lead Time and Research Outputs of Each Stage

<u>Lead Time of Each Stage:</u>

In SPSS, descriptive statistics and frequency statistics were conducted to measure the mean and the distribution of lead-time at stage 1, 2, 3, and 4 respectively. Data of lead-time of starting a company were not included in the analysis because the answers were not applicable. Outputs of SPSS are shown in **Table 15** and **Figure 20** for these two analyses.

Table 15 Means of Lead Time at Each Stage (in months).

Descriptive Statistics

	N	Minimum	Maximum	**Mean**	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	**Statistic**	Statistic	Statistic	Std. Error	Statistic	Std. Error
Stage1	71	.00	60.00	**18.01**	12.98	1.02	.29	.83	.56
Stage2	46	.00	120.00	**13.48**	17.57	5.18	.35	31.25	.69
Stage3	30	.00	120.00	**26.07**	24.00	2.57	.43	8.29	.83
Stage4	8	2.00	42.00	**17.88**	14.58	.83	.75	-.81	1.48
Valid N (listwise)	8								

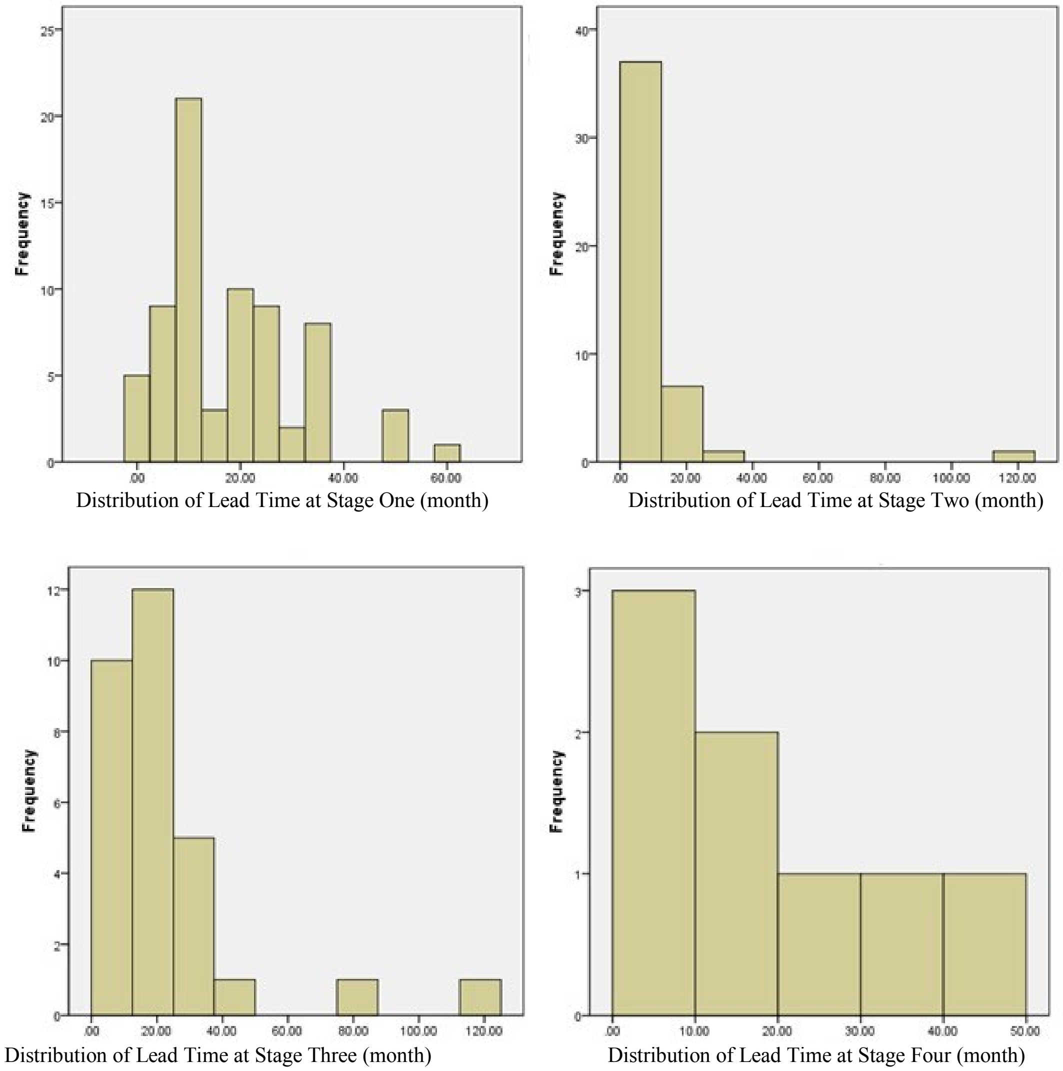

Figure 20 Histograms of Lead Time at Each Stage.

As **Table 15** showed, skewness scores of all four datasets were higher than 1, indicating that the data were not normally distributed and positively skewed. A thorough review of the statistics outputs revealed that the much higher skewness scores of stage 2 and 3 would be attributed to two extreme values in the dataset. As seen in the histograms of stage 2 in **Figure 20**, there was one extreme value (120 months) that was greatly different from the mean. This outlier had caused not only a high skewness but also a greater standard deviation. A similar case was also found in the dataset of stage 3. For proper interpretation of the data, both extreme values were removed from the dataset and adjusted data were analyzed again with descriptive and frequency statistics. Outputs of the second analyses are shown in **Table 16** and **Figure 21**.

Table 16 Adjusted Means of Lead Time at Each Stage (in month).

Descriptive Statistics

	N	Minimum	Maximum	**Mean**	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	**Statistic**	Statistic	Statistic	Std. Error	Statistic	Std. Error
Stage1	71	.00	60.00	**18.01**	12.98	1.02	.29	.83	.56
Stage2	45	.00	36.00	**11.11**	7.22	1.10	.35	2.34	.70
Stage3	29	.00	84.00	**22.83**	16.46	1.80	.43	5.95	.85
Stage4	8	2.00	42.00	**17.88**	14.58	.83	.75	-.81	1.48
Valid N (listwise)	7								

As shown in **Table 16**, skewness of data from stage 2 and 3 was largely reduced after removal of the extreme values. Standard deviation of both datasets also decreased accordingly. Though the skewness scores were still higher than 1, distributions of the data had become closer to normal distribution than they were, as shown in **Figure 21.**

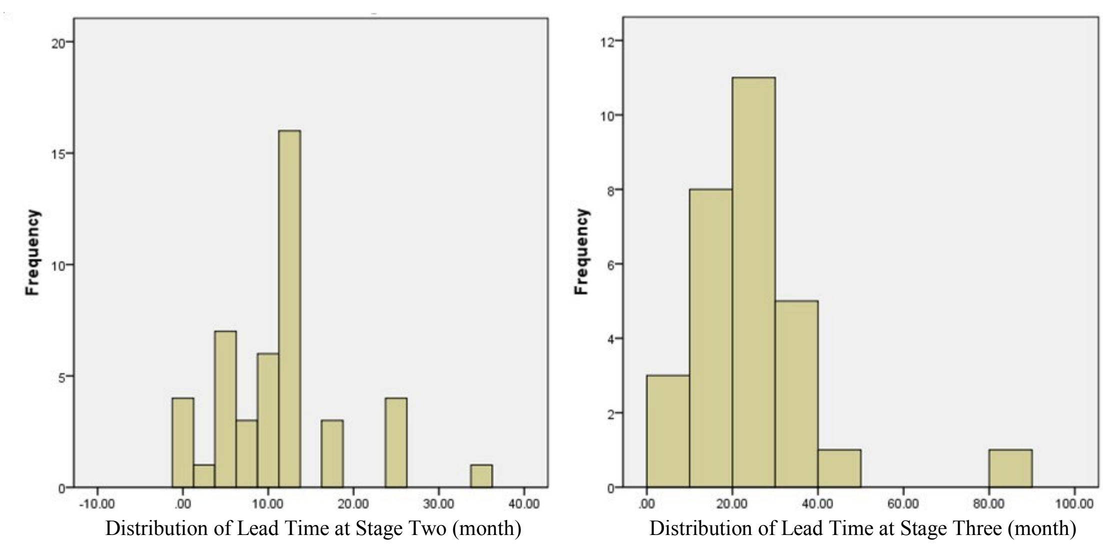

Figure 21 Histograms of Adjusted Responses of Lead Time at Stage 2 and 3.

As summarized in **Table 16**, the average lead time for stage 1, 2, 3, and 4 was about 18, 11, 23, and 18 months, respectively. Added together, all lead time resulted in a total process time of 70 months, meaning that it would take an average of six years to transfer a research idea into a licensed patent. As to the investigation of stage that took the longest lead time, it could be seen that expect for the period (stage 2) when invention disclosure was prepared and filed, the rest periods that involved conducting research (stage 1), filing for patent (stage 3), and getting patent licensed (stage 4) all took relatively longer time. Therefore, these three stages were the potential areas for kaizen bursts and the priority for future investigation.

Outputs of Each Stage:

Data of outputs of each stage were first analyzed with frequency analysis. At each stage, the output was different. For the periods of stage1, stage 2, stage 3, and stage 4, outputs were defined as the no. of invention disclosures, the no. of patents applied, the no. of patents, and the no. of patents licensed. In this section, this study also included the research outputs at the beginning of stage 1, the research proposals, which represented the research ideas at the beginning of a commercialization process. **Figure 22** demonstrated the results of frequency analysis of outputs. It can be seen that data of distribution of outputs at each stage followed a similar trend of skewness as that of lead time. Also, an extreme value (200 research proposals) was identified in the datasets for research proposal number. However, different from the previous cases, the extreme value here appeared to be a normal case rather than an outlier, because three respondents had reported this high value. It would be wise to keep those data. Following frequency analysis, descriptive analysis was conducted to measure the means of outputs and results were shown in **Table 17**.

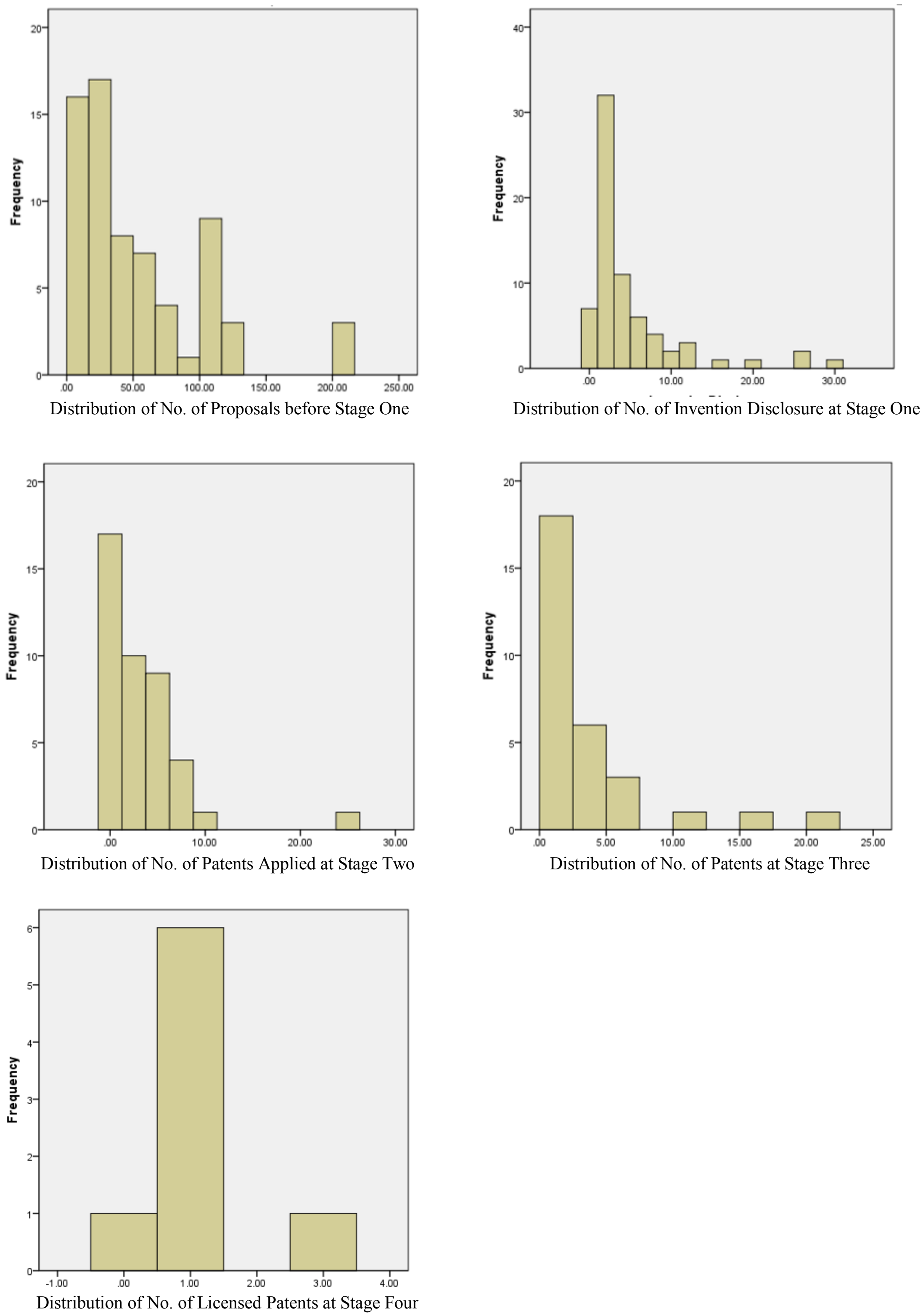

Figure 22 Histograms of Responses of Research Outputs of Each Stage (X axis represented the output of each stage, and Y axis represented the frequency of one value).

As summarized in **Table 17**, the average outputs for stage 1, 2, 3, and 4 was about 4, 3, 3, and 1, respectively. Means for output conversion rates for stage 1, 2, 3, and 4 was 8.6%, 81.2%, 90.0%, and 34.0%, respectively. Based on the output conversion rates, it can be observed that **stage 1** had the lowest rate, representing an area for improvement (kaizen burst in the VSM). Though it could be argued that in a university not all research was intended for commercialization, this result at least indicated that less than 10% of research ideas were turned into projects for commercialization purpose. Further investigation was needed to identify why conversion rate was low at stage 1.

Table 17 Means of Outputs at Each Stage.

Descriptive Statistics

		Before stage 1 No. of research proposals	Stage1 No. of invention disclosures	Stage 2 No. of patent applied	Stage 3 No. of patent	Stage4 No. of patent licensed
N	Valid	68	70	42	30	8
	Missing	2	0	28	40	62
Mean		**51.62**	**4.44**	**3.60**	**3.31**	**1.13**
Median		35.00	2.00	2.00	1.00	1.00
Mode		100.00	1.00	1.00	1.00	1.00
Minimum		.00	.00	.00	.00	.00
Maximum		200	30	25	22	3
Std. Deviation		47.57	6.15	4.36	4.79	.83
Skewness		1.47	2.51	3.13	2.75	1.69
Kurtosis		2.15	6.52	13.58	8.25	4.97

Stage 2 was another area that caught the investigator's attention. Though conversion rate of 81.2% indicated a good outcome, it should be noted that the number of respondents had decreased from 70 to 42, with a 40% reduction. This indirectly implied that the conversion of an invention disclosure to a provisional patent was not high. In this sense, stage 2 should also be an area that

called for improvement. Recalling the discussion in the demographic section, it had been suggested that it could be a matter of technology and also a matter of VTIP's reviewing process that might have resulted in the reduction of invention disclosures transferred into provisional patents. Further investigation of this matter can be found in the following chapter.

Comparison of Importance of Different Resources at Each Stage

Stage one: Idea Generation – Invention Disclosure

Hypothesis 1: Between the period of conducting research and invention disclosure, *research funding*, *experienced professionals from the IP office*, and *research materials and equipment* were more important than other resources in facilitating the transition of invention from stage one to stage two.

At this stage, data of respondents of all categories were included for analysis. Recalling the data modifications for missing data, some data had been removed. Therefore, the resulting number of data for each respondent category varied from the number of responses listed in **Table 8**. A summary of adjusted number of data for each category is listed in **Table 18**. ANOVA tests were conducted to compare the mean of responses on availability of each type of resources from all categories, as introduced in **Table 9**. Means and standard deviations of responses on availabilities of all type of resources for each category were calculated and shown in **Figure 23** and **Table 19** . Outputs of ANOVA tests are shown in **Table 20**.

Table 18 Number of Data for Each Respondent Category after Modification of Missing Data.

Respondent Category No.	Category Description	No. of Data
1	Having at most experience with "invention disclosure"	27
2	Having at most experience with "patent application"	16
3	Having at most experience with "granted patent"	15
4	Having at most experience with "patent licensed"	9
5	Having at most experience with "forming a company"	6

Table 19 Means and Standard Deviations of Responses on the Availability of Each Type of Resource.

	Research Materials		Research Equipment		Research Assistant		Professionals from VTIP		Connection s with Industries		Government al Funding		Industrial Funding	
	Avg.	Stdv.	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv
Category1	3.56	1.07	3.59	1.03	3.22	1.20	2.81	1.02	1.89	1.03	2.59	1.50	1.85	1.15
Category2	3.38	1.26	3.56	1.03	2.88	0.81	2.13	1.02	2.38	1.20	2.94	1.29	2.00	0.97
Category3	3.87	0.99	4.07	0.59	3.33	1.05	2.80	1.47	3.27	1.53	3.20	1.15	2.87	1.77
Category4	3.89	0.93	3.89	0.93	3.89	0.93	3.11	1.17	3.22	0.83	3.22	1.48	2.00	0.87
Category5	3.67	1.03	3.83	0.98	2.83	0.75	2.67	1.63	3.50	0.84	3.00	0.89	2.50	1.05

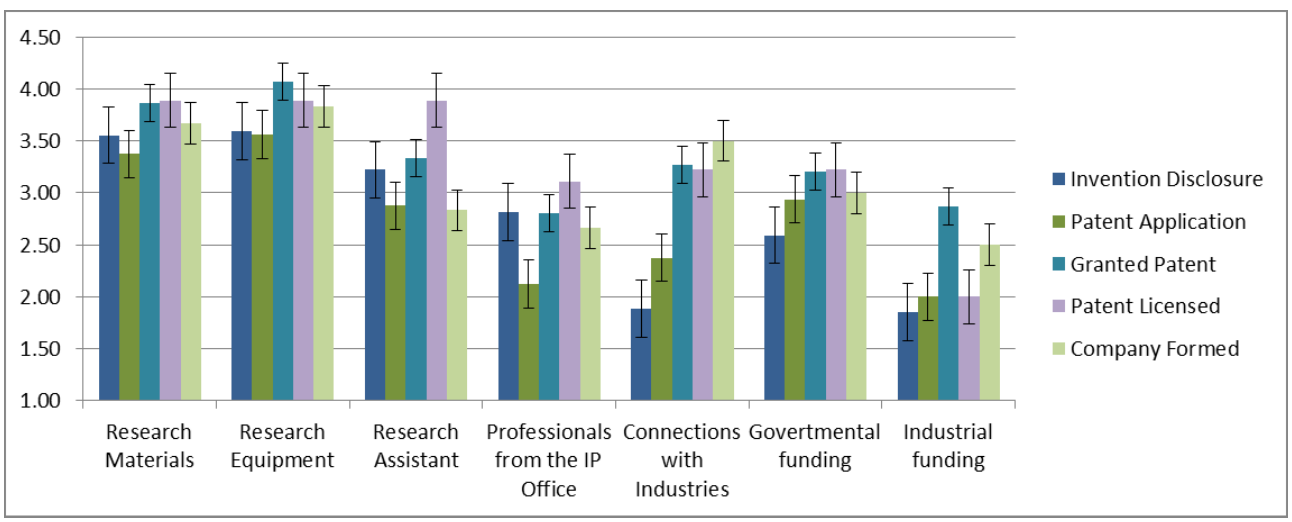

Figure 23 Mean of Availability Levels of Different Resources among all Categories at Stage One.

At stage one, as **Figure 23** shows, research materials and research equipment were equally sufficient among respondents from all categories (sig. 0.693 for material, 0.518 for equipment).

It was then assumed that research materials and research equipment was not the critical resource impacting commercialization at the early stage. As to help from research assistants, though the bar chart showed difference between the mean of responses from category 1 and 4, ANOVA test indicated there was no significant difference among this group (sig. 0.178). Regarding the support from VTIP, as a whole, respondents from all categories reported lower value than that of previous resources. Comparison of VTIP support among this category also did not identify significant difference in mean (sig.0.294). This result corresponded to the information obtained from the interview with VTIP. As VTIP claimed, they were not involved in the commercialization until an invention disclosure was filed to them. However, as general interaction, they did provide consultation and visit researchers across campus on a regular basis. This fact helped to explain why respondents indicated they received support from VTIP when there was not official involvement of VTIP at an early stage. Responses to connections with industry started to vary among five categories. While ANOVA test could only tell there was at least one variable significantly different from the rest (sig. 0.001), it did not specify which variables were different. Therefore, t-test between category 1 and the rest of the categories was conducted. Statistical analyses revealed that, with regard to industry connections, category 1 was not significantly different from category 2 (sig. 0.173), but it was significantly different from category 3(sig. 0.005), 4 (sig. 0.002), and 5 (sig. 0.001). Therefore, it was reliable to conclude that industrial connection was a critical factor that impacted the transition from invention disclosure to patent application at stage one. The last two groups of columns represented the responses of availability of research funding including governmental and industrial funding. Taken as a whole, all respondents indicated possession of more funding from government than from industries. Looking at each type of funding individually, as the bar chart shows, respondents with more experience appeared to have more governmental funding, while a similar trend was also identified for industrial funding. However, ANOVA test did not show evidence to prove any significant difference among responses for either governmental funding (sig. 0.617) or industrial funding (sig. 129). As a result, the most influential factor at stage 1 was the researchers' industrial connections. Therefore, hypothesis 1 was rejected.

Table 20 Outputs of ANOVA Tests Comparing Responses of Categories 1,2,3,4 and 5.

		Sum of Squares	df	Mean Square	F	Sig.
Material	Between Groups	2.641	4	.660	.559	.693
	Within Groups	80.372	68	1.182		
	Total	83.014	72			
Equipment	Between Groups	2.943	4	.736	.819	.518
	Within Groups	61.112	68	.899		
	Total	64.055	72			
Assistant	Between Groups	7.021	4	1.755	1.625	.178
	Within Groups	73.472	68	1.080		
	Total	80.493	72			
VTIP	Between Groups	7.307	4	1.827	1.262	.294
	Within Groups	98.446	68	1.448		
	Total	105.753	72			
Connection	Between Groups	29.430	4	7.358	5.414	.001
	Within Groups	92.406	68	1.359		
	Total	121.836	72			
Govfunding	Between Groups	4.917	4	1.229	.667	.617
	Within Groups	125.412	68	1.844		
	Total	130.329	72			
Indfunding	Between Groups	11.387	4	2.847	1.850	.129
	Within Groups	104.641	68	1.539		
	Total	116.027	72			

Stage two: Invention Disclosure - Patent Application

Hypothesis 2: Between the period of invention disclosure and patent application, *professional competency of the personnel from the IP office* was more important than other resources in facilitating the transition of invention from stage two to stage three.

At the second stage of commercialization, data only involved responses from category 2, 3, 4, and 5, because respondents from category 1 did not have experience in this stage and no inputs were received from them. A summary of numbers of data for all categories is shown in **Table 21**. Means and standard deviations of responses on availabilities of all types of resources for each category were calculated and shown in **Figure 24** and **Table 22** . Outputs of ANOVA tests are shown in **Table 23**.

Table 21 Numbers of Data for Each Respondent Category after Modification of Missing Data.

Respondent Category No.	Category Description	No. of Data
2	Having at most experience with “patent application”	13
3	Having at most experience with “granted patent”	15
4	Having at most experience with “patent licensed”	8
5	Having at most experience with “forming a company”	6

Table 22 Means and Standard Deviations of Responses on the Availability of Each Type of Resource.

	Research Materials		Research Equipment		Research Assistant		Professionals from VTIP		Connections with Industries		Governmental Funding		Industrial Funding	
	Avg.	Stdv.	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv
Category2	3.15	1.21	3.62	0.96	3.00	1.00	2.54	1.20	2.38	1.26	2.62	1.50	1.69	1.18
Category3	3.93	1.16	3.93	1.03	3.40	1.30	3.47	1.19	3.40	1.35	3.13	1.25	2.87	1.55
Category4	3.75	1.04	3.63	0.92	3.75	1.04	3.50	1.20	3.25	0.71	3.50	1.31	2.00	0.93
Category5	3.50	1.38	3.67	1.37	3.00	1.10	3.17	1.17	3.17	1.17	2.83	1.17	2.83	1.17

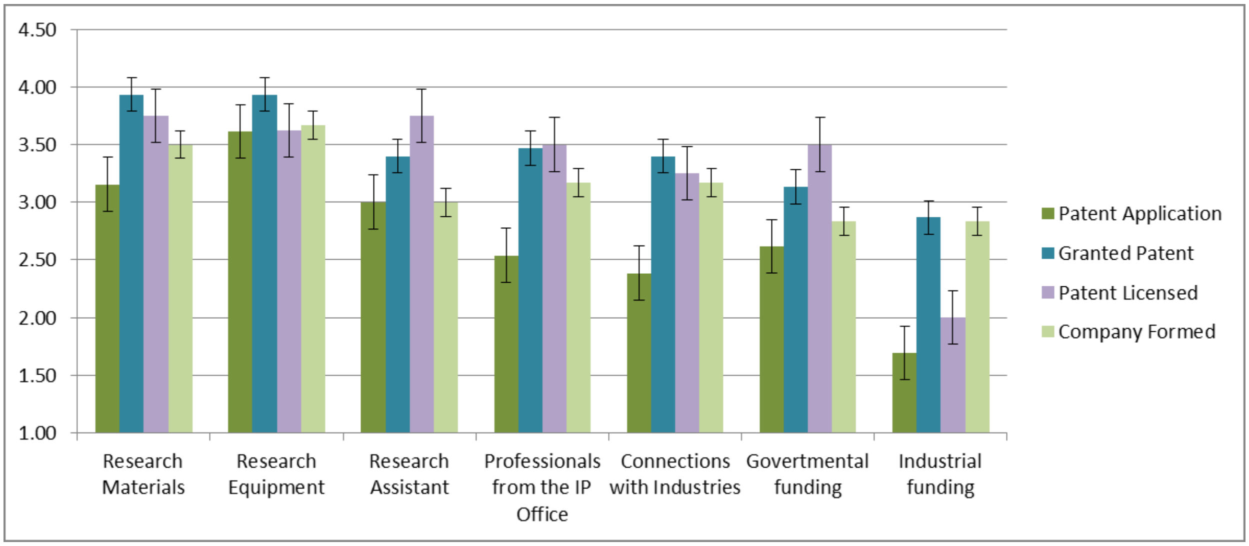

Figure 24 Means of Availability Levels of Different Resources Among all Categories, except for Category of Respondents with Only Invention Disclosure Experience.

As shown in **Table 22** and **Figure 24**, means of availabilities of professionals from the IP office, connection with industries, and industry funding shown differences between respondents of category 2 and the other categories. However, outputs of ANOVA tests (**Table 23**) indicated that there was no significant difference of availabilities of all types of resources among categories 2, 3, 4 and 5. It was surprising to see the difference was not significant although it looked like it was as shown in **Figure 24**. Low significant levels might be caused by an uneven sample size. Based on statistical outputs, we rejected hypothesis 2 and concluded that, no resource was more important than others at stage two. However, it should be noted that attention be given to the resources of professionals from the IP office, connection with industries, and industry funding at this stage.

Table 23 Outputs of ANOVA Tests Comparing Reponses of Categories 2,3,4 and 5.

		Sum of Squares	df	Mean Square	F	Sig.
Material	Between Groups	1.812	3	.604	.449	.720
	Within Groups	51.164	38	1.346		
	Total	52.976	41			
Equipment	Between Groups	.900	3	.300	.277	.842
	Within Groups	41.219	38	1.085		
	Total	42.119	41			
Assistant	Between Groups	3.471	3	1.157	.896	.452
	Within Groups	49.100	38	1.292		
	Total	52.571	41			
VTIP	Between Groups	7.345	3	2.448	1.729	.177
	Within Groups	53.797	38	1.416		
	Total	61.143	41			
Connection	Between Groups	7.966	3	2.655	1.834	.157
	Within Groups	55.010	38	1.448		
	Total	62.976	41			
Govfunding	Between Groups	4.356	3	1.452	.816	.493
	Within Groups	67.644	38	1.780		
	Total	72.000	41			
Indfunding	Between Groups	11.997	3	3.999	2.399	.083
	Within Groups	63.336	38	1.667		
	Total	75.333	41			

Stage three: Patent Application – Patent Granted

Hypothesis 3: Between the period of patent application and patent issued, *there is no resource more important than others* in facilitating the transition of invention from stage two to stage three.

Table 24 Number of Data for Each Respondent Category after Modification of Missing Data.

Respondent Category No.	Category Description	No. of Data
3	Having at most experience with "granted patent"	14
4	Having at most experience with "patent licensed"	8
5	Having at most experience with "forming a company"	6

Table 25 Means and Standard Deviations of Responses on the Availability of Each Type of Resource.

	Research Materials		Research Equipment		Research Assistant		Professionals from VTIP		Connections with Industries		Governmental Funding		Industrial Funding	
	Avg.	Stdv.	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv
Category3	3.67	1.45	4.00	1.13	3.33	1.54	3.20	1.37	3.33	1.40	2.80	1.42	2.73	1.67
Category4	3.63	0.92	3.63	0.92	3.63	0.92	3.25	1.28	3.25	1.04	3.50	1.31	2.25	1.04
Category5	3.50	1.38	3.67	1.37	2.50	1.22	3.17	1.17	3.33	1.21	2.67	1.21	3.00	1.26

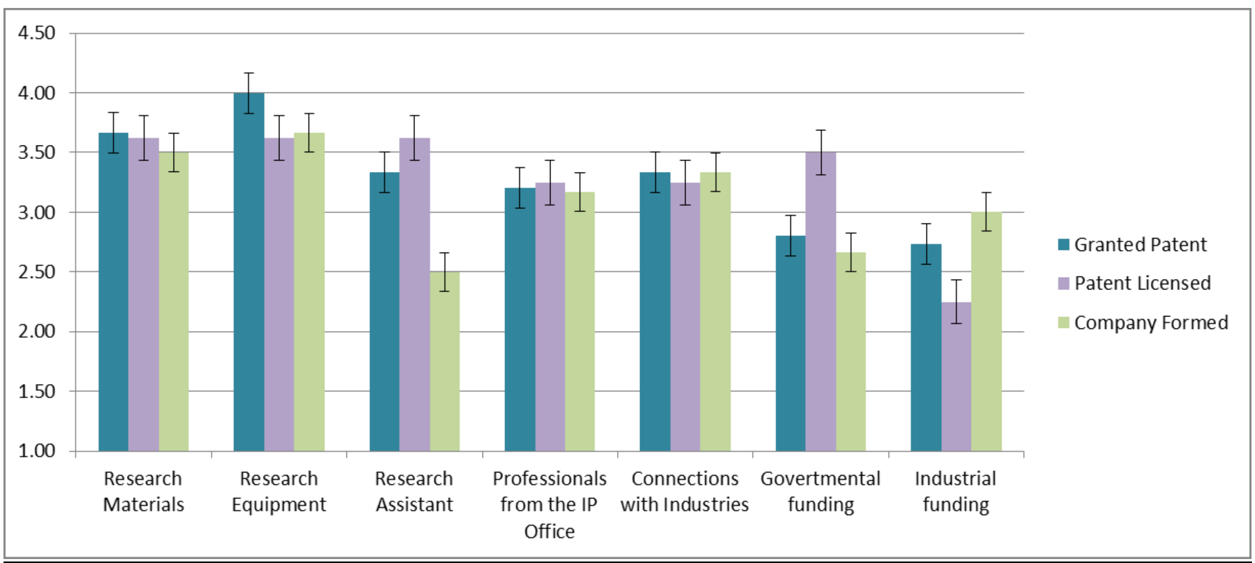

Figure 25 Means of Availability Levels of Different Resources among all Categories, except for Category of Respondents with Only Invention Disclosure and Respondents with Only Patent Application Experience.

Stage three represented the period between the time a patent application was submitted and the time this application was approved by the U.S. patent office. Outputs of ANOVA tests (**Table 26**) indicated that there was no significant difference of availabilities of all types of resources among categories 3, 4 and 5. This result corresponded to what was assumed before distribution of the survey. During this period, patent applications had been submitted. The chance of getting a patent largely depended on the U.S. Patent Office. Therefore, we accepted hypothesis 3 and concluded that, all resources were equally important at stage three.

Table 26 Outputs of ANOVA Tests Comparing Responses of Categories 3, 4, and 5.

		Sum of Squares	df	Mean Square	F	Sig.
Material	Between Groups	.119	2	.060	.035	.966
	Within Groups	44.708	26	1.720		
	Total	44.828	28			
Equipment	Between Groups	.930	2	.465	.364	.698
	Within Groups	33.208	26	1.277		
	Total	34.138	28			
Assistant	Between Groups	4.602	2	2.301	1.281	.295
	Within Groups	46.708	26	1.796		
	Total	51.310	28			
VTIP	Between Groups	.025	2	.013	.007	.993
	Within Groups	44.733	26	1.721		
	Total	44.759	28			
Connection	Between Groups	.040	2	.020	.012	.988
	Within Groups	42.167	26	1.622		
	Total	42.207	28			
Gov funding	Between Groups	3.232	2	1.616	.880	.427
	Within Groups	47.733	26	1.836		
	Total	50.966	28			
Ind funding	Between Groups	2.118	2	1.059	.506	.609
	Within Groups	54.433	26	2.094		
	Total	56.552	28			

Stage four: Patent Granted – Patent Licensed

Hypothesis 4: Between the period of patent issued and patent licensed, *inventors' business experience* and *relationship with the industry* is more important than other resources in facilitating the transition of invention from stage three to stage four.

Hypothesis 5: Between the period of patent issued and forming a company, *financial support*, and *relationship with the industry* is more important than other resources in facilitating the transition of invention from stage four to stage five.

Table 27 Number of Data for Each Respondent Category after Modification of Missing Data.

Respondent Category No.	Category Description	No. of Data
4	Having at most experience with "patent licensed"	8
5	Having at most experience with "forming a company"	5

Table 28 Means and Standard Deviations of Responses on the Availability of Each Type of Resource.

	Research Materials		Research Equipment		Research Assistant		Professionals from VTIP		Connections with Industries		Governmental Funding		Industrial Funding	
	Avg.	Stdv.	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv	Avg.	Stdv
Category 4	3.63	0.74	3.50	0.93	3.50	0.93	2.88	1.25	3.38	1.06	3.13	1.13	2.25	0.89
Category 5	3.40	1.52	3.60	1.52	2.60	1.14	3.20	1.30	3.40	1.52	2.60	1.14	3.00	1.58

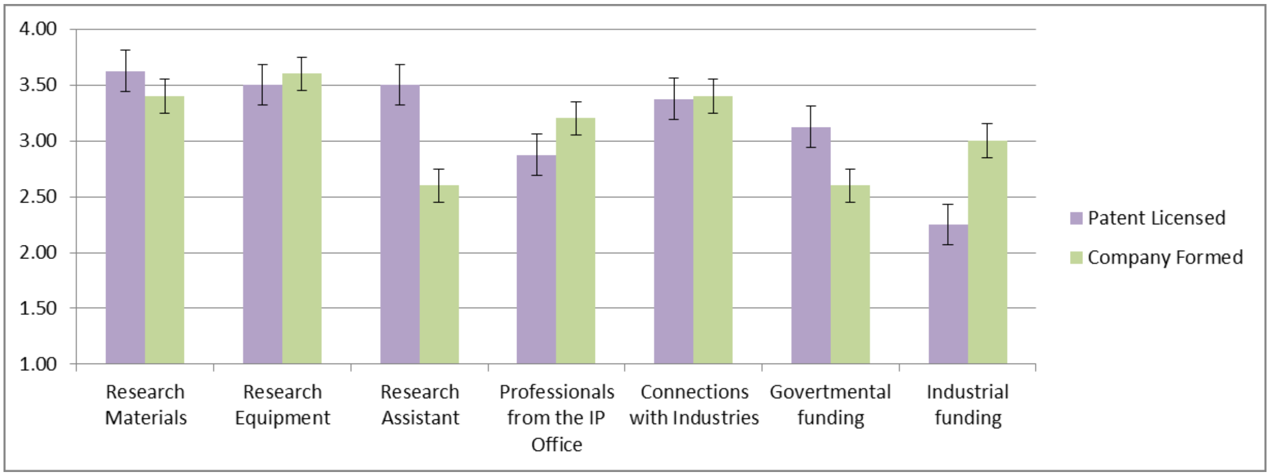

Figure 26 Means of Availability Levels of Different Resources among Category of Respondents with Patent Licensing and Respondents with Building New Company Experience.

Stage four referred to the period when a patent had been successfully licensed, representing the official start of research entering the market. Depending on the case, a patent could be licensed through an existing company or licensed by an inventor. In the case of licensing through a company, comparison of availability of different resources between category 4 and 5 was conducted with t-tests. Results (**Table 29**) showed that there was no significant difference between these two categories with regard to any type of resource. Therefore, we rejected hypothesis 4 and concluded that there was no resource more important than others at stage four. Similar to the situation at stage 2, although t-tests did not identify any significant difference, differences of means were observed for the resource of industry funding as shown in **Figure 26**. To some extent, it could be suggested that keeping industrial funding was important at the last stage of commercialization.

With regard to hypothesis 5, due to the fact that respondents indicated a different process that did not fit with what was suggested in this study, their responses were not feasible for analysis.

Table 29 Outputs of T-test Comparing Responses of Categories 4 and 5.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VTIP	Equal variances assumed	.106	.751	-.450	11	.662	-.325	.723	-1.916	1.266
	Equal variances not assumed			-.445	8.323	.668	-.325	.731	-1.999	1.349
Material	Equal variances assumed	2.255	.161	.362	11	.724	.225	.622	-1.143	1.593
	Equal variances not assumed			.309	5.226	.769	.225	.727	-1.621	2.071
Equipment	Equal variances assumed	.538	.479	-.149	11	.884	-.100	.670	-1.575	1.375
	Equal variances not assumed			-.133	5.898	.899	-.100	.753	-1.951	1.751
Assistant	Equal variances assumed	.202	.662	1.565	11	.146	.900	.575	-.366	2.166
	Equal variances not assumed			1.485	7.270	.179	.900	.606	-.522	2.322
Connection	Equal variances assumed	.656	.435	-.035	11	.973	-.025	.710	-1.588	1.538
	Equal variances not assumed			-.032	6.474	.975	-.025	.775	-1.888	1.838
Govfunding	Equal variances assumed	.195	.667	.814	11	.433	.525	.645	-.894	1.944
	Equal variances not assumed			.812	8.548	.439	.525	.647	-.950	2.000
Indfunding	Equal variances assumed	1.804	.206	-1.108	11	.291	-.750	.677	-2.239	.739
	Equal variances not assumed			-.970	5.602	.372	-.750	.773	-2.676	1.176

Value Stream Map

Based on the results from the survey study and above suggestions, a current state value stream map (VSM) was drawn and shown below in **Figure 27**. For the following studies, instead of answering research question three, focus was also given to the kaizen bursts identified from the survey.

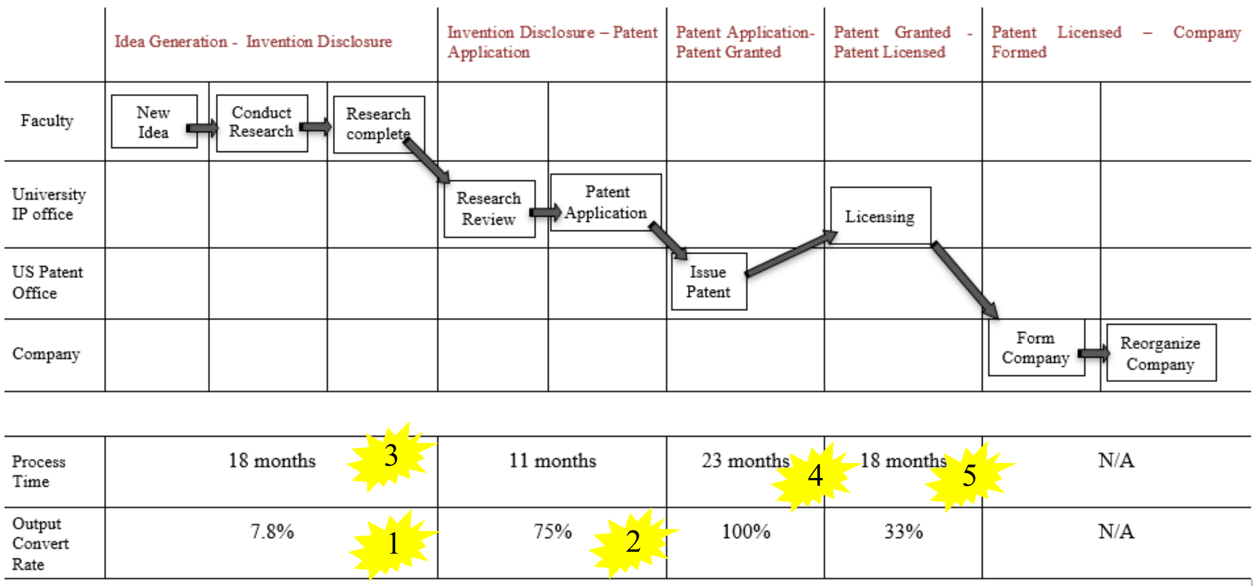

Figure 27 Current State VSM of Research Commercialization Process of Virginia Tech.

Conclusions

With completion of the survey, it was confirmed that university commercialization was not a linear process. There was numerous variation between cases. With regard to the importance of different resources, it was revealed that the influence of all resources also varied at different stages of the commercialization process. In general, industry connection was more important than other resources at the early stage of commercialization. After an invention disclosure was submitted, support from VTIP started to play an important role. During the period when a patent application was reviewed by the U.S. Patent Office, the importance of all resources was equally distributed. Once a patent was granted, commercialization required continuous focus on industrial connections and funding.

Demographically, researchers from the field of engineering appeared to be more active in commercialization. While involvement from other departments of Virginia Tech was observed at the beginning, as the process progressed, they disappeared from the list.

As to research outputs within the entire commercialization process, the number of research ideas (research proposals) started very high. However, less than 10% of these research ideas were turned into invention disclosures. When the commercialization proceeded, the number of research at the following stages experienced further reduction. Though this reduction was not reflected by the reported numbers of patents and licensed patents, the decreased numbers of respondents from the following stages indirectly corresponded to this conclusion. Finally, the conversion rate of research ideas to the commercialized research ideas was less than 2%.

The process time also varied within and across different stages of commercialization. For time range within each stage, except for stage two, period of provisional patent application, the rest generally had broad ranges. As to stage one, this finding mirrored the reality that the duration of the research conduction period was usually unpredictable. Also, as the survey covered a spectrum of research fields, the difference of required time to complete the research should have also contributed to the board range of duration. Stage 2, on the other hand, was relatively short and was usually less than a year. Because the patent law allowed and inventor only a year to turn in patent application once a provisional patent was submitted, if the inventor failed to meet the deadline, he or she would lose the right to claim the patent for the invention in the future. However, in certain circumstances, extension of the provisional patent was permitted. Therefore, except for special cases, once a provisional patent was submitted, it took less than a year to proceed to the stage of patent application. Processing of a patent application usually took a very long time. Depending on the technology being claimed, the process time varied from less than a year to more than three years. The survey study indicated a high frequency of answers of one to two years, while cases with more than three years were relatively low. The end of the commercialization process referred to the period of licensing or establishing a company. Either case involved a scenario in which there were lots of uncertainties. Getting a patent licensed required not only efforts but also opportunities. Especially for a new product, it was hard to estimate when the market would be ready and when existing companies started to show interest in the new products. A range of a few months to three or four years was expected to license a patent. As to the case of creating a company, the success largely depended on the entrepreneurs' capabilities to acquire seed money and venture capital. Similarly, there was not a defined time frame specifying how long it took to build a company. Every case had its own path and the total time needed to build a new company varied among cases. Based on responses from the questionnaire, it was indicated that new companies were usually established before the patent application. While those respondents' experiences did not apply to the framework provided in the questionnaire, answers with regard to the time required to form a new company were not available. In all, it took an average of six years to complete the entire process from the time a research idea was framed to the time a relevant patent was licensed.

Chapter 6: Assess the University Characteristics that Impact Research Commercialization

Overview

In Lean management, it is said that no process improvement will succeed if the "true north" of the company, its final goal, was not to achieve a more efficient process. This saying could be applied to this study: before taking any steps to improve the research commercialization process in a university, it should be sure that the university was driven for commercialization.

In this research, the investigation of a Virginia Tech's "true north" was conducted by studying the organizational characteristics related to research commercialization, which was also the third research question: how favorable are the organizational characteristics of the targeted university to research commercialization? Information of this matter was gathered through individual interviews with Virginia Tech faculty, administration, and VTIP.

In addition to addressing the subject above, as an approach to address research question four, research focuses at this section were also given to issues identified from the survey study: 1) why did stage 1 and stage 2 have the most dramatic reductions of research outputs? And 2) why did stage 1, stage 3, and stage 4 have the largest range of lead time?

At the end, questions related to the importance of different resources were addressed again during the interviews. This repetition was conducted for the concern that expression through a survey was limited and it was not certain if respondents understood the questionnaire the same way as the investigator intended it to be. Due to the complexity of research commercialization, it was likely that respondents found their experience not applicable to the framework provided in the questionnaire and their responses might not reflect the real situation.

Objective

University characteristics played an important role in impacting the performance of research commercialization. While some characteristics were catalysts to facilitate the commercialization process, some might be impediments. Therefore, for universities that aimed to foster research commercialization, it was critical to understand if they were characteristically beneficial to the commercialization. So, the main goal of the study in this section was to identify how favorable were the characteristics of the targeted university to research commercialization. Also, this section aimed to validate the relationship between different resources and the performance of research commercialization. At the end, this section intended to conduct research towards the fourth research question, what are the actions a university can conduct to improve its commercialization performance, by answering the questions: why did research outputs greatly drop at stage 1 and stage 2 and why the range of lead time was long at stage 1, stage 3, and stage 4.

Methods

Sub-cases Selection

Commercialization activities of individual faculty were defined as the embedded units of analysis in this single case study (sub-cases). A total of 25 sub-cases were planned for the interview, with 5 sub-cases from each stage of research commercialization. Responses from the survey served as the reference for sub-case selection. All experienced faculty that indicated willingness to participate in the interview were selected, resulting in a sample size of 12 as the initial sample group. For the rest of the13 sub-cases, the "snowball sampling" technique was adopted by asking for referrals from the existing sample at the end of each interview. By the time interviews were completed, a total of 22 sub-cases were covered by this study.

Besides interviewing faculty, this study also included interviews with three representatives from the administration of Virginia Tech, one representative from an organization that provided consultation in creating start-ups, and the same representative from VTIP the investigator had interviewed previously.

Interview Questions

<u>Factors Related to Characteristics</u>

Previous studies had identified various factors that were related to university characteristics (Rasmussen *et al.*, 2010). As summarized in chapter one, those factors could be grouped into two categories: 1) institutional factors and 2) social factors. **Table 20** provides a list of factors that were closely relevant to the university characteristics. Based on these factors, interview questions were drafted to explore how Virginia Tech reacted to and supported research commercialization.

Table 30 Factors Related to University Characteristics.

Category	Factors
Institutional Factors	Expenditures on R&D
	Intellectual property policy
	Research field
Social Factors	Key individuals
	Commitment to innovation
	Networking with external relations

Interview Questions

The interview adopted a narrative and semi-structured approach. Prior to the interview, an interview guide was prepared with a list of questions covering the main topics. The interview guide included three sections: 1) general information; 2) questions of resources-based factors; and 3) organizational characteristics related questions. Questions in section 1 served to open a conversation between the interviewee and investigator and to get a basic understanding of the interviewee's experience in research commercialization. Questions in this section included: "can you please explain the reasons to be a professor?", "why did you join Virginia Tech?", "please describe your commercialization experience at Virginia Tech", and "is commercialization common in your field?" etc. Section 2 included questions of importance of different resources and suggestions for commercialization. For example, what they thought should have been done, either by themselves or the university, to enable more research outputs and faster processing at each stage. While the last section of the interview was designed to target the objective related to university characteristics, many questions related to this topics usually had been covered in section 1 and section 2 during the conversation. Therefore, throughout the interview, questions on the interview guide were asked randomly or skipped, depending on how interviewees answered previous questions. A complete interview guide can be found in **Appendix F**.

Interview Implementation

The first interview invitation emails were sent to the initial sample group through Microsoft Outlook. The invitation email included a reminder of the survey study respondents had participated in, a brief introduction of the research, and a kind request to schedule an interview (**Appendix H)**. A reminder email (**Appendix H**) was sent after a week if no reply was received from the respondents. At the end of the second week, a total of 10 interviews were scheduled.

At the beginning of this study, each interview was planned for 1 to 2 hours. Because many interviewees indicated 2 hours was too long, the interview was then reduced to no more than 1 hour. Both on-site and phone interviews were used in this study (phone interview was used only when the interviewees were not within driving distance). For a total of 27 interviews, 24 were on-site and 3 were phone interviews.

Before each interview, a web search of the interviewee was conducted at Virginia Tech's website to get a basic understanding of interviewee's research, publication, patent, or any awards received. At the beginning of each interview, a brief introduction of this study was given to the interviewees and their signatures on the IRB approved content form were obtained. Also, as the interview required recording, all interviewees were informed of this matter and asked for permission. Once the interview started, a narrative approach was adopted for the interview execution (Rasmussen, 2011). At the end of each interview, the investigator would asked a kind request for interviewee's referrals of faculty they know having research commercialization experience at Virginia Tech. A thank you email was sent to the interviewee the next day after each interview.

Other methods

To ensure the adequacy of data collected to describe the current state of research commercialization at Virginia Tech, except for conducting interviews, this study also accessed other available materials, such as online patent databases, administrative documents, and university websites.

Data Analysis

Cross-case comparison was used to analyze the data collected from the interview. For objective one, qualitative comparisons were made of the factors related to organizational characteristics among faculty with different levels of commercialization experience. For cases in which no comparison was available, a narrative approach was used to describe the current situation at Virginia Tech. For objective two, a narrative approach was taken to answer the two "why" questions. For objective three, a summarized list of important resources was compared with that from the survey study.

Results and Discussions

Organizational Characteristics Assessment

Research Expenditures at Virginia Tech

Officially opened on Oct. 1, 1872, Virginia Tech is one of the many U.S. public land-grant universities that currently offer 225 undergraduate and graduate degree programs to more than 31,000 students. With a research portfolio of $496 million, Virginia Tech is actively engaging in and creating new discoveries in agriculture, biotechnology, human health, energy management, and sustainability, etc. (VirginiaTech, 2014b). As data obtained from the Virginia Tech administration office showed (**Figure 28)**, NSF-based research expenditures at Virginia Tech have continuously increased since 2000 and reached the aforementioned approximately $496 million in 2013. As found in a literature review, a university's research expenditures were positively related to the performance of research commercialization. Therefore, the data below implied that Virginia Tech had established a stable foundation for research commercialization.

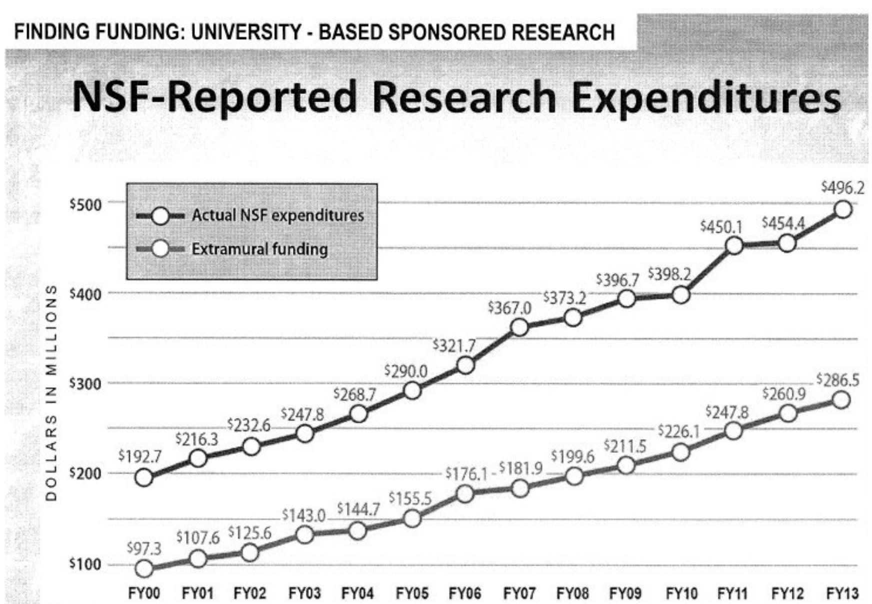

Figure 28 NSF-reported Research Expenditures at Virginia Tech from 2000 to 2013.

Industry funded research expenditures, as our survey study identified, played an important role in fostering research commercialization. Data obtained from the Virginia Tech administration office (**Figure 29**) showed that since 2009 industry funded research expenditures at Virginia Tech had been staying at the level of about 5 percent of the government funded research expenditures. It did show steady growth for the past few years. However, as one representative from administration implied, Virginia Tech might expect an increase in industry funded research expenditures. Because as the representative implied, compared with peer universities, Virginia Tech still had space to grow in this matter.

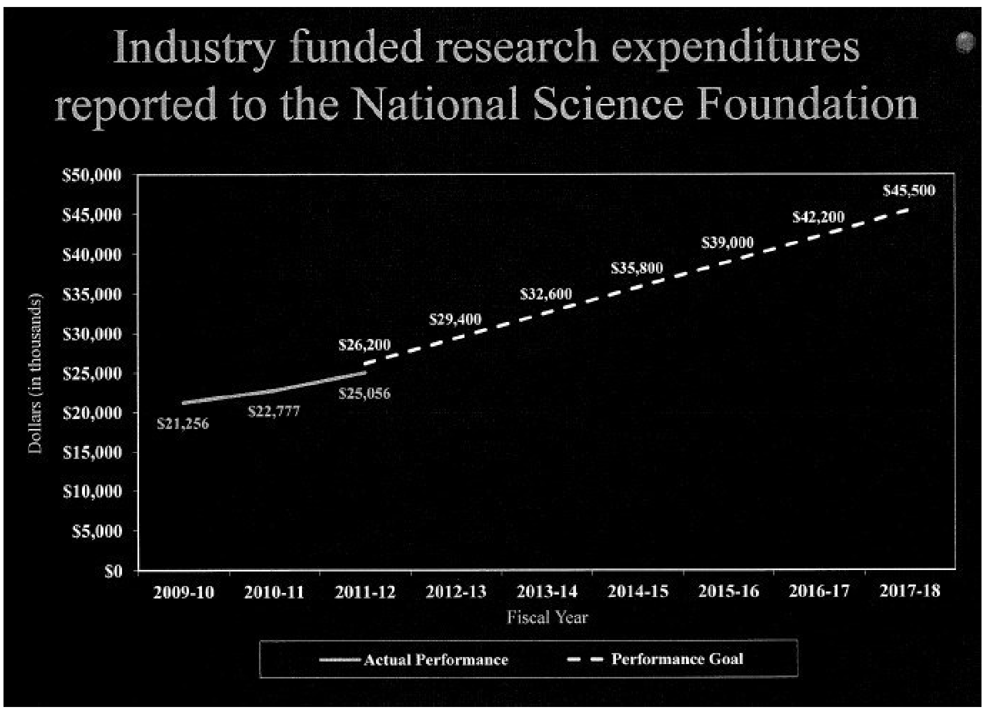

Figure 29 NSF-reported Past, Current, and Projected Industry Funded Research Expenditures of Virginia Tech since 2009.

Intellectual Properties (IPs) Policy

In the U.S., every university was allowed to develop its own IP policy. At Virginia Tech, the policy of IP was developed and managed by the intellectual properties committee and implemented by VTIP. As explained in the IP policy of Virginia Tech, the existence of IP policy helped the university to disseminate IPs in the most efficient and effective way and to realize industrial utilization of some IPs for financial considerations (VirginiaTech, 2013). At Virginia Tech, ownership of IP was categorized into two situations: "*1) the traditional results of academic scholarship, i.e. textbooks, literary works, artistic creations and artifacts; and 2) the novel results of research such as products, processes, machines, software, biological technology, etc*."

(VirginiaTech, 2013). In general, in the first case, IPs right of creation remained with the author and the university has the right of free use of the creation in teaching, research, and extension, etc. For the second case, the university claimed ownership of the IP rights and the originators had a right to share some benefits derived from the creation (VirginiaTech, 2013). Because this study focused on research outcomes of faculty and researchers, cases discussed in this study belonged to the second situation. Under the second situation, there were special occasions where IP rights were handled differently (e.g. joint inventions, industrial sponsored research, and commissioned works, etc.), this study did not distinguish these cases during discussion.

It was written in the IP policy and also mentioned by the interviewees that researchers at Virginia Tech were obligated to disclose their inventions through VTIP as soon as possible if they considered applying for IP for the invention and pursued commercialization in the future. This meant that, as long as a researcher thought, in his or her opinion, an invention was valuable for IP and commercialization, he or she should submit an invention disclosure at a timely manner. This policy, to some extent, did encourage the generation of invention disclosures. However, from the perspective of efficiency, it created a bottleneck in the process. When the amount of disclosures surpassed the capacity of VTIP, many disclosures had to wait to be processed and evaluated. In terms of Lean thinking, there was not a flow in the commercialization process and the pool of disclosures was like the work-in-process in a manufacturing plant. A deeper investigation of VTIP's evaluation process, which is elaborated in the following section, also confirmed this assumption. It was found that VTIP did not have the capacity to process all invention disclosures in a timely manner. Constrained with human resources and knowledge of technologies, VTIP had to give priorities to disclosures that were well prepared and showed higher potential of commercialization. Therefore, a large amount of disclosures might not even be reviewed carefully, so were wasted as expressed with a Lean term. Therefore, if the university intended to improve the efficiency, the area of invention disclosures submission should be the focus of attention. Associated policy of this subject might also need adjustments.

Research Field

The survey of this research showed that research commercialization at Virginia Tech was concentrated in limited research fields, such as electrical engineering, biotechnology, and chemistry. Therefore, to some extent, it could be assumed that research field had an impact on the performance of research commercialization. To validate this conclusion, a search on the database of Web of Science was conducted to gain an overview of all patents owned by Virginia Tech.

Field: Subject Areas	Record Count	% of 500	Bar Chart
ENGINEERING	339	67.8000 %	
INSTRUMENTS & INSTRUMENTATION	310	62.0000 %	
CHEMISTRY	296	59.2000 %	
PHARMACOLOGY & PHARMACY	113	22.6000 %	
POLYMER SCIENCE	103	20.6000 %	
BIOTECHNOLOGY & APPLIED MICROBIOLOGY	85	17.0000 %	
AGRICULTURE	69	13.8000 %	
ENERGY & FUELS	60	12.0000 %	
COMPUTER SCIENCE	54	10.8000 %	
COMMUNICATION	37	7.4000 %	
GENERAL & INTERNAL MEDICINE	36	7.2000 %	
OPTICS	22	4.4000 %	
IMAGING SCIENCE & PHOTOGRAPHIC TECHNOLOGY	20	4.0000 %	
MATERIALS SCIENCE	20	4.0000 %	
METALLURGY & METALLURGICAL ENGINEERING	17	3.4000 %	
TRANSPORTATION	17	3.4000 %	
FOOD SCIENCE & TECHNOLOGY	12	2.4000 %	
CONSTRUCTION & BUILDING TECHNOLOGY	9	1.8000 %	
WATER RESOURCES	9	1.8000 %	

Figure 30 Summarization of Research Field of Patents Owned by Virginia Tech at Web of Science.

All identified patents were analyzed through the Web of Science, based on the counts of patents in different research fields. The percentage of the numbers of patents in each research field out of total number of patents was calculated and displayed in a declining order. Because the list was very long and surpassed the display limit, only the top portion was captured, as shown in **Figure 30**. It could be seen that the sum of all displayed percentages had exceeded 100 percent. This might attribute to the fact that some patents had been cited with more than one research field so the counts were calculated twice or more than that. Counts of multiple research fields did not affect the results of this study. In fact, it reflected the reality that research these days was interdisciplinary and its completion required knowledge of different research fields. Similar to the results of survey study, data from the Web of Science showed that most patents were identified in the field of engineering. Following that, it was instrument and instrumentation, chemistry, pharmacology and pharmacy, polymer science, and biotechnology, etc. Given these data, the assumption that there was a correlation between the research fields and the commercialization performance was further proved. Engineering was still the research field that had higher potential for commercialization.

Key Individuals

During the search of key individuals/organizations that facilitated the research commercialization at Virginia Tech, it was found that VTIP was the only organization that was mentioned frequently by interviewees. An affiliated corporation of Virginia Tech, VTIP played a role in the commercialization process more than a helper in patent application or license document preparation, but also a gatekeeper and promoter of new technology. Data collected from the interviews implied that VTIP's engagement in commercialization was generally highly appreciated by faculty with rich commercialization experience (at least had patents), however, feedback from the ones with less experience was less positive. When a probing question was asked to the interviewee why they thought VTIP was helpful or not helpful, answers from these two groups suggested that the distinct opinions of VTIP's performance are attributed to different expectations of VTIP from faculty. Usually, faculty with more commercialization experience had personal industrial connections and were familiar with the commercialization process. In cases like this, faculty's expectations of VTIP were relatively low. In their opinion, VTIP's main job was to process any necessary documents that were relevant to commercialization. Once these documents were prepared and ready, VTIP's job was fully accomplished. However, for faculty that had limited commercialization experience, the situation was very different. Faculty in this case normally did not have industrial connections and needed additional help in searching for sponsors that were willing to pay for patent application fees. They were very busy in conducting research and replied greatly on VTIP. As these faculty claimed, responses from VTIP often came late and the agent did not have a good assessment of the technology. Therefore, they did not think the help from VTIP was sufficient. Their comments were justifiable to the extent that no agent was able to understand every discipline very well given the diversity of research areas at Virginia Tech. When being asked what could be done to improve research commercialization at the university level, more than half suggested that, if allowed, each department should have a specialist that was knowledgeable of both the research and business. It was a lot to ask for VTIP considering their limited staff in the office. In the investigator's opinion, a comment from one faculty that had been with Virginia Tech for more than 20 years provided an unbiased conclusion on VTIP's performance: "*…VTIP had changed a lot since it was first established. At the beginning, its main role was to help faculty to handle patent related documents. Nowadays, they are playing more roles and were given more responsibilities. I think they have done a very good job. Maybe they need to have more people…* "

Commitment to Innovation, Networking with External Relations, and Market Focus Attitude

Virginia Tech had been dedicated to conducting research over the past ten years. Since 2000, there had been a continuous increase in research expenditures, spending in infrastructure, and investments in faculty (Pastor, 2013). As indicated in Virginia Tech's 2012-2018 long range plan goals, this progress was still expected to grow. Strategically, Virginia Tech had increased investment in interdisciplinary areas that addressed top-notch research topics (Pastor, 2013). The establishment of the Institute for Critical Technology and Applied Science and the Virginia Bioinformatics Institute, are strong indicators of Virginia Tech keeping its prominence to "invent the future", as declared in its tagline.

With regard to networking with external relations, it was indicated in the university's website that building connections with industries and other external institutions was an important element of Virginia Tech's social activities (VirginiaTech, 2014a). However, based on the feedback of interviews with faculty, this commitment was not distinctly reflected at the empirical level. For example, when asked if the university had provided opportunities for faculty to network with industries, all interviewees gave a negative answer and indicated that most of their networking opportunities were self-generated. Also, as mentioned above, industry funded research at Virginia Tech only accounted for a small portion of the entire university's research portfolio. This fact indirectly implied that, compared with its research achievement, Virginia Tech was relative weak in networking with the industry.

The factor of market focus attitude was investigated through asking faculty the reason they pursued commercialization. Nineteen out of twenty-two interviewees indicated that research commercialization was not planned at the beginning and it happened only when there was an opportunity. In all, the focus of research was still on scientific discovery and student education. To identify the research focus at the university level, interviewees were asked how their work was evaluated and rewarded, and whether commercialization was encouraged by the university. Very identical answers were also received for this question: the number of publications and the amount of generated research grants were still the focus for the university's tenure review process. There was no evidence showing that the university was encouraging faculty to commercialize and to conduct research based on the market need. However, commercialization was also not discouraged as long as the faculty fulfilled the requirements of being employed by Virginia Tech.

With all being said, data collected from the administration office of Virginia Tech did show that the university had experienced steady growth in many aspects of commercialization, such as the number of invention disclosures, the number of provisional patent applications, the number of patent applications, and license revenue, etc. Details of those data can be found in the **Table 21** below.

Table 31 IP Related Outputs of Virginia Tech for Fiscal Year of 2011, 2012, 2013.

	2013	2012	2011
Invention Disclosures	174	170	140
License and Option Agreements	17	32	24
Startup Companies Licensed/Optioned	6	6	
U.S. Provisional Patent Applications	132	83	77
Patent Applications	31	27	28
U.S. Plant Variety Patent Applications	4	1	
Patent Cooperation Treaty Applications	14	12	15
Foreign Patent Applications	39	65	27
U.S. Plant Variety Patent Issued	3		
U.S. Patents Issued	16	17	26
Foreign Patents Issued	23	6	14
Patent Expenses	$1,052,090	$814,005	$996,384
Patent Expenses Reimbursed	$762,326	$593,574	$718,368
Net Patent Expenses	$289,763	$220,431	$278,016
License Revenue	$2,368,556	$2,269,991	$1,815,681

Assess the Identified Problems from the Survey Study

This section aimed to answer why research outputs greatly dropped at stage 1 and stage 2, and why the range of lead time was long at stage 1, stage 3, and stage 4. For the first question, an analysis of both faculty's and VTIP's feedback revealed that the large reduction of research outputs at stage 1 was caused by IP policy, VTIP's evaluation process of invention disclosures, and limited budgets to support patent applications. An explanation of how IP policy affected the process has been addressed above. Here, explanation of two other causes is provided.

<u>VTIP evaluation process</u>

In a normal setting, once an invention discourse was submitted to VTIP, a case was created at VTIP's database. This case would first be reviewed by a staff (intellectual property specialist) that checked the database on a daily basis. Since there was no decision making at this stage, the intellectual property specialist would forward all new cases to the VTIP president for review shortly after the cases were spotted. After that, decisions would be made by the president with regard to the distribution of cases among licensing managers and associates. There is a total of two licensing managers and two licensing associates at VTIP, each specialized in certain research fields, such as software development, chemistry, and life science. In many cases, the research field described in the disclosure was not clear or was an interdisciplinary subject. The president would leave the decision to licensing managers for more appropriate distribution. An organization chart of VTIP was provided below in **Figure 31**.

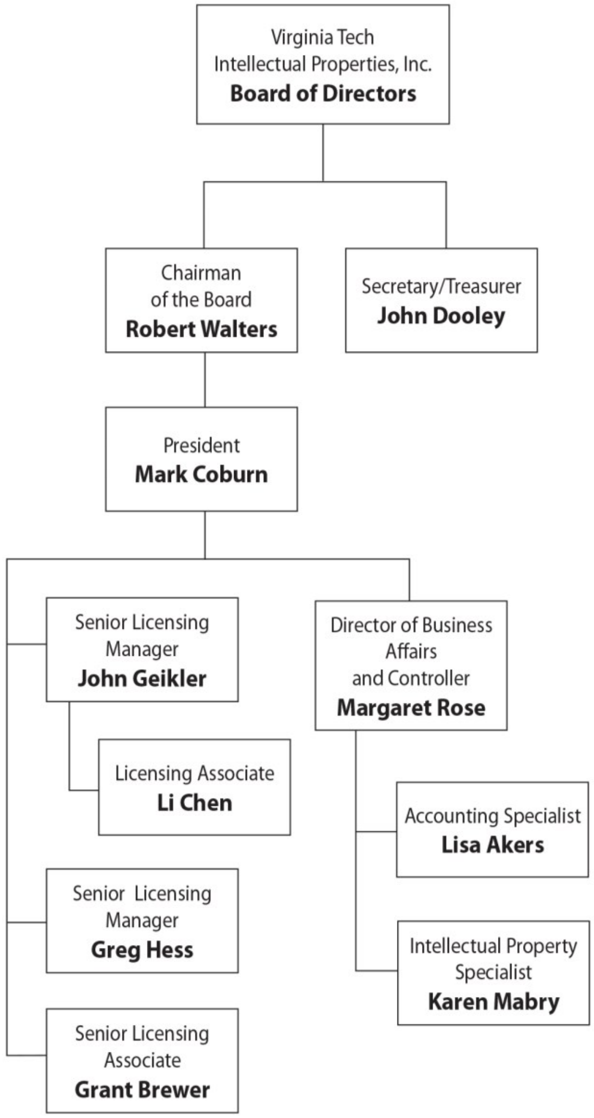

Figure 31 Organization Chart of VTIP.

Case evaluation officially started after licensing managers/associates took the case from the president. To determine if VTIP will continue the case and take it to the next level (i.e. patent application), licensing managers/associates ran an assessment of each case following some criteria, as described below (It should be noted that each manager/associate had his or her own criteria, what was explained here is not applicable to all managers/associates at VTIP):

- **Public Disclosure**

If the end goal of a researcher was commercialization, it was very important that details of the research had not been publicly disclosed in any form, such as publication and presentation in conferences. However, in academia, since the number of publications is one of the most important criteria for performance evaluation, faculty or researchers usually published research findings as soon as enough data had been collected. If that was the case, their invention disclosures would not be considered by licensing managers for patent application.

- **Funding Sources**

University had various funding sources for research, including federal government, state and local government, business, nonprofit organizations, and institution funds, etc. Generally speaking, research grants funded by government, such as the National Science Foundation, were used for basic science and did not necessarily require applicants to provide proof of application of the research. This type of research usually focused on the fundamentals of a subject. Time scale was relatively long and the outcomes were not ensured. On the other hand, very often, research that was funded by companies had the goal of solving a real life problem identified by the market. As the company needed to respond to the market on a timely base, time scale of this type of research was normally shorter. So research outcomes were more applicable to the industry, with higher likelihood of commercialization. Therefore, if it was indicated on an invention disclosure that the research had partnership with or was funded by the industry, licensing managers would pay more attention to it. However, for most land-grant universities, compared with government-funded research, industry-funded research was still very few. At Virginia Tech, as one representative from administration indicated during interview, government funded research still accounts for a significant portion of the total research expenditures, approximately 70 to 80 percent. Therefore, large amounts of the invention disclosures VTIP received did not involve industry partnership. Also, it was not absolute that research funded by government did not generate commercializable products. In this sense, licensing managers would not devalue a case simply because the research was not funded by the industry.

- **Technology**

Eligibility of patent application of the technology was another important factor that a licensing manager considered during the review of invention disclosure. As required by the U.S. Patent and Trademark Office, in order to be valid for a patent, a technology must be "useful", "novel", and "nonobvious". As to “useful”, the patent law requires that the subject matter must have a useful purpose and be operable. For example, if it was a machine, it should operate and perform the intended purpose.

“Novelty” requirement specified that an invention must be new. It could not be patented if any public disclosure of this invention had been made. The following circumstances were the three most common situations, under which the invention was not patentable (Bitlaw, 2014):

- the invention was known by the public in the U.S. before the patent applicant invented it;
- the invention was described in a publication more than one year prior to the filing date; or
- the invention was used in public, or offered for sale in the U.S. more than one year prior to the filing date.

It should be noted that there was a one year period after the first public disclosure, during which patent application of an invention was still valid. However, patent application must be filed before the end of one year, or the inventor would lose the right to patent this invention in the future. In a real life practice, it was usually difficult to define the date of first disclosure because information could be made public in various forms, both formally and informally. The one-year clock could start even if the inventor simply explained details of his or her research to colleagues or friends. Therefore, inventors should be very cautious of any possible public disclosure of their inventions.

The third patent requirement is “nonobvious”. This criterion required that all features of an invention claimed in the patent application should show sufficient difference from what had been used and that a person in a relevant field would not be able to make the same discoveries easily. Take the cup design as an example. If an existing cup was designed as pure white with animal figures on the cup, a design to change the animal figures to plant figures was obvious to a cup design so it did not meet the requirement of “nonobvious”. However, if a new design changed the shape of this cup or found a more environmental friendly paint to decorate the cup, this design might be viewed as nonobvious and patentable.

- **Description of Market Potential**

To have market potential was very critical for commercialization of an invention. After all, it is the market that will decide if the invention could become a successful product. For inventions coming out from a university research laboratory, an estimate of market potential was very difficult. This became even harder for a person that was not an expert in the related research field.

Therefore, VTIP required that inventors provide a detailed description of the technology, potential applications, and companies that might have interests in this technology in the invention disclosure form. For cases that have much of this information missing, VTIP was not able to continue the process and had to contact the inventor when time allowed.

- **Involvement of Inventors**

In many cases, there was more than one inventor for an invention. In a university setting, it usually involved faculty, students, research associates, or research scientists, etc. to complete a research project. U.S. patent law requires proof of significant time spent on the invention for every claimed inventor. If a student simply dropped by the lab and helped with cleaning, he or she could not be claimed as an inventor. Therefore, VTIP usually would contact the main inventor and confirm the contribution of each listed inventor if more than one inventor was claimed in the invention disclosure form.

- **Research Status**

University research has a distinct characteristic, i.e. discontinuity. A research project could be terminated before completion anytime if the researcher ran out of funding, students graduated, or the researcher had no interest in the topic anymore. This could happen after invention disclosures had been submitted. As mentioned before, not all disclosures were reviewed by VTIP upon submission. Therefore, by the time VTIP started the evaluation process, the research project might be no longer active, and acquisition of further information of the invention then became less possible. In these cases, if VTIP processed the case without knowing the status of the research of the claimed invention, a significant amount of time might be wasted on this invention.

Knowing the evaluation process of invention disclosures, the investigator then asked the representative from VTIP how often a disclosure was rejected because the aforementioned criteria were not met. The answers implied, most frequently, it was actually because there was missing or incomplete information in the invention disclosure that the evaluation could not continue. If time allowed, VTIP would try to contact the inventor for missing information. However, when there was a time constraint, VTIP might have to focus on only disclosures with sufficient information. In this representative's opinion, an invention disclosure was more than an application form, but a business proposal. A well prepared invention disclosure determined a good start of further research commercialization. This finding was somehow contradictory to the feedback received from faculty. When being asked if it was difficult to fill an invention disclosure and if they needed help from VTIP, most interviewees indicated applying for invention disclosures was very easy. It was only filling out pages of forms.

Clearly, there was a misperception of the importance of invention disclosures between most faculty and VTIP. While faculty thought they were simply following the university's requirement to file an invention disclosure, it might not occur to them that VTIP took the disclosure as important evidence to evaluate if an invention was patentable. Therefore, if an invention disclosure was not appropriately prepared, the likelihood that the invention could proceed for patent application was low.

Except for constraint of human resources, VTIP also had limited budgets to pay for patent application fees. Once VTIP decided to support an invention for patent application, it would expect that this patent would be granted and licensed. And the licensor would reimburse the patent application fee in the future. Therefore, for a large pool of invention disclosures, when there was budget constraints, only a limited amount of inventions would be selected for patent application. With regard to this problem, VTIP advised that it is very beneficial to facilitate the commercialization process if the inventors had their own industrial connections and found sponsors to pay for the patent application fees in the first place.

For the second question, why was the range of lead time long at stage 1, stage 3, and stage 4, the investigator first asked each interviewed faculty of their average lead time of stages 1, 3, and 4. Based on the answers, an open-ended questions similar to "*In your opinion, what were the reasons that the lead time was long/short at stage 1/3/4?"*was followed.

For stage 1, the period for conducting research, the answers from all interviewees were very similar. It was said that conducting research was a long and unpredictable process. In the university, except for the research that was proposed to solve an industrial problem, the purpose of most research was to explore and discover unknown areas. To some extent, a significant finding might depend on luck. For the worst scenario, a research project might go through many failures and did not gain any valuable outcomes. Additionally, most research projects were conducted by graduate students. While it took about two to five years for a graduate student to earn a Master's or PhD degree, the research project would last that long accordingly.

For stage 3, the period for patent application, answers varied among interviewees. There were cases that a patent was granted within a year, and there were also cases that took more than three years to get a patent granted. When being asked if there were a correlation between the process time and type of technology, among fifteen interviewees with patenting experience, except that most interviewees in the field of life science indicated long waiting time of patent application, the rest of the interviewees were not sure if there was any connection. Two interviewees did mention that, based on what they knew of, inventors in the field of software development usually did not wait as long as most inventors of physical creations did. One interviewee with lots of patenting experience brought up a factor he thought might impact the process time of patent application. As he suggested, the process time of patent application might be affected by the number of features an inventor claimed for the invention. The more features that were claimed, the longer it might take for the U.S. Patent Office to review. If fewer features were claimed, however, it would be hard to meet the two of the three criteria the U.S. Patent Office required, "novelty" and "nonobvious". Therefore, without more information, it could not be concluded if the number of claimed features was correlated to the patent application process time, and what was the most appropriate number to achieve both success of patent application and shorter process time.

With regard to stage 4, the licensing period, the answers from a total of five interviewees were included for analysis. One interviewee indicated that all of the licensing did not take long. His students had been in touch with companies before patent application. Therefore, once the patent was issued, it was licensed right away. He did have one patent that was not successfully licensed, because the company with interests went out of business and he was not able to find a new sponsor. The other interviewee also indicated a short lead time of licensing, about less than a year. In this case, the invention was the outcomes of a joint research project with USDA. There was a specialist on the other side handling the commercialization. So the faculty was not aware of what had been done to get the patent licensed. The third interviewee that indicated a short lead time of licensing seemed to be very active in research commercialization. As he indicated, he was frequently in touch with the industry and proactive in learning the market need in his research area. He would not pursue a patent before a licensor was settled. Therefore, in his opinion, licensing should start before the patent application. Both of the other two interviewees suggested longer licensing time, however, their situation was different. In one case, the interviewee did not have any intention to look for a licensor for his patents. He was contacted by a company many years after he got the patent. This company learned about his research from his publications. In the other case, the interviewee did try to find a licensor for his research. However, as the purpose of his main research was to identify a drug that could be provided to the third world for free to kill a specific disease, it was hard to find a company that shared the same idea. For another research project, he indicated, the patent was licensed but it took a long time to find a licensor and he had limited time to contribute to this type of activity. Though the five cases above were different, it was not hard to see that having an industrial connection was very critical to facilitate the licensing process. While all of the five cases represented different research fields, we could not conclude which research field was more attractive to the industry and took less time for licensing. More studies were needed to further investigate this matter.

Verification of the Important Resources for Research Commercialization

During the exploration of resources that were important to research commercialization, the investigator received various answers, such as connections with industries, assistance from VTIP, business partners, incubator, time, business education, funding, and students, etc. Among all interviewees, about 90 percent of them mentioned the help from VTIP was very important for commercialization; about 80 percent pointed out the importance of having industrial connections, and for the rest of the resources, they got votes from less than 10 percent of all interviewees. This result corresponded to what was found in the survey study that VTIP and industry connection was the most influential resources on research commercialization.

As an additional finding from the interview, most interviewees had suggested that the inventor should be very proactive if he or she wanted to succeed in commercialization. Although the specialty of faculty was not in commercialization, it was very helpful to at least gain a basic understanding of business, patenting, licensing, and other related subjects. This information could be easily accessed by attending seminars on research commercialization, consulting with VTIP, or communicating with colleagues that had commercialization experience. Also, use of spare time was a must, while the normal working hours of a faculty had been spent on conducting research, teaching, writing proposals, and other administrative works. Therefore, no matter what resources were available, an inventor should first be motivated. The determination to pursue research commercialization was more important than any other external factors that could impact the outcomes of commercialization.

Conclusions

From this study, it was evident that university characteristics played an important role impacting the performance of research commercialization. An investigation of indicators of research expenditures, commitment of innovation, networking with industry, and market focus attitude revealed that Virginia Tech has made significant achievements in conducting research. However, it was not market-oriented. Virginia Tech was still following the traditional way of how a university performed, dedicated in research and teaching. Although it had developed IP policy and a support group of VTIP, when its culture was not encouraging research commercialization, the external help always seemed insufficient. Additionally, no strong evidence was found to motivate faculty to commercialize their research.

Chapter 7: Case Study of Industrial Research Commercialization Process

Introduction

In order to provide recommendations to improve the performance of university research commercialization, it is beneficial to understand the goal to accomplish, that is to say, the "best practice" to achieve. Research commercialization is a common practice in the industry with developed procedures and routines. While the performance of research and development (R&D) in different companies varies, as a whole, these processes are more effective and efficient than those of universities. Therefore, it is proposed that companies' research and development processes could be used as a good reference to develop the "best practice" of university research commercialization.

To gather information about research commercialization processes in the industry, interviews were conducted with two companies. Characteristics of the "best practices" were summarized based on the comparison of research commercialization processes between the company and university.

Objectives

The main goal was to gain insight about how research commercialization was managed in the industry so as to provide a "best practice" to which universities can compare their commercialization processes.

Methods

Cases Selection

Selected companies should meet a few criteria to be eligible for participating in the interview. First, as identified before, research areas of engineering, chemistry, and life science were the fields that generated more research commercialization at Virginia Tech. To reduce variance of commercialization activities from different research fields, selection of companies was focused on these three areas. Also, the company should at least have a R&D department or team, meaning that it was still active in bringing new products to the market. As to sample size, a total of 5 companies was planned at the beginning of this study. To find companies to participate in the interview, the investigator asked faculty, alumni, and colleagues for references and obtained contact information. After screening of all suggested companies based on the criteria above, a total of 5 companies were left as potential candidates for interview. To invite companies, personal invitation emails were sent to all contacts through Microsoft Outlook. The invitation email included a brief introduction of the research and the investigator, name of reference, what was needed from the company, and a kind request to schedule an interview. A reminder email was sent after a week if no reply was received from the respondent.

At the end, four companies replied and two indicated their willingness to participate. For the two companies that denied the invitation, one rejected because of strict policy of information disclosure; the other because the manager in charge was too busy to get involved in this study. And for the two companies that had accepted the interview invitation, one (company A) was an engineering-based company that provided air data measurement systems to the industries of aerospace, automotive, turbomachinery, wind turbine, and wind tunnel testing. It was a relatively small company with 25 employees and was formed about 10 years ago. The other company (company B) is a multinational corporation in the paint and coatings industry. With close to 100 years of history, it hired thousands of employees and provided products that could be used across a spectrum of industries, such as home building, automotive, and manufacturing, etc.

Interview Questions

Ahead of the interview, an interview guide was prepared with a list of questions. To link the study of research commercialization in the industry with that in the university, interview questions were designed and tailored to this study's three research questions and previous research findings. Specifically, the interview aimed to address the topics below:

- Research and development process;
- Important resources to support the process;
- Impediments within the process;
- Lead time of different stages within the process; and
- Output of different stages within the process.

Interview Implementation

For the two companies that had accepted the interview invitation, one was local and the other was not within driving distance. Therefore, both on-site and phone interviews were used. Before each interview, a web search of the company was conducted to get a basic understanding of the company's history, products, and recent news. The interview also adopted a narrative and semi-structured approach. At the beginning of each interview, a brief introduction of this study was given to the interviewees and their signatures on the IRB approved content form were obtained.

In the case that a phone interview was adopted, an electronic IRB content form was sent to the interviewee for signature in advanced. Signed IRB content form was then scanned by the interviewee and sent to the investigator. Additionally, as the interview required recording, all interviewees were informed of this matter and asked for permission before the interview.

Data Analysis

Cross-case comparison was used to analyze data collected from the interview. Specifically, a narrative approach was first used to describe the process of research commercialization in the company. Comparison of the processes between industry and university was then conducted with regard to the process steps, resource requirements, research outputs, and lead time. Based on the differences between the two commercialization processes, characteristics of the "best practice" were proposed for lateral exploration of recommendations to improve university research commercialization.

Results and Discussions

Research and Development Process

Based on the feedback from the interviews with the two companies, it was implied that there were different types of product development projects in a company: 1) refining the current products; 2) adding a new product to existing product lines; and 3) developing a brand new product. Depending on the nature of the product development project, different methods or processes were adopted. The first two types of product development were relatively more common in a company, because in these cases, decision making was easier when the market, customer, and manufacturing of the product had been well understood. For these types of products, there were usually defined routines and procedures to lead the product development process. As to creating a brand new product, the case became complicated. Similar to commercializing the university research, introducing a brand new product had many uncertainties. The targeted customer was not defined, market size was not known, and manufacturing scale-up was also uncertain. Therefore, simply applying the common method of product development would not work well in this case and special treatments were needed. While the focus of this study was not on detailed product development processes for different types of new products in a company, the investigator asked interviewees whether all those product development processes shared some similarities, , if there was a general path that the company followed. It was indicated by both interviewees that the stage-gate model was the most commonly used method to guide a product development project in the company.

Originally designed by Robert G. Cooper, the stage-gate model is a conceptual road map that helped companies to manage their idea-to-launch project and to make strategic decisions at different critical stages within a product development process (PDI, 2014). This model divides the process into a series of stages (activities) that are separated by gates (decision making), as shown in **Figure 32**. At each stage, there are specific activities to be done and preset deliverables. To pass through the gate and proceed to the next stage, pre-defined deliverables should be met. In general, deliverables at each stage reflected various aspects of a product, such as technical feasibility, market potential, and financial return, etc.; therefore, to address the various aspects, a cross-functional team is needed to complete all tasks. Combining the feedback from the interviewees and existing literature of conceptual stage-model, a typical product development process in the company is elaborated below.

Figure 32 The Standard Framework of Stage-gate Model (Robert G, 2007).

Idea Generation and Gate 1: A product development project was triggered by idea generation. In general, an idea of new products came from a variety of sources, such as a company's annual strategic planning, research scientists' ideas, findings at conferences, or voice of customer, etc. (Robert G, 2007). For both interviewed companies, it was indicated that ideas mainly came from their engineers, scientists, and customers. For company B, there were also semi-annual conferences organized by the company for people to share and exchange good ideas.

All new ideas were reviewed and screened at gate 1. At this point, evaluation criteria focused on qualitative measures, such as strategic fit, technical soundness, and a rough estimate of financial returns. People involved in this stage were usually senior managers of R&D departments, vice presidents, marketing and business development persons. Company A shared a similar process as described above. Company B, however, due to its small company size, skipped this step and proceeded to Gate 2 directly.

Stage 1 (Scoping) and Gate 2: Once an idea passed the first screening, it arrived at the stage of scoping. As company A described, this stage involved preliminary technical and market assessment of the idea. Activities mainly included IP search, literature review, resource identification, and potential customer feedback. Basically, this stage is intended to collect evidence to show that an idea was valuable enough to be officially included in the company's product development portfolio. Gate keepers at gate 2 were the same as at gate 1, their evaluation mainly looked at the results of market analysis, economic feasibility, technology feasibility, and legal issues, etc.

Stage 2 (Business Case Building) and Gate 3: Critical planning started at stage 2, where a comprehensive business plan of the new product was developed, and any necessary laboratory work completed. Different from the preliminary work conducted at stage 1, investigation of the new products in all aspects was to be done in detail, with both qualitative and quantitative information. Product specifications, marketing plan, manufacturing plan, financial evaluation, and legal requirements of the new product should have been fully illustrated in the business plan. Gate keepers that reviewed the business plan involved not only the same persons from gate 1 and gate 2, but also more senior managers and external experts or customers if necessary. As company B indicated, it involved the most amount of people at this stage for decision making, because from here the company was going to have significant spending to develop and commercialize the product.

Stage 3 (Development) and Gate 4: As mentioned above, once the idea passed gate 3, it meant that the company was going to commercialize this idea and create "prototypes", as named by company B, for further evaluation. At this stage, what was mentioned in the business plan was converted into concrete deliverables and actual products. This stage usually involved iterative experiments and multiple reviews to get the product ready for manufacturing scale-up. Gate keepers at this point were reduced from what was needed at gate 3, mainly technical persons, or scientists, and experts from the industry.

Stage 4 (Testing) and Gate 5: If an idea could get as far as stage 4, it had become very close to the commercialization stage. Multiple testing was to be done to ensure that the product performed as expected. As both company A and B implied, there would be first some internal testing, and then customers and other industrial experts would be invited for further testing and validation. If necessary, more laboratory work would be done to refine the product based on feedback from the testing. At gate 5, the key players for gate keepers were still similar to the group at gate 4, however, the role of customers and external helpers became more important at this stage.

Stage 5 (Commercial Launch): Full commercialization of the product began at this stage.

Key Resources and Impediments

The most important resources to facilitate product development, as both companies suggested, were customer input and feedback. While other resources, such as human effort and financials, were also necessary within the process, it was more critical to first understand the market and what customers wanted. If a new product was not appropriately defined throughout the process, initial investment of any resources in a product development project would be wasted. And it was why both interviewees mentioned that not understanding the customer was also the biggest impediment to commercialize an idea, especially for a totally new product. When asked how the company handled a situation when there was limited information about the market, interviewees indicated that making small investments to collect a little information step by step would be the initial work. While it was time consuming, there would be a point where big decisions could be made to move the project one step further.

Outputs and Lead time

With regard to the outputs or success rates of product development projects in a company, it was mentioned that it depended on the nature of the projects. Projects that involved only adding new functions to existing products or adding new products in current product lines usually resulted in high success rates. In the case of developing a totally new product, the chance of success was very low. For quantitative data, interviewee from company A was not able to give an exact number of outputs considering the size of the company and number of projects going on each year. An estimate of 10~20% success rate was suggested for developing a brand new product. For company B, because the company was small, there were not as many product development projects as in company B each year. For this year when the interview was taken, a total of 15 ideas were proposed, and 5 of these ideas were turned into prototypes and 3 were commercialized.

Similar to the case of estimating outputs, providing an average lead time for product development projects was also very challenging, because a case could vary from a small project that only dealt with making minor modifications to existing products to a large project that involved creating something new. For the former case, it might take less than a month; and for the latter one, the company might spend years. As company B explained, even for a new product, the time really depended on how complicated the product was. It could be less than a year, and also more than years. They had experienced both. As to lead time, interviewees were also asked which stage took the longest time throughout the product development process. Both companies agreed that actual development of the new product, or stage 3, was the most time consuming process.

Comparison with University Research Commercialization

Comparison of research commercialization processes between companies and the university revealed that these two processes were not identical but shared some similarities. First, both processes faced the problem of not knowing the market of new products at the onset of a product development project. And it took very long and required substantial investments in developing a product in both cases. However, these two situations also differed greatly from each other in many ways:

First, the two processes were managed from different perspectives. In the university, progress of commercialization was usually perceived and evaluated according to the status of a patent application. To some extent, patent application was a required activity if a researcher in the university planned to commercialize an invention. In the company, however, the progress was closely related to the development and market readiness of the product. Acquisition of IP projection was only one of many aspects that a company would consider for product development. Because it was very difficult and took very long to get a patent, in many cases, a company might skip the step of getting legal projection to reduce the time to move products to the market. As interviewees implied, being the first one to the market could also be a way of protection. Because once the market position was seized, it would be hard for competitor to compete. After all, the market accepted a product not because it had full IP protection, but because the product met its needs. Therefore, in this study, if evaluating the product development process only from the perspective of commercializing a product, IP policy of Virginia Tech might have impeded the research commercialization process. When a university had too much emphasis on the importance of IP protection, it might have sent a message to the researchers that getting a patent was more important than any other merits to commercialize an invention. Also, cases from the industry had indicated that many commercializable products might not be qualified for a patent. When VTIP rejected a proposal for patent application, it might have also lost a chance to commercialize a valuable product.

Secondly, the intent of starting a research project was also different. As indicated by faculty during the interview, the reason that they wanted to join the academic area was because there was more freedom for research topic selection. They wanted to study what interested them the most. Therefore, in the university, the trigger to develop a new product usually came from a researcher's personal research interests, though sometimes came from requests from the industry. Also, as long as the research project could generate publications and research grants, it would be continued. And tailoring of the product to meet market needs normally came at the end of the project. Key players throughout the processes were mostly faculty and students that had limited knowledge of business. Their interaction with industries was very rare. In the company, the situation was very different. As explanation of the stage model above implied that identifying an opportunity to meet customers' needs was always the reason to begin a product development project. Involvement of customer inputs was constantly seen at every stage of the process from idea generation to commercialization launch. Other than that, people from different functions joined and evaluated the project at a very early stage to ensure feasibility of the project. Speaking from this perspective, business assessment of a product development project was more adequate in the company.

At last, as the investigator perceived, customers of these two product development processes were different. While there was only one type of customer for the product development project in a company, the person or organization that would consume the product, there were two types of customers in a university, the customer similar to that of a company and the university. The reason the university was considered as a customer was that expected outcomes of a research project in a university was not only successful licensing of patents or establishment of a start-up, but also educated students, dissertations, and publications, etc. To some extent, in many cases, serving the university's needs was more important throughout the process, and research commercialization only came along when an opportunity appeared. For the cases that faculty had successfully commercialized their research, when asked how they balanced the work to satisfy both university requirements and commercialization. They all responded: "*Spend extra time outside of normal working hours*" In this regard, the most important customer is the university itself.

Conclusions

Based on the comparison of product development processes of a company and a university, it was found that characteristics of the "best practice" of research commercialization identified at this stage corresponded to a previous finding of this study. That was, industrial input was the most important element to facilitate research commercialization. While this had been a well-known conclusion from existing literature, this study wanted to stress that on top of all other resources or factors, industrial interaction was the most important one. It was the prerequisite to acquire other resources. Aside from that, business knowledge was also very important. This knowledge could be an inventor's own experience, or external help. At the end, a product development project should be driven by meeting customer needs. While approval of a patent could largely prove three aspects of a product, i.e. novelty, usefulness, and nonobviousness, it was not equal to the voice of customers.

As a summary, these conclusions were listed as below:

1. A new product development project should be customer or market driven, reflected by consulting with potential customers and asking feedbacks throughout the process;
2. Business inputs, including marketing, finance, manufacturing, and legal requirements, should be included at the early stages of the commercialization process;
3. While IP protection was important, it was not necessary for commercializing a product.

Chapter 8: Recommendations to University Research Commercialization

Introduction

This study took two steps to develop recommendations for improvement of research commercialization at Virginia Tech. First, an ideal state VSM was created based on the results from the survey study, interviews with faculty, and interviews with companies. An ideal state represented a situation where everything was perfect and no problems existed. Therefore, an ideal state VSM served as a long-term goal that guided the improvement but could not be achieved shortly. Once the ideal state VSM was created, a future state VSM was then developed according to the result of a gap analysis between the ideal state VSM and current state VSM of Virginia Tech's research commercialization process provided in chapter five. A future state VSM was like a short-term plan, consisted of recommendations to improve Virginia Tech's research commercialization process in the near future.

An Ideal State Value State VSM

Before developing the commercialization process in an ideal state, an ideal environment should be defined. First, from the resource perspective, as found in this study, the most important resources in the commercialization process were industrial connections and assistance from VTIP. Therefore, it was assumed that in an ideal state, Virginia Tech had developed a research environment with rich industrial connections and had sufficient human resources at VTIP to assistant all commercialization activities. Also, from the perspective of university characteristic, it was found that, currently, Virginia Tech was still functioning as a traditional university that focused on conducting research, which left faculty insufficient time and low motivation to get involved in commercialization activities. Therefore, it was assumed that in an ideal state, commercialization achievement would be weighted and evaluated equally as other research accomplishments, such as publications, research grants, and graduated students, etc.

A “best practice” of research commercialization had been introduced in chapter six. In this study’s initial plan, the best practice would be used as the ideal state VSM for university research commercialization. However, as found during interviews with companies, research commercialization in the company was managed with a different perspective (while companies focused on customers’ needs, universities placed more emphasis on IP generation). Also, universities and companies do have different goals. Therefore, direct use of the company’s research commercialization process as the ideal state value stream was not feasible. Only feasible characteristics of the best practice were used as references to build the ideal state VSM of university research commercialization.

In the ideal state VSM, the first step of a research commercialization process was idea generation. As indicated in the best practice, all new product or research ideas came from customers’ feedback, or market needs. In the university, while final outcomes of any research were also used to help the public or human society, the concept of taking market needs as research ideas did not conflict with the research purpose of a university. Therefore, it was proposed that in an ideal state, faculty or researchers from the university selected would have a higher tendency to select research ideas according to market needs in their research fields.

In the current state, as revealed from interviews with faculty, there was little or no contact between faculty and the industry before completion of research. This had been pointed out by the majority of interviewees as a drawback of university research commercialization. Faculty with successful commercialization experience suggested that frequent interaction with the industry at the early stage of a research project was very necessary to foster research commercialization. This viewpoint was also proven during the study of companies' product and development processes. Given the ideal environment this study had assumed at the beginning, it was proposed that, in the ideal state, there would be frequent communication between faculty and the industry with regard to the direction and modifications of research projects before invention disclosure. In additional to that, licensing of the research outcomes would also be addressed at this stage.

By the time the majority of research was completed and ready for invention disclosure, as described before, VTIP started to play an important role. In the current state, there was not enough staff at VTIP to review all invention disclosures in a timely manner while they were busy with other activities, such as searching for licensees, marketing the invention, or working with companies to nail down a licensing agreement, etc. Also, many invention disclosure forms were not prepared in the correct manner, such as missing important information, not properly describing the research, or providing insufficient data, etc. These problems created unnecessary work for VTIP because each time when paper work was not properly prepared, staff from VTIP had to contact faculty or researchers to get clarification for forms. Therefore, in an ideal stage, it was assumed that all the problems described above no longer existed. When a research project proceeded to the stage of invention disclosure, it could be handled by VTIP right away. This process, as VTIP implied, would take only few hours when they had time to review a properly prepared invention disclosure.

In the best practice, patent application was only part of the considerations of many other issues. At Virginia Tech, however, patent management was an important topic and it was required that all inventions planned for commercialization go through VTIP for settlement of ownership of the invention. To some extent, it meant that an invention was unlikely to be commercialized if it did not get support for patent application. In this study, as explained in previous chapter, an invention might not be filed for a patent application at Virginia Tech because of technical or systematical reasons. From the technical point of view, patent application for an invention was not filed due to the lack of meeting all requirements to be filed for a patent; in a systematical case, the invention might qualify for a patent, however, it was screened out during the review process conducted by VTIP. This happened when illustration of the invention was not well documented in the invention disclosure form, when VTIP was not familiar with the subject, or when VTIP did not have sufficient budget to support all inventions for patent application. As identified through the survey and interviews with faculty, many inventions were not commercialized because they did not pass the stage to proceed for patent application. Therefore, in an ideal state, the above issues were assumed to no longer exist and all inventions that were disclosed were patentable and would be supported for patent application, either by companies or VTIP.

Getting a patent licensed was another issue in the current state, while not all inventions met market needs or were fully developed to show market value. In an ideal state, all inventions were licensed right after patents were granted. In these cases, as described before, a research idea had been modified multiple times with the help of industrial feedback, and licensing had been discussed at an early stage. In any case, once an invention was filed for patent, this application was executed based on the fact that the patent would be licensed by a company in the future. For the case of establishing a start-up, similarly, a company would be formed before patent application. The activities of searching for seed money or venture capital started early when significant research outcomes had been attained. To some extent, development of the new company and patent application went parallel within the commercialization process.

A summary and complete demonstration of the ideal state VSM for the case of licensing and start-up was provided in **Figure 33 and Figure 34** below:

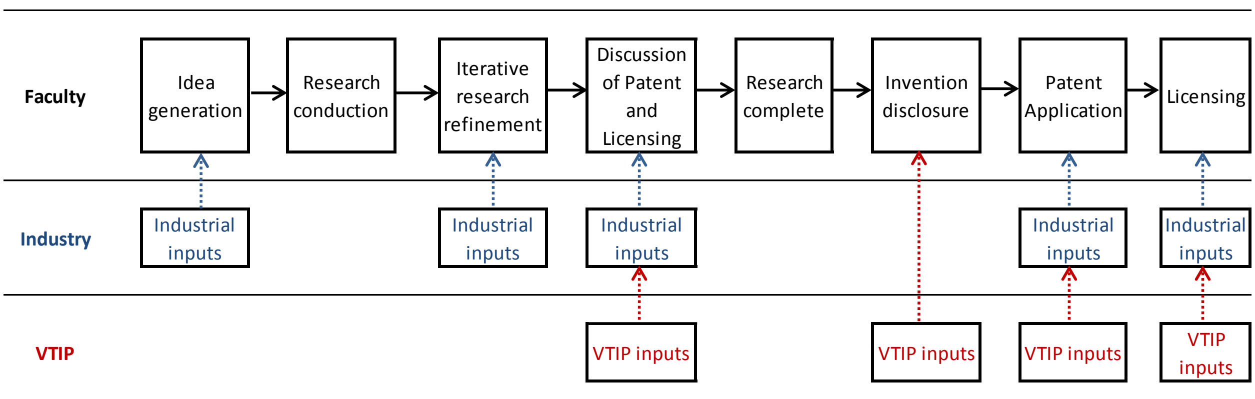

Figure 33 The Ideal State VSM of Research Commercialization at Virginia Tech (licensing).

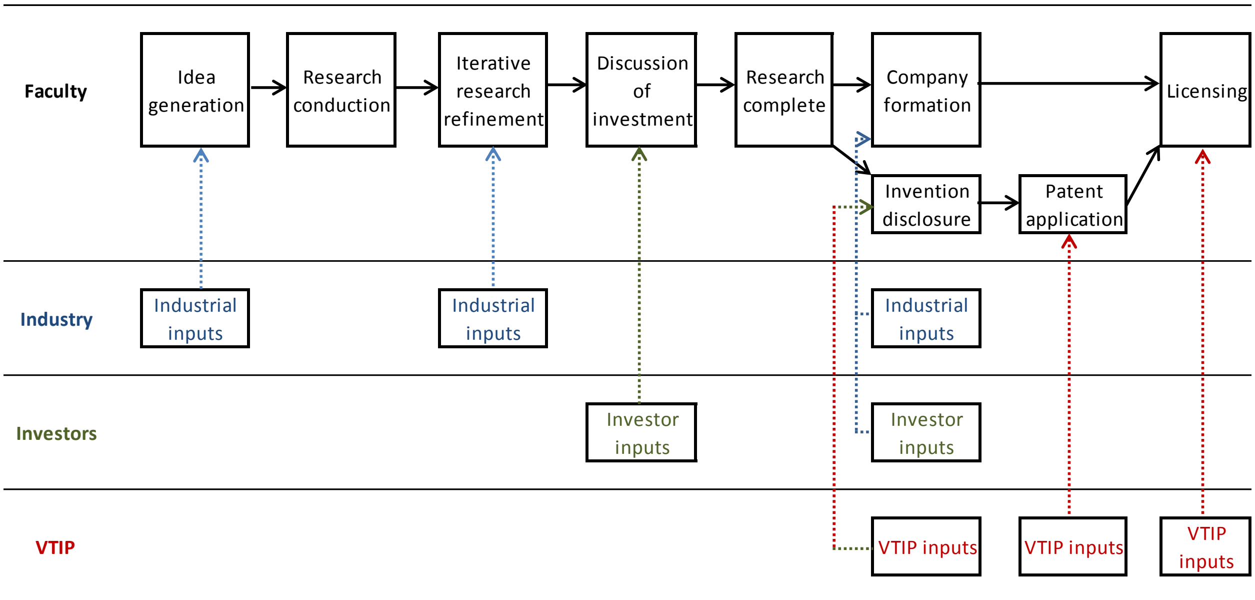

Figure 34 The Ideal State VSM of Research Commercialization at Virginia Tech (start-up).

A Future State Value State VSM / Recommendations

The ideal state of a research commercialization process at Virginia Tech is a long term goal that could not be achieved in the near future. As described above, to achieve the ideal state, it was expected that distinct policy changes had taken place, and tremendous investments will be distilled into development of industrial connections and VTIP human resources. After comparison of the current state and ideal state of research commercialization process at Virginia Tech, this study proposed a future state value stream map that could be used as a short-term improvement plan.

When Lean was adopted in an industrial setting, large process improvement plans usually started from a small pilot project that involved less dramatic changes to the company or a single product.

After implementation of improvement suggestions, if the pilot project was successful, the same improvement ideas were then applied to other units or other products of the company. Adopting this concept, this study suggested that Virginia Tech could first focus on one or few departments to implement some changes. To select a pilot department, Virginia Tech could consider the department that had demonstrated active involvement in research commercialization for the past few years. As this study identified, at Virginia Tech, research commercialization had largely taken places in few research areas, such as engineering, life science, and chemistry. Therefore, a pilot department could be selected from departments with those above research fields.

Once targeted departments were identified, Virginia Tech could start process improvement by working with department heads or deans to create a commercialization friendly environment for faculty and researchers. First, it was proposed to provide incentives to encourage research commercialization. As proposed for the ideal state, faculty's achievements in research commercialization should have been included as one of the criteria for tenure evaluation across campus. However, because the traditional tenure review system had been long used in most universities in the U.S., adding any criteria to the system would be very difficult and might require many steps of decision making. As a short term plan, it was then suggested that faculty's accomplishment in patenting or licensing be added to tenure evaluation only at pilot departments, without impacting the overall policy of the university.

In addition to the creation of incentives, external business assistance to work with faculty or researchers on commercialization should be provided. While the ideal case would be to have VTIP send one or a few business specialists for specific research fields to serve each department exclusively for its entire research commercialization activities, such as industry outreach, business consultation, and invention promotion, etc., the fact that Virginia Tech did not have enough budget for such investment made it challenging to hire more people for VTIP. During interviews with faculty, the investigator found that faculty with commercialization experience were usually equipped with basic business and patenting knowledge. They did not rely on VTIP and handled most of commercialization activities independently. Their business knowledge, as the investigator perceived, was a very valuable resource and could be shared with other faculty and researchers that also had interests in commercialization. Therefore, this study proposed that Virginia Tech could select a group of faculty that had rich commercialization experiences and form a committee for pilot departments. This committee would serve to provide consultation to other faculty and researchers for general questions about commercialization, such as preparation of invention disclosure forms, important dates about patent application, industrial connections, and university IP policy, etc. When business consultation had been covered by the committee, one candidate from VTIP could be selected to work solely on processing of invention disclosures, patent applications, and licensing settlement for the pilot department. Also, to overcome the drawback of having limited industrial connections for most faculty, the same candidate from VTIP could also actively engage in communicating with faculty and work with them to build more industrial connections and promote the research to the market.

Once all the initial improvements were made as introduced above, a future state value steam of research commercialization would look like the processes, as shown in **Figure 35** and **Figure 36** below:

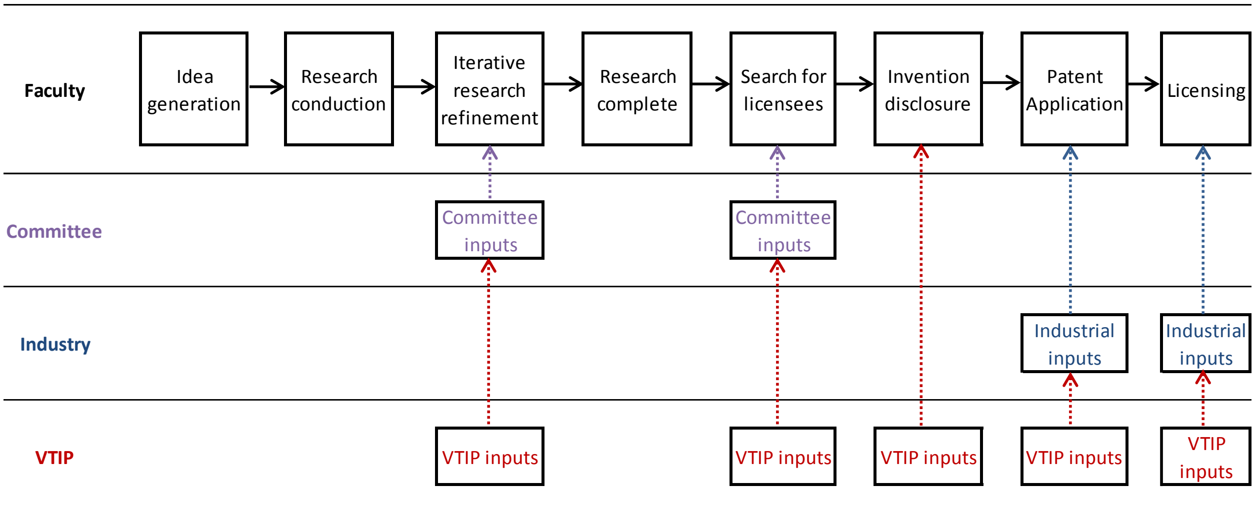

Figure 35 The Future State VSM of Research Commercialization for Selected Department at Virginia Tech (licensing).

As shown in the future state VSMs for both cases of licensing and start-up, while short-term improvement suggestions had been built into the future state VSM, the entire research commercialization process remained similar to the current state. Research ideas still came from faculty's research interests. While involvement of industrial feedback at the early stage of research conduction was not common, the committee and VTIP had gradually got into their role of providing suggestions to faculty. In the case of licensing, with limited industrial connection, the search for licensees probably would not start until research was completed. This was also similar to the current stage. However, differing from the current state, it was suggested in the future state that faculty only start to file invention disclosures when a licensee could be identified. By doing this, the number of invention disclosures sent to VTIP could largely decrease and workload of VTIP would be reduced accordingly. Also, as licensee was going to sponsor the patent application fee, the burden on VTIP's budget could be relieved in the future state. In the case of building a start-up, the search for investors also started after research was finished. Once investors were identified, this study suggested faculty start forming a company and filing invention disclosures at the same time. Therefore, development of the company could go simultaneously with patent applications, and time would not be wasted on the waiting for patent approval from the U.S Patent Office.

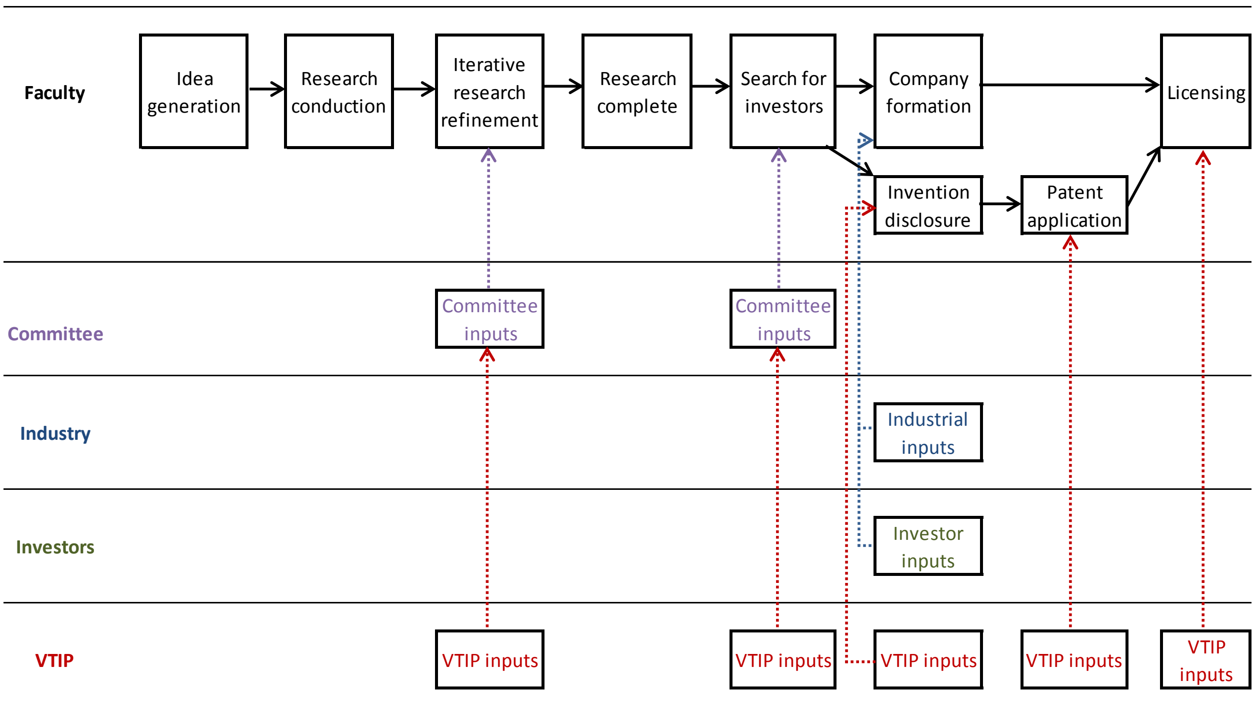

Figure 36 The Future State VSM of Research Commercialization for Selected Department at Virginia Tech (start-up).

Chapter 9: Conclusions, Limitation and Future Research

Conclusions

This study was conducted to investigate if a process improvement tool from manufacturing could be used to study and improve the research commercialization process in the university. The first objective of this study was to investigate if a conceptual framework developed from value stream mapping could be applied to analyze the research commercialization process. As found, while not all criteria from this tool could be applied to the case of research commercialization, after adjustments, the main concepts of the tool could be adopted.

The second objective was to determine the most important resources on the performance of research commercialization. A combination of survey and interviews with faculty revealed that there were certain types of resources playing more important roles in fostering research commercialization. Also, at different stages of the process, different resource's importance varied. The two most important resources that impacted the success of research commercialization were industrial connections and business assistance. Communications with industry for feedback on the research at the early stage were very beneficial for an invention's performance in the market. However, in the current state, most faculty or researchers took a different approach and started the interaction with the industry towards the end of a research project. Getting in touch with the industry early will help not only to reduce the time to bring an invention to the market, but also to increase the chance of success of research commercialization. In addition to industrial connection, business assistance from VTIP or other institutes was also very necessary. Similar to the finding from existing research, to commercialize an invention, simply knowing the technology was not enough. Different aspects, such as marketing, manufacturing, and legal projection, etc., should be taken into consideration. While the majority of faculty and researchers were not trained to understand that knowledge, it became important that external business assistance is provided to facilitate research commercialization in the university. At the university being studied, due to lack of budget and staff, business assistance was not sufficient. VTIP was the only organization that managed research commercialization at Virginia Tech. In many cases, either VTIP was not able to provide comprehensive business support due to limited expertise in few research fields, nor could not respond to faculty in a timely manner due to lack of staff. This study also found that, as suggested by faculty with successful commercialization experience, to accelerate the commercialization process, researchers should gain basic business knowledge for commercialization. It was not feasible to require the external business assistance, like VTIP, to be specialized in all research areas. In regards with technical aspects, the inventor was the best candidate to promote a new product to the market. Having inventors equipped with general business knowledge will largely ease the work required from VTIP.

The third objective of this study aimed to investigate if Virginia Tech had characteristics that were favorable to research commercialization. It was found that Virginia Tech was strong in conducting research and generating research merits, while research commercialization was not widely supported. Based on the data provided by Virginia Tech administration, for the past ten years, the university had made distinct progress on research grant generation and research diversification. Research funding has also shown steady growth. As to commercialization, sporadic support was identified, such as launch of seminars for commercialization education, provision of office space for business meetings, and invitation of external commercialization experts to help faculty, etc. However, centralized and systematic effort to improve commercialization was not seen. Also, incentives for commercialization were not developed at Virginia Tech. The greatest motivation to commercialize an invention generally came from personal pursuits.

In search of the best practice of research commercialization, this study interviewed two companies and studied their product development processes. It was found that companies took a very different approach from universities in managing a commercialization process. In the company, the product development process was monitored and evaluated according to the level of readiness of a product to meet market needs; in a university, however, IP readiness and revenues generated from IP licensing were largely emphasized by the administration. Speaking from the commercialization point of view, the company's approach was more feasible because the final goal of commercialization was to produce a product that customers were willing to consume. IP protection only came along when needed. Therefore, to better manage the research commercialization process, Virginia Tech can consider reducing the focus simply on IP generation. When evaluating an invention for commercialization, more emphasis can be given to its market value and market readiness. In addition to the finding above, a similar conclusion was found that early involvement of people from business functions was very important for a product development project. In a company, except for scientists or engineers, representatives from marketing, accounting, manufacturing, and legal departments, and customers were all invited to provide feedback on the new products. Based on the comments and suggestions, iterative adjustments on the product were then made to gain final approval. This fact corresponded to the suggestions provided by faculty interviewees. Inventors should actively interact with the industry at early stages.

At the end, with all the information received, this study suggested a few recommendations to Virginia Tech to improve its research commercialization process. First, it was proposed that Virginia Tech could start making improvements in a few selected departments. This approach was suggested because making adjustments on small areas requires fewer resources and less dramatic changes. Secondly, this study recommended that Virginia Tech add faculty's accomplishment on commercialization as one of the criteria for tenure review at selected departments. This change was very critical for the improvement of commercialization performance at Virginia Tech, as it was directly linked to faculty's willingness and determination to get involved in commercialization activities. While developing recommendations, the investigator realized the fact that Virginia Tech currently did not have sufficient budget to expand the size of VTIP or to invest in establishing industrial networks. However, as this study identified, having VTIP support and industrial connections were the two most important resources to facilitate research commercialization. To overcome this drawback, the investigator suggested utilizing the existing resources: faculty that had commercialization experience. A committee can be created with faculty having successfully commercialized their inventions. This committee would serve to provide consulting to other faculty that have interests in commercialization but do not know where to start. Doing this, most inquiries will be directed to the committee, instead of VTIP, so VTIP can focus on other important activities, such as processing invention disclosure and IP application, marketing inventions, and communicating with potential licensers, etc. With the above changes made, if improvements on commercialization are observed at selected departments, Virginia Tech can expand the scale and make the same changes in other departments.

Limitations

One of the biggest challenges of this research was working on the complexity of the commercialization activities in universities. Invention was transferred from university to industry in different forms. And within each form, variation also existed between cases. With time and resource constraints, this research could only target one university, Virginia Tech in this case, to study its research commercialization activities. Therefore results from this research would not provide suitable solutions for every university. However, for the case that belonged to or was similar as Virginia Tech, adoption of the proposed process improvement suggestions should be feasible with appropriate adjustments or modifications.

Also, as had been explained in the text before, this study failed to conduct multiple regression analysis to test the relationship between different types of resources and the performance of research commercialization. This drawback should have been foreseen at the beginning of design of experiment. The investigation involved numerous independent variables, so a large sample size was required and responses from one university were not sufficient to satisfy this requirement.

Additionally, as complex as other social science cases, research commercialization involved unorganized processes, intricate interactions, and unclear responsibilities, etc. As found in the survey study, in many cases, it was very difficult for respondents to provide absolute values or an exact answer.

Very often, certain quantitative or qualitative data was unattainable or not accurate and guesses or estimations were provided. These uncertainties undermined the integrity of evidence and weakened the validity of propositions.

At last, while recommendations provided in this study included university policy adjustments, it did not have inputs of policy makers when recommendations were made. Therefore, it could be possible that implementation of certain process improvement ideas is not feasible at Virginia Tech.

Future Research

Though this study was completed, it left a few areas that could be future investigated. First, for development of an ideal research commercialization process, lateral studies can also consider taking universities that have many successful commercialization cases as examples. It was found at the end of this study that Virginia Tech was benchmarking itself to ten other U.S. universities with regard to generated research grants, graduated students, and commercialization performance, etc. Therefore, if successful cases are selected from these ten universities, the resulting ideal state of commercialization process would be more convincing to Virginia Tech's administration. Secondly, if time allows, future study on this subject could conduct a longitudinal study of one or a few research commercialization cases from the time a research idea is generated to the time this idea turned into a product. Close observation of a research commercialization process will allow investigators to gain a deeper and clearer understanding of what has happened at different stages within the process. So recommendations are developed based on actual facts, instead of guesses or estimation. Finally, this study had provided only the first future state VSM of research commercialization at Virginia Tech. There are still large gaps between the future state and the ideal state of research commercialization. To finally arrive at the ideal state, process improvements should be done continuously. Therefore, if recommendations of this study are adopted by Virginia Tech, after implementation of improvement ideas, the future state VSM will become another current state VSM, and the second, the third, and the fourth future state VSMs are then needed to keep improvements going before the ideal state is achieved. Hence, future studies on this subject can focus on the progress of improvement on research commercialization and developed additional future state VSMs of the process.

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Appendix

Appendix A. Survey Study Informed Consent Form

Informed Consent Form

Introduction
Commercialization of university research is an important activity in the research environment in the U.S. Universities have adjusted their policies and opened the door to welcome business activities, which has not been the traditional routine. However, due to the nature of universities being academic institutions, there are challenges within the commercialization process. These challenges provide universities opportunities to change and to achieve a better transition from academic to business.

Objective
The main objective of this study is to assess and improve the university research commercialization process, from the time an idea is generated to the time this idea is transferred into a product. Furthermore, the study aims to address how factors, such as business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. A process model of commercialization will be suggested at the end of our study.

Procedure
This study focuses on the process of university research commercialization and divides the whole process into five stages:

Stage One: Conducting research - Invention Disclosure
Stage Two: Invention Disclosure - Patent Application
Stage Three: Patent Application - Patent Issued
Stage Four: Patent Issued - Patent Licensed/Company formed
Stage Five: Company formed - Sustainable Growth

According the five stages above, this questionnaire was designed to consist of five parts, with each part containing questions related to the issues or activities in that stage.Filling out the questionnaire will take approximately 10 minutes or less. Please answer all questions based on your familiarity with the university research commercialization process by choosing the most appropriate response or by filling out the blanks as indicated.

Benefits
A summary of the results will be made available to all participants. Participants will gain a better understanding of the research commercialization process at Virginia Tech and the critical resources within the process. The research will also provide performance metrics and recommendations for process improvement, enabling participants to benchmark and improve their work.

Confidentiality
All data obtained from participants will only be reported in an aggregate format. Participants' characteristics will not be identified in connection with the data. All questionnaires and data collected will be kept strictly confidential, and none other than the primary investigator and her assistant will have access to them.

Participation
Participation in this research is voluntary and participants have the right to withdraw at any time or to refuse to participate without any penalty.

Risks/Discomfort
No risk is expected for involvement in this study.

Contact Information
If you have any questions about the research, or if you have any problems in loading or accessing the questionnaire, please contact Yu Zhou by phone at (540)808-7670, or e-mail:angelayu@vt.edu.

Contact IRB: Dr. David Moore, email: moored@vt.edu, phone: (540)231-4991

Signature: ________________________ **Date:** ________________________

Appendix B.

Pretest Invitation Letter

Dear Dr. (First Name) (Last Name)

I am conducting research, for my doctoral dissertation, to **assess and improve the university research commercialization process**, from the time an idea is generated to the time this idea is transferred into a product. The study seeks to determine how factors, such as business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. And it will provide valuable information as to current commercialization practice and benchmarks to evaluate and improve the process.

We need your help to pretest a questionnaire. Filling out the questionnaire would take no more than 15 minutes. After you complete it, may I also kindly ask you to email me back and let me know if the questionnaire's wording is understandable, the content clear, and length acceptable?

The questionnaire can be accessed at https://qtrial.qualtrics.com/SE/?SID=SV_9LAMD8Ue8WL5OjH.

We would like to thank you for your assistance in advance. Please be assured that your response will be treated with **complete confidentiality**. Your name will never be identified in the study results nor will your participation be disclosed to anyone.

Thank you very much for your time to complete the survey. Should you have any questions, please contact me by phone at (540) 808-7670, or e-mail: angelayu@vt.edu.

Sincerely,

Yu Zhou (Angela),
Doctoral Candidate
Department of Sustainable Biomaterials
200 Cheatham Hall
Virginia Tech
Blacksburg, VA 24061

Pretest Reminder Letter

Dear Dr. (First Name) (Last Name)

I am conducting research, for my doctoral dissertation, to **assess and improve the university research commercialization process**, from the time an idea is generated to the time this idea is transferred into a product. The study seeks to determine how factors, such as business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. And it will provide valuable information as to current commercialization practice and benchmarks to evaluate and improve the process.

It is a kind reminder that we need your help to pretest a questionnaire. Filling out the questionnaire would take no more than 15 minutes. After you complete it, may I also kindly ask you to email me back and let me know if the questionnaire's wording is understandable, the content clear, and length acceptable?

The questionnaire can be accessed at https://qtrial.qualtrics.com/SE/?SID=SV_9LAMD8Ue8WL5OjH.

We would like to thank you for your assistance in advance. Please be assured that your response will be treated with **complete confidentiality**. Your name will never be identified in the study results nor will your participation be disclosed to anyone.

Thank you very much for your time to complete the survey. Should you have any questions, please contact me by phone at (540) 808-7670, or e-mail: angelayu@vt.edu.

Sincerely,

Yu Zhou (Angela),
Doctoral Candidate
Department of Sustainable Biomaterials
200 Cheatham Hall
Virginia Tech
Blacksburg, VA 24061

Appendix C.

Survey Invitation Letter

Dear Dr. (First Name) (Last Name)

I am conducting research, for my doctoral dissertation, to **assess and improve the university research commercialization process**, from the time an idea is generated to the time this idea is transferred into a product. The study seeks to determine how factors, such as business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. Also, it will provide valuable information as to current commercialization practice and benchmarks to evaluate and improve the process.

We are asking for your help by completing a questionnaire. It would take no more than 15 minutes. The questionnaire can be accessed at https://qtrial.qualtrics.com/SE/?SID=SV_9LAMD8Ue8WL5OjH.

We hope to see your responses by Oct 30th. And we will send out reminders prior to that date. **Since the number of participants is small, your response is vital for the success of this research and my graduation**☺

Please be assured that your response will be treated with **complete confidentiality**. Your name will never be identified in the study results nor will your participation be disclosed to anyone. Only aggregated results will be reported.

We would like to thank you in advance for your time to complete the survey. Should you have any questions, please contact me by phone at (540) 808-7670, or e-mail: angelayu@vt.edu.

Sincerely,

Yu Zhou (Angela),
Doctoral Candidate
Department of Sustainable Biomaterials
200 Cheatham Hall
Virginia Tech
Blacksburg, VA 24061

Survey Reminder Letter

Dear Dr. (First Name) (Last Name)

I am a graduate student at Virginia Tech.

I am conducting research, for my doctoral dissertation, to **assess and improve the university research commercialization process**, from the time an idea is generated to the time this idea is transferred into a product. The study seeks to determine how factors, such as business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. Also, it will provide valuable information as to current commercialization practice and benchmarks to evaluate and improve the process.

It is a kind reminder that we need your help to complete a questionnaire. It would take no more than 15 minutes. You can access the survey by Click Here, or copy and paste the URL below into your internet browser:
https://virginiatech.qualtrics.com/WRQualtricsSurveyEngine/?Q_SS=0rfYv6NzVaM1fqB_9LAMD8Ue8WL5OjH&_=1

We hope to see your responses by Oct 30th. **Since the number of participants is small, your response is vital for the success of this research and my graduation**:)

Please be assured that your response will be treated with **complete confidentiality**. Your name will never be identified in the study results nor will your participation be disclosed to anyone. Only aggregated results will be reported.

We would like to thank you in advance for your time to complete the survey. Should you have any questions, please contact me by phone at (540) 808-7670, or e-mail: angelayu@vt.edu. You can also contact my advisor, Dr. Audrey Zink-Sharp by agzink@vt.edu.

Sincerely,

Yu Zhou (Angela),
Doctoral Candidate
Department of Sustainable Biomaterials
200 Cheatham Hall
Virginia Tech
Blacksburg, VA 24061

Appendix D. Questionnaire for the Survey Study

Informed Consent Form

Introduction

Commercialization of university research is an important activity in the research environment in the U.S. Universities have adjusted their policies and opened the door to welcome business activities, which has not been the traditional routine. However, due to the nature of universities being academic institutions, there are challenges within the commercialization process. These challenges provide universities opportunities to change and to achieve a better transition from academic to business.

Objective

The main objective of this study is to assess and improve the university research commercialization process, from the time an idea is generated to the time this idea is transferred into a product. Furthermore, the study aims to address how factors, such as business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. A process model of commercialization will be suggested at the end of our study.

Procedure

This study focuses on the process of university research commercialization and divides the whole process into five stages:

Stage One: Conducting research - Invention Disclosure
Stage Two: Invention Disclosure - Patent Application
Stage Three: Patent Application - Patent Issued
Stage Four: Patent Issued - Patent Licensed/Company formed
Stage Five: Company formed - Sustainable Growth

According the five stages above, this questionnaire was designed to consist of five parts, with each part containing questions related to the issues or activities in that stage.

Filling out the questionnaire will take approximately 10 minutes or less. Please answer all questions based on your familiarity with the university research commercialization process by choosing the most appropriate response or by filling out the blanks as indicated.

Benefits

A summary of the results will be made available to all participants. Participants will gain a better understanding of the research commercialization process at Virginia Tech and the critical resources within the process. The research will also provide performance metrics and recommendations for process improvement, enabling participants to benchmark and improve their work .

Confidentiality

All data obtained from participants will only be reported in an aggregate format. Participants' characteristics will not be identified in connection with the data. All questionnaires and data collected will be kept strictly confidential, and none other than the primary investigator and her assistant will have access to them.

Participation

Participation in this research is voluntary and participants have the right to withdraw at any time or to refuse to participate without any penalty.

Risks/Discomfort

No risk is expected for involvement in this study.

Contact Information

If you have any questions about the research, or if you have any problems in loading or accessing the questionnaire, please contact Yu Zhou by phone at (540)808-7670, or e-mail:angelayu@vt.edu.

Contact IRB: Dr. David Moore, email: moored@vt.edu, phone: (540)231-4991

I have read, understood, and desire of my own free will to participate in this study (You may print a copy of the above consent form for your record).

- ○ Yes
- ○ No

Introduction

This study focuses on the process of university research commercialization and divides the whole process into five stages:

1. Conducting research - Invention Disclosure
2. Invention Disclosure - Patent Application
3. Patent Application - Patent Issued
4. Patent Issued - Patent Licensed/Company formed
5. Company formed - Sustainable Growth

According the five stages above, this questionnaire was designed to consist of five parts, with each part containing questions related to the issues or activities in that stage.

Note: You may or may not need to answer the questions for all five stages, depending on your experience with university research commercialization.

Before you start to fill out this questionnaire, please indicate if you have any of the experiences listed below (You may have multiple answers for this question).

- ☐ Filing an invention disclosure
- ☐ Applying for a patent
- ☐ None of the above

Stage One: Conducting Research - Invention Disclosure

Stage one refers to the time when the research idea was written into a research proposal to the time when the research was completed for invention disclosure.

Please answer the following questions based on your experience in conducting research and other related activities in this stage. If you had unfinished research when you filed the invention disclosure, please take the date you filed the invention disclosure as the end of stage one.

1. In stage one, please indicate the availability of the following resources during this time frame. If you share resources among multiple research projects, please give an average estimate (Higher numbers indicate higher levels of availability).

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Research Materials	◯	◯	◯	◯	◯
Research Equipment	◯	◯	◯	◯	◯
Research Assistants	◯	◯	◯	◯	◯
Professionals from the IP Office	◯	◯	◯	◯	◯
Connections with Industries	◯	◯	◯	◯	◯
Governmental Funding	◯	◯	◯	◯	◯
Industrial Funding	◯	◯	◯	◯	◯

2. In stage two, for all your research that was complete for invention disclosure, please give an average rating with regard to their scientific merits and uniqueness. (Higher numbers indicate higher level of scientific merits or uniqueness.)

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Scientific Merits of the Research	◯	◯	◯	◯	◯
Uniqueness of the Research	◯	◯	◯	◯	◯

3. Please indicate the average duration between the time a research idea was turned into a research proposal to the time the research was completed for invention disclosure.

(Please state in month, e.g. 10 months)

4. Please indicate approximately how many research proposals you had submitted since you were are at Virginia Tech.

5. Please indicate approximately how many invention disclosures you had filed since you were are at Virginia Tech.

Please indicate here if you have experience in applying for a patent

◯ Yes

◯ No

Stage Two: Invention Disclosure - Patent Application

Stage two refers to the time when an invention disclosure was filled to the time when a patent application was filled.

Please answer the following questions based on your experience in patent application and other related activities in this stage. And please relate your answers only to the research that had been disclosed.

6. In stage two, please indicate the availability of the following resources during this time frame. If you share resources among multiple research projects, please give an average estimate (Higher number indicate higher levels)

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Research Materials	○	○	○	○	○
Research Equipment	○	○	○	○	○
Research Assistants	○	○	○	○	○
Professionals from the IP Office	○	○	○	○	○
Connections with Industries	○	○	○	○	○
Governmental Funding	○	○	○	○	○
Industrial Funding	○	○	○	○	○

7. In stage two, for all your research that was complete for patent application, please give an average rating with regard to their scientific merits and uniqueness. (Higher numbers indicate higher level of scientific merits or uniqueness.)

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Scientific Merits of the Research	○	○	○	○	○
Uniqueness of the Research	○	○	○	○	○

8. Please indicate the average duration between the time an invention disclosure was filled to the time a patent application was filled.

(Please state in month, e.g. 10 months)

9. Please indicate approximately how many provisional patents you had filed since you were are at Virginia Tech.

Please indicate here if you have been issued a patent

○ Yes

○ No

Stage Three: Patent Application - Patent Issued

Stage three refers to the time when a patent application was filled to the time when a patent was issued.

Please answer the following questions based on your experience in patent application and other related activities in this stage. And please relate your answers only to the research that had been issued a patent.

10. In stage three, please indicate the availability of the following resources during this time frame. If you share resources among multiple research projects, please give an average estimate (Higher numbers indicate higher levels of availability).

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Research Materials	○	○	○	○	○
Research Equipment	○	○	○	○	○
Research Assistants	○	○	○	○	○
Professionals from the IP Office	○	○	○	○	○
Connections with Industries	○	○	○	○	○
Governmental Funding	○	○	○	○	○
Industrial Funding	○	○	○	○	○

11. In stage three, for all your research that was issued a patent, please give an average rating with regard to their scientific merits and uniqueness. (Higher numbers indicate higher level of scientific merits or uniqueness.)

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Scientific Merits of the Research	○	○	○	○	○
Uniqueness of the Research	○	○	○	○	○

12. Please indicate the average duration between the time a patent application was filled to the time a patent was issued.

(Please state in month, e.g. 10 months)

13. Please indicate on average how many times you needed to modify the patent application before a patent was issued.

- A. Never
- B. Once
- C. Twice
- D. Three times
- E. More than three times

14. Please indicate approximately how many patents you had had since you were are at Virginia Tech.

Please indicate here if you have experience in licensing your patent (license the patent to an existing company , or through yourself to form a new company)

- Yes, I have only licensed my patent through myself to form a new company.
- Yes, I have only licensed my patent to an existing company.
- Yes, I have experienced both licensing my patent to an existing company and to form a new company.
- No

Stage Four (A): Patent Issued - Patent Licensed

Stage four refers to the time when a patent was issued to the time when the patent was licensed to an existing company.

Please answer the following questions based on your experience in licensing your patents to existing companies and other related activities in this stage. And please relate your answers only to the research that had been licensed.

15. In stage four, please indicate the availability of the following resources during this time frame. If you share resources among multiple research projects, please give an average estimate (Higher numbers indicate higher levels of availability).

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5

Research Materials	◯	◯	◯	◯	◯
Research Equipment	◯	◯	◯	◯	◯
Research Assistants	◯	◯	◯	◯	◯
Professionals from the IP Office	◯	◯	◯	◯	◯
Connections with Industries	◯	◯	◯	◯	◯
Governmental Funding	◯	◯	◯	◯	◯
Industrial Funding	◯	◯	◯	◯	◯

16. In stage four, for all your research that was licensed, please give an average rating with regard to their scientific merits and uniqueness. (Higher numbers indicate higher level of scientific merits or uniqueness.)

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Scientific Merits of the Research	◯	◯	◯	◯	◯
Uniqueness of the Research	◯	◯	◯	◯	◯

17. Please indicate the average duration between the time a patent was issued to the time the patent was licensed.

(Please state in month, e.g. 10 months)

18. Please indicate approximately how many patents you had licensed since you were are at Virginia Tech.

Stage Four (B): Patent Issued - Company formed

Stage four refers to the time when a patent was issued to the time when the patent was licensed to form a new company.

Please answer the following questions based on your experience in starting a new company and other related activities in this stage. And please relate your answers only to the research that had been licensed to form the new company.

15. In stage four, please indicate the availability of the following resources during this time frame. If you share resources among multiple research projects, please give an average estimate (Higher numbers indicate higher levels of availability).

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5

Research Materials	○	○	○	○	○
Research Equipment	○	○	○	○	○
Research Assistants	○	○	○	○	○
Professionals from the IP Office	○	○	○	○	○
Connections with Industries	○	○	○	○	○
Governmental Funding	○	○	○	○	○
Industrial Funding	○	○	○	○	○

16. In stage four, for all your research that was licensed to form the new company, please give an average rating with

16. In stage four, for all your research that was licensed to form the new company, please give an average rating with regard to their scientific merits and uniqueness. (Higher numbers indicate higher level of scientific merits or uniqueness.)

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Scientific Merits of the Research	○	○	○	○	○
Uniqueness of the Research	○	○	○	○	○

17. Please indicate the average duration between the time a patent was issued to the time a company was formed.

(Please state in month, e.g. 10 months)

18. Please indicate approximately how many companies you had created from your patents since you were are at Virginia Tech.

Please indicate if the company you formed is still operating

○ Yes

○ No

Stage Five: Company formed - Sustainable Growth

Stage five refers to the period after the company was formed and it started to operate.

Please answer the following questions based on your experience in managing a company and other related activities in this stage. And please take the date the company had the first break-even as the end of this stage. If your company hasn't had break-even, please use the projected break-even date as the end of this stage.

19. In stage five, please indicate the availability of the following resources during this time frame. If you share resources among multiple research projects, please give an average estimate (Higher numbers indicate higher levels of availability).

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5
Research Materials	○	○	○	○	○
Research Equipment	○	○	○	○	○
Research Assistants	○	○	○	○	○
Professionals from the IP Office	○	○	○	○	○
Connections with Industries	○	○	○	○	○
Governmental Funding	○	○	○	○	○
Industrial Funding	○	○	○	○	○

20. Please indicate on average <u>how long</u> it took for your company to break even? If your company hasn't had break-even, please indicate a break-even projection.

(Please state in month, e.g. 10 months)

21. Please indicate approximately how many <u>companies</u> you created since you were are at Virginia Tech are <u>still operating</u>.

General Information

Please give an average rating of the research and business experience of different individuals that were involved in your commercialization activities. If any listed individuals were not involved in your commercialization process, you may skip the rating for them (Higher numbers indicate higher level of experience)?

	Low 1	Relatively Low 2	Neutral 3	Relatively High 4	High 5

Research Competency of the main Researcher	○	○	○	○	○
Research Competency of the Research assistants	○	○	○	○	○
Business Experience of the main Researcher	○	○	○	○	○
Business Experience of the Professionals from the IP Office	○	○	○	○	○
Leadership of the Entrepreneur	○	○	○	○	○

Please indicate your position at Virginia Tech

- Professor
- Research Scientist
- Research Assistant
- Postdoctoral Associate
- Others

Please indicate the department you are associated with

Please briefly describe your research focus

Please indicate whether you are willing to participate in a case study, which will involve only couples of short interviews with you to answers some commercialization-related questions.

If you answer "Yes", please also indicate the email address that we can get in touch with you. Thank you!

- No
- Yes

You have completed the questionnaire. By clicking the forward arrow below, you will submit your answers.

Appendix E. Interview Study Informed Consent Form

Informed Consent Form

Introduction
Commercialization of university research is an important activity in the research environment in the U.S. More and more universities have adjusted their policies and opened the door to welcome business activities, which has not been the traditional routine. However, due to the nature of universities being academic institutions, there are several challenges within the commercialization process. These difficulties provide universities opportunities to change and to achieve a better transition from academic to business.

Objective
The main objective of this study is to assess and improve the university research commercialization process, from the time an idea is generated to the time this idea is transferred into a product. Furthermore, the study aims to address how issues, such as business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. An ideal process model of commercialization will be suggested at the end of our study.

Procedure
This study focuses on the process of university research commercialization and divides the whole process into five stages:
Stage One: Conducting research - Invention Disclosure Stage Two: Invention Disclosure - Patent Application Stage Three: Patent Application - Patent Issued Stage Four: Patent Issued - Patent Licensed/Company formed Stage Five: Company formed - Sustainable Growth

According to the five stages above, this interview will cover questions related to resource, organizational policy, and personal motivation related to research commercialization. The interview will take about 1 to 2 hours, depending on the experience of the participant. Also, the interview will be audio-recorded, only if you agree.

Benefits
A summary of the results will be made available to all participants. With the results, participants will gain a better understanding of the research commercialization process at Virginia Tech and the critical resources within the process. The research will also provide performance metrics and recommendations for process improvement, enabling participants to benchmark and improve their work in the future.

Confidentiality
All data obtained from participants will only be reported in an aggregate format. Participants' characteristics will not be identified in connection with the data. All data collected will be kept strictly confidential, and no one other than the primary investigator and her assistant researcher will have access to them.

Participation
Participation in this research is voluntary and participants have the right to withdraw at any time or to refuse to participate without any penalty.

Risks/Discomfort
Risks are minimal for involvement in this study.

Contact Information
If you have any questions about the research, please contact Yu Zhou by phone at (540)808-7670, or email:angelayu@vt.edu. You can also contact Dr. Audrey Zink-Sharp by agzink@vt.edu.

Contact IRB: Dr. David Moore, email: moored@vt.edu, phone: (540)231-4991

Signature: ______________________ **Date:** ______________________

Appendix F. Interview Questions

Interview Guide

Section 1

1. Before you joined Virginia Tech, did you have industry experience? If yes, where?
2. Could you please describe your commercialization experience at Virginia Tech?
3. Is research commercialization common in your field?
4. What was the typical commercialization process you went through?
5. What were the research outputs at each stage? And do you think this number could be higher? Why?
6. What was the lead time of each stage? And do you think the lead time could be shorter? Why?

Section 2

1. What are the important resources to have to commercialize the university research? How do you rank their importance? Did their importance vary at the different stage of commercialization?
2. How did you balance the conflict of publication and patent application?
3. What suggestions do you have to the faculty that has interests in commercialization?
4. What suggestions do you have to the university to improve the commercialization activities?

Section 3

1. Could you briefly describe a typical day as a Faculty/Research Scientist/Post-doc?
2. Could you briefly describe the reasons you want to commercialize your research? (Planned or unexpected)
3. Could you briefly describe how your works were awarded?
4. What are you satisfied with the most as a Faculty/Research Scientist/Post-doc?
5. Did you get supports for your commercialization activities from the university?

Appendix G. IRB Approval Letter

Office of Research Compliance
Institutational Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia
24061 540/231-4606
Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: August 22, 2013

TO: Yu Zhou, Audrey Zink-Sharp

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)

PROTOCOL TITLE: Investigation of the Role of Universities in the Performance of Research Commercialization- Part I

IRB NUMBER: **13-655**

Effective August 22, 2013, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Amendment request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined

at: http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: **Exempt, under 45 CFR 46.110 category(ies) 2**
Protocol Approval Date: **August 1, 2013**
Protocol Expiration Date: **N/A**
Continuing Review Due Date*: **N/A**
*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Date*	OSP Number	Sponsor	Grant Comparison Conducted?

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.

Appendix H.

Interview Invitation Letter

Dear Dr. (Last Name),

I am a graduate student at Virginia Tech. I have previously sent you a questionnaire and asked for your experience in research commercialization at Virginia Tech. At the end of the questionnaire, you indicated your willingness to participate in the case study and left your email address.

Thank you for your help to participate in the case study. At this point**, I would like to schedule an interview with you. Please let me know when you will be available to meet** **between Nov.25 to December 31, 2013.** The interview will take about **1 hour**. And it will cover questions related to resource, organizational policy, and personal motivation related to research commercialization. The interview might be audio-recorded, but only if you agree.

As a reminder, the goal of my research is to assess and improve the university research commercialization process, from the time an idea is generated to the time this idea is transferred into a product. The study seeks to determine how factors, such as organizational policy, business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. Also, it will provide valuable information as to current commercialization practice and benchmarks to evaluate and improve the process.

Please be assured that your response will be treated with **complete confidentiality**. Your name will never be identified in the study results nor will your participation be disclosed to anyone. Only aggregated results will be reported.

I would like to thank you again for completing the questionnaire and participating in the case study. Should you have any questions, please contact me by e-mail angelayu@vt.edu. You can also contact my advisor, Dr. Audrey Zink-Sharp by agzink@vt.edu.

Sincerely,

Yu Zhou (Angela),
Doctoral Candidate
Department of Sustainable Biomaterials
200 Cheatham Hall
Virginia Tech
Blacksburg, VA 24061

Interview Reminder Letter

Dear Dr. (Last Name),

I am a graduate student at Virginia Tech. I have previously sent you a questionnaire and asked for your experience in research commercialization at Virginia Tech. At the end of the questionnaire, you indicated your willingness to participate in the case study and left your email address.

Thank you for your help to participate in the case study. At this point**, I would like to schedule an interview with you. Please let me know when you will be available to meet between Nov.25 to December 31, 2013.** The interview will take about **1 hour**. And it will cover questions related to resource, organizational policy, and personal motivation related to research commercialization. The interview might be audio-recorded, but only if you agree.

As a reminder, the goal of my research is to assess and improve the university research commercialization process, from the time an idea is generated to the time this idea is transferred into a product. The study seeks to determine how factors, such as organizational policy, business experience, funds requirements, human resources, and social networks, are related to the outcomes of commercialization. Also, it will provide valuable information as to current commercialization practice and benchmarks to evaluate and improve the process.

Please be assured that your response will be treated with **complete confidentiality**. Your name will never be identified in the study results nor will your participation be disclosed to anyone. Only aggregated results will be reported.

I would like to thank you again for completing the questionnaire and participating in the case study. Should you have any questions, please contact me by e-mail angelayu@vt.edu. You can also contact my advisor, Dr. Audrey Zink-Sharp by agzink@vt.edu.

Sincerely,

Yu Zhou (Angela),
Doctoral Candidate
Department of Sustainable Biomaterials
200 Cheatham Hall
Virginia Tech
Blacksburg, VA 24061

Appendix I.

Questionnaire Data for Stage One

Table 32 Answers of respondents with only invention disclosure experince on importance of different resources at Stage one.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmenta l funding	Industrial funding
	2	2	3	3	2	1	1
	4	4	4	2	2	4	3
	3	3	2	3	1	1	1
	4	4	3	4	1	1	1
	5	5	5	2	3	5	4
	2	2	1	1	3	3	3
	3	4	1	4	1	1	1
	4	4	4	4	1	4	1
	4	3	4	4	2	3	2
	4	4	2	1	1	3	2
	3	3	2	2	1	1	1
	3	4	4	3	2	2	1
	3	3	3	2	1	3	1
	3	4	2	4	2	2	1
	4	4	4	2	3	4	3
	4	4	4	4	1	1	1
	4	4	3	3	2	4	1
	4	4	4	4	1	1	1
	4	4	5	3	1	5	1
	4	4	3	3	3	1	1
	4	4	2	4	2	4	4
	1	1	1	2	1	1	1
	1	1	4	2	4	1	4
	5	5	5	1	1	5	1
	5	4	4	4	1	1	3
	5	5	4	2	4	4	2
	4	4	4	3	4	4	4
Avg.	3.56	3.59	3.22	2.81	1.89	2.59	1.85
Stdv.	1.07	1.03	1.20	1.02	1.03	1.50	1.15

Table 33 Answers of respondents with "patent application" experience on importance of different resources at Stage one.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Govertmental funding	Industrial funding
	2	5	2	1	2	5	3
	1	2	2	1	4	1	2
	4	4	3	3	2	3	2
	3	2	3	2	2	3	2
	2	2	2	3	1	2	1
	3	4	4	2	2	2	2
	4	4	3	3	2	2	2
	2	2	3	1	1	2	1
	4	4	3	3	2	4	2
	2	4	2	1	2	2	2
	4	4	4	1	1	4	1
	5	3	2	3	4	5	2
	4	4	4	4	4	3	4
	5	4	2	3	1	4	1
	4	4	3	1	4	1	1
	5	5	4	2	4	4	4
Avg.	3.38	3.56	2.88	2.13	2.38	2.94	2.00
Stdev.	1.26	1.03	0.81	1.02	1.20	1.29	0.97

Table 34 Answers of respondents with "patent" on importance of different resources at State one.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Govertmental funding	Industrial funding
	3	4	4	2	4	4	5
	5	4	4	3	5	5	5
	4	4	2	1	5	5	5
	3	3	3	1	3	2	2
	5	5	2	5	5	1	5
	5	4	4	4	4	3	4
	4	4	4	1	1	4	1
	3	4	2	2	1	3	1
	5	5	5	4	4	4	1
	5	5	5	5	5	3	1
	4	4	3	3	3	2	4
	3	4	3	2	2	3	3
	3	3	3	4	1	3	1
	2	4	2	1	2	2	1
	4	4	4	4	4	4	4
Avg.	3.87	4.07	3.33	2.80	3.27	3.20	2.87
Stdev.	0.99	0.59	1.05	1.47	1.53	1.15	1.77

Table 35 Answers of respondents with "licensing" experience on importance of different resources at Stage one.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	3	3	3	3	3	3	3
	5	4	5	3	4	3	2
	5	5	5	5	4	5	3
	4	4	4	4	2	3	3
	4	5	4	4	4	4	1
	4	4	4	3	3	4	1
	4	4	4	3	2	1	2
	2	2	2	1	3	1	2
	4	4	4	2	4	5	1
Avg.	3.89	3.89	3.89	3.11	3.22	3.22	2.00
Stdev.	0.93	0.93	0.93	1.17	0.83	1.48	0.87

Table 36 Answers of respondents with "start-up" experience on importance of different resources at Stage one.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	2	2	2	1	2	2	2
	4	4	2	2	4	4	4
	5	5	3	1	4	3	3
	3	4	3	5	4	2	2
	4	4	3	3	3	3	3
	4	4	4	4	4	4	1
Avg.	3.67	3.83	2.83	2.67	3.50	3.00	2.50
Stdev.	1.03	0.98	0.75	1.63	0.84	0.89	1.05

Questionnaire Data for Stage Two

Table 37 Answers of respondents with "patent application" experience on importance of different resources at Stage two.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	1	5	2	2	2	1	
	2	2	2	1	4	1	2
	4	4	4	3	2	3	2
	3	4	4	2	1	2	2
	4	4	3	4	3	1	1
	4	4	4	4	1	4	1
	2	4	2	1	2	1	1
	4	4	4	4	1	4	1
	2	2	2	2	2	4	2
	4	4	4	4	4	3	4
	5	4	2	3	1	5	1
	2	2	2	2	4	1	1
	4	4	4	1	4	4	4
Avg.	3.15	3.62	3.00	2.54	2.38	2.62	1.69
Stdev.	1.21	0.96	1.00	1.20	1.26	1.50	1.18

Table 38 Answers of respondents with "patent" on importance of different resources at State two.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	3	4	4	1	4	4	4
	5	4	5	3	5	5	5
	5	5	2	3	4	2	4
	3	3	3	1	3	2	1
	5	5	1	5	5	1	5
	5	4	4	4	4	3	4
	1	1	1	3	1	1	1
	3	4	3	3	2	3	1
	5	5	5	4	3	4	3
	5	5	5	5	5	4	1
	4	4	3	4	4	3	3
	4	4	4	4	4	3	4
	3	3	3	4	1	3	1
	4	4	4	4	2	5	2
	4	4	4	4	4	4	4
Avg.	3.93	3.93	3.40	3.47	3.40	3.13	2.87
Stdev.	1.16	1.03	1.30	1.19	1.35	1.25	1.55

Table 39 Answers of respondents with "licensing" experience on importance of different resources at Stage two.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	5	4	5	4	4	4	1
	5	5	5	5	4	5	3
	4	4	4	4	3	3	3
	3	3	3	4	3	3	1
	4	4	4	4	3	4	3
	3	3	3	3	2	3	1
	2	2	2	1	3	1	2
	4	4	4	3	4	5	2
Avg.	3.75	3.63	3.75	3.50	3.25	3.50	2.00
Stdev.	1.04	0.92	1.04	1.20	0.71	1.31	0.93

Table 40 Answers of respondents with "start-up" experience on importance of different resources at Stage two.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	1	1	1	2	1	1	1
	4	4	4	2	4	4	4
	5	5	3	3	3	3	3
	3	4	3	5	4	2	2
	4	4	3	3	3	3	3
	4	4	4	4	4	4	4
Avg.	3.50	3.67	3.00	3.17	3.17	2.83	2.83
Stdev.	1.38	1.37	1.10	1.17	1.17	1.17	1.17

Questionnaire Data for Stage Three

Table 41 Answers of respondents with "patent" on importance of different resources at State three.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	3	4	4	1	3	3	3
	5	5	5	3	5	5	5
	1	3	1	4	4	1	4
	3	3	3	1	3	2	1
	5	5	1	5	5	1	5
	5	5	5	4	5	3	5
	1	1	1	1	1	1	1
	2	4	2	3	1	1	1
	5	5	5	4	3	4	3
	5	5	5	5	5	4	1
	4	4	3	3	2	3	2
	4	4	3	2	4	2	4
	3	3	3	4	2	3	1
	5	5	5	4	3	5	1
Avg.	3.67	4.00	3.33	3.20	3.33	2.80	2.73
Stdev.	1.45	1.13	1.54	1.37	1.40	1.42	1.67

Table 42 Answers of respondent with "licensing" experience on importance of different resources at State three.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	4	4	4	4	4	4	1
	5	5	5	5	4	5	3
	4	4	4	3	4	4	4
	3	3	3	4	3	3	3
	4	4	4	4	3	3	2
	3	3	3	2	1	3	1
	2	2	2	1	3	1	2
	4	4	4	3	4	5	2
Avg.	3.63	3.63	3.63	3.25	3.25	3.50	2.25
Stdev.	0.92	0.92	0.92	1.28	1.04	1.31	1.04

Table 43 Answers of respondents with "start-up" experience on importance of different resources at State three.

	Research Materials	Research Equipmen t	Researc h Assistant	Professional s from the IP Office	Connection s with Industries	Governmental funding	Industrial funding
	1	1	1	2	1	1	1
	4	4	3	2	4	4	4
	5	5	1	3	4	2	4
	3	4	3	5	4	2	2
	4	4	3	3	3	3	3
	4	4	4	4	4	4	4
Avg.	3.50	3.67	2.50	3.17	3.33	2.67	3.00
Stdev.	1.38	1.37	1.22	1.17	1.21	1.21	1.26

Questionnaire Data for Stage Four

Table 44 Answers of respondents with "licensing" experience on importance of different resources at Stage four.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	4	4	4	4	4	4	1
	5	5	5	5	4	5	3
	4	4	4	3	3	3	3
	3	3	3	3	3	3	3
	3	3	3	3	4	3	2
	3	3	3	2	1	3	1
	3	2	2	1	4	1	3
	4	4	4	2	4	3	2
Avg.	3.63	3.50	3.50	2.88	3.38	3.13	2.25
Stdev.	0.74	0.93	0.93	1.25	1.06	1.13	0.89

Table 45 Answers of respondents with "start-up" experience on importance of different resources at Stage four.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	1	1	1	2	1	1	1
	5	5	2	2	5	3	5
	3	4	3	5	4	2	2
	4	4	3	3	3	3	3
	4	4	4	4	4	4	4
Avg.	3.40	3.60	2.60	3.20	3.40	2.60	3.00
Stdev.	1.52	1.52	1.14	1.30	1.52	1.14	1.58

Questionnaire Data for Stage Five

Table 46 Answers of respondents with "start-up" experience on importance of different resources at Stage five.

	Research Materials	Research Equipment	Research Assistant	Professionals from the IP Office	Connections with Industries	Governmental funding	Industrial funding
	1	1	1	2	1	1	1
	3	4	3	5	4	2	2
	4	4	3	3	3	3	3
	4	4	4	4	4	4	4
Avg.	3	3.25	2.75	3.5	3	2.5	2.5
Stdev.	1.41	1.50	1.26	1.29	1.41	1.29	1.29