AALBORG UNIVERSITET

Commercial Application of The Bolt Tension Estimator Technology

Masters Thesis

Department of Materials and Production

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Abstract

With the ever increasing safety demands of cranes, elevators, high voltage power lines etc. service and maintenance companies are tasked with conducting inspection of these structures with great level of vigilance. One of the main components that service technicians check are bolts because they hold the entire structure together. The presence of loose bolts in such structures, puts them at risk of collapse resulting in damages and if worse, injuries. In order to better monitor loose bolts in structures, an invention from the Technical University of Denmark named, the bolt tension estimator technology has the ability to detect loose bolts on different types of structures. So the aim of this thesis is to answer the research question "*In view of new product development theory, what are the key factors for a startup to consider in order to commercialize the vibration-based bolt tension estimator technology?*"

The research approach used for this study is case study, where I identified all companies that might find this technology relevant. I used judgemental sampling when choosing my sample size in order to collect sufficient data for analysis. Only half of the companies I contacted requested for a presentation. The limitations experienced in this process was the long wait for company representatives to respond to interview requests. I eventually collected and compiled my interview transcripts and analysed them using grounded theory. This process enabled me to develop themes from the transcripts and grouped them into categories which formed New Product Development as my theoretical basis.

FORCE Technology emerged as the only company that displayed a strong interest in establishing a collaboration with DTU to develop the technology. On the other hand, Tivoli and DTU Campus Service concluded that the technology was not fit for their routined service of their machinery and structures. KONE and Energinet came up with the same conclusion except that they recommended me to approach construction companies that they contract to construct and maintain high voltage power lines. The reason for this is that quality assurance documentation is of high importance for them and the bolt tension estimator technology is perceived as having the capability of providing this.

Moving forward with FORCE Technology, we concluded that by using the New Product Development (NPD) theory, the timing aspect for developing this technology is right, because FORCE Technology is a potential user and it matches their product strategy and development. Furthermore, the expected growth of the offshore industry in the coming years makes the timing of this technology even better.

Through idea stage of the NPD process, I concluded that a strong team consisting of DTU researchers can contribute with scientific knowledge of the technology while FORCE Technology can contribute with market insights and industry knowledge. Moreover, ideas exchanged between DTU researchers and FORCE Technology's industry experts and service technicians can increase the likelihood of developing an innovation that is fit for purpose.

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Abbreviations and Acronyms

Technical University of Denmark (DTU)

Business-to-Business (B2B)

Abernathy and Ubernack Model (A–U Model)

Research and Development (R&D)

Intellectual Property (IP)

Net Present Value (NPV)

Internal Rate of Return (IRR)

Research and Technology Organization (RTO)

Technology Readiness Level (TRL)

New Product Development (NPD)

Profitability Index (PI)

Decision Making Unit (DMU)

Dye Penetrant Inspection (DPI)

Magnetic Particle Inspection (MPI)

Chapter 1 – Background

Bolts are threaded fasteners widely used in the fastening of machinery and structural components ranging from airplanes, railways, bridges, etc. Once structural components are bolted together, a periodic inspection must be conducted in line with the manufacturer's guidelines. The frequency for inspecting different components varies so that some consist of moving parts, thus requiring regular checks, while others consist of non-moving parts that are checked less frequently.

Components with bolted joints that consist of moving parts can become problematic during prolonged operation due to recurrent pressure applied to the overall structure that would result in shutdowns or accidents with severe consequences. Therefore, scheduled maintenance protocols are implemented and monitored by facility managers to ensure that the operation of systems in the built environment works harmoniously. However, this is known to have its challenges, especially with increasing costs of labor. Another aspect is the limited flexibility when conducting maintenance. This occurs when countless resources are deployed to fulfill a limited set of activities within a tight time frame.

A potential solution to overcome some of the challenges is by using a vibration-based bolt tension estimator. A vibration-based bolt tension estimator is an invention developed at the Technical University of Denmark (DTU), enabling one to measure bolt tension. The technology works by exerting vibrations onto a bolt head and measuring its frequency. The data output is then processed using algorithms that will obtain the bolt tension estimation.

Therefore, this invention aims to offset a significant amount of resources required to plan and conduct inspections prone to human errors.

X-Tech Entrepreneurship

On the 1st of September 2020, I enrolled in a 13-week course named X-Tech Entrepreneurship at DTU. The objective of the course was to group different students together and then present them with technologies from corporations and academia, which they will be tasked to commercialize.

After being grouped with four other students, we were presented with the vibration-based bolt tension estimator technology and assessed the different industries that we could approach. After brainstorming on the various opportunities that laid ahead of us, we decided to pursue the railway industry. We managed to speak to major railway players in Denmark, such as Metro Service, Banedanmark, and Lokaltog.

Based on our conversations and presentation of a potential solution (inspection robot) to these companies, we concluded that automated inspection of bolt tension on railways is not a critical need. This is because other activities parallel to bolt inspection, e.g., inspection of sleepers, are conducted manually. Our value proposition can entice these companies if parallel tasks can be incorporated into the proposed inspection robot.

After the course ended on the 15th of December 2020, our group held a meeting a few weeks later to share our thoughts on the project's future. I decided to continue working on the project but shift my focus to another industry that can get more value from automating its bolt inspection activities. As it stands now, we are two students working together while the rest decided to focus on other commitments.

Challenges experienced by startups

Startup failure has become a norm in the entrepreneurial world. According to Havard Business School Professor Shikhar Ghosh, if the failure of a startup is defined as liquidating all assets with investors losing their money, then the rate is between 30 and 40 percent (Nobel 2011). On the other hand, if failure is defined as not realizing the projected return on investment, then the rate is between 70 and 80 percent (Nobel 2011). Lastly, if the failure is defined as setting projections and then coming up short of realizing these, then the rate is between 90 and 95 percent (Nobel 2011).

So what could be the leading causes of these failures? Part of the reason can be attributed to the fact that entrepreneurs suffer from elevated rates of overconfidence (Adams og Adams 1961), which impacts the decision-making that could lead to negative outcomes. Other studies have shown that to be a successful entrepreneur, one has to have a high level of self-efficacy (Drnovsek, Wincent and Cardon 2010).

Indeed, the probability of startup success can be increased by concentrating on key areas that entrepreneurs overlook. Figure 1 illustrates the aspects that can be improved to increase the chances of startup success.

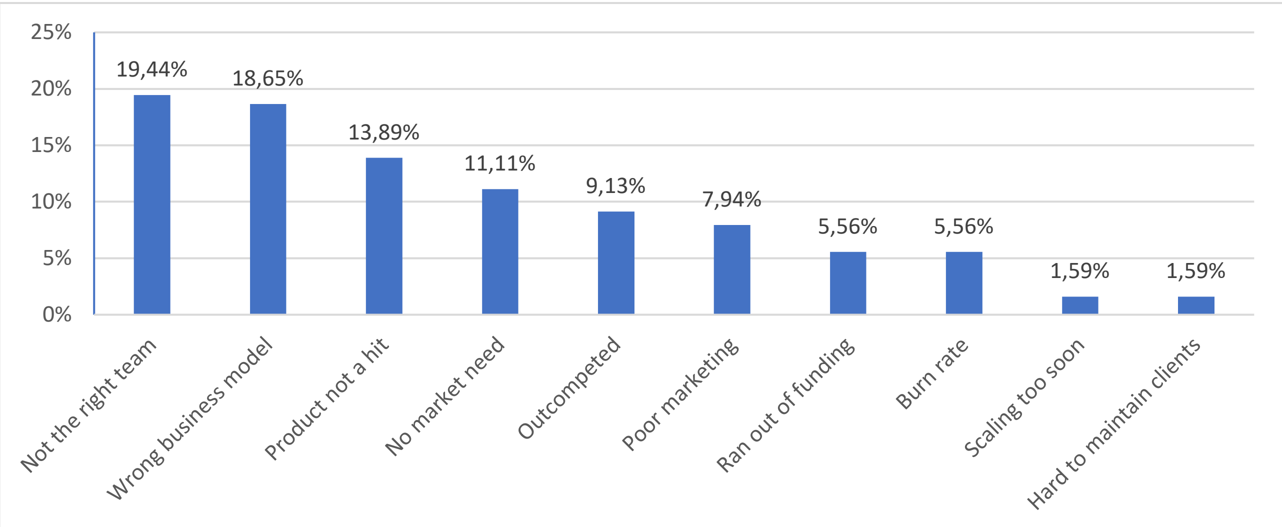

Figure 1: Top 10 reasons startups fail based on 300 failed startup autopsies (Autopsy 2021)

The results show that around 20 percent of the reasons for failure were derived from having a wrong founding team. This is because having a team of co-founders that do not possess the required skill set to execute on the startup's targets can result in an unbalanced team that primarily focuses on product development and neglect areas such as commercial development, marketing, fundraising, etc.

Other reasons for failure are attributed to selecting the wrong business model, which stands at around 19 percent. These startups struggled to define how their business is to make money as well as revenue channels. Some of these startups had a clear business model that only had a single source of revenue which was viewed as unscalable. This would go on to affect the startups on receiving additional funding from investors.

Coming at around 14% is the product not being a hit. Several of these startups developed products and services that were full of bugs and other types of inconsistencies. This made users frustrated when using their products, causing them to seek alternative solutions in the market.

Finally, No market need consisted of 11 percent of the reasons for startup failure. This is due to startup teams committing a lot of resources to develop a product or service without validating the market need.

According to Michael Porter, one of the key drivers of technological change is competitive advantage through structural change as well as giving rise to new industries (M. E. Porter 1985). It can also propel smaller firms towards incumbents and, in some cases, outcompete them (M. E. Porter 1985). However, technological change can also have a negative impact on competitive positioning and industry attractiveness, e.g., commoditization of the smartphone industry. On the contrary, technology can boost a company's competitive advantage if it can significantly position itself as a cost leader or differentiator.

Since I am working in close collaboration with the research team at DTU, my approach shall focus on evaluating the possibilities of commercializing the bolt tension estimator technology through licensing or selling the technology to 3rd parties.

Given the above, this paper will seek answers to the question,

In view of new product development theory, what are the key factors for a startup to consider in order to commercialize the vibration-based bolt tension estimator technology?

Team

As mentioned previously, a new team has been formed to develop the project further. On the 13th of October, Nils Meile and I agreed to continue working together on commercializing the technology. This was then followed by contacting the inventor and DTU's patent administrator to decide on the terms of cooperation.

We believe that we are the right team to move this project forward due to our combined experience. Marie Brøns is a Postdoc in the Mechanical Engineering department and has experience working with bolt tension for more than three years, where she invented the bolt tension estimator technology. Nils Meile studies MSc. Autonomous Systems at DTU and has experience in prototyping, computer coding, robotics, and product testing. As for myself, I have experience in conducting market research, sales, and finance. With my background in MSc. Entrepreneurial Engineering, I believe I have developed the required skill set to take this project to the next level.

Since I am part of a team as the only thesis student, this paper has been written by myself, with some support in conducting interviews and presentations.

Chapter 2 – Methodology

Research Background

Regarding my research question, I took the first step by mapping out potential industries that own and operate infrastructure that requires periodic inspection of bolted joints (see Appendix 2A). This was then followed by initiating contact with these companies by sending an email with a description of what the technology is about (shown in Appendix 2B), which I followed up on a couple of days later with a phone call.

The research approach that I applied in this paper is case study. The reason for choosing this approach is to conduct an in-depth study of how the vibration-based bolt tension estimator technology can be commercialized. The type of case study that I will be using is a single case study that will focus on one specific company within a particular industry and how it can create value by integrating the technology into its business operations.

I am aware that making general conclusions based on how a single company interacts with the technology is weak. However, due to the time constraints for writing this paper, I shall draft some recommendations for the next steps that can aid the process of moving forward.

Sampling method

I employed judgemental sampling, which is a subjective method of choosing who is to participate. I chose this method because my target companies need to consist of innovators as described under the innovation adoption cycle in Appendix 1B. In Chapter 4, I summarized and analyzed the interviews conducted with Tivoli, DTU Campus Service, KONE, FORCE Technology, and Energinet because I needed to understand whether inspecting bolted joints is problematic. Furthermore, I also needed to determine whether they are innovators who can absorb the technology in its early stages through licensing or purchasing intellectual property rights.

This sampling method is also a time and cost-effective way of conducting interviews, considering that it took me several weeks to secure appointments with these companies.

On the other hand, judgmental sampling has its shortcomings in terms of volunteer bias and concluding from a small sample size. Therefore, the reliability and validity of the responses will be verified through peer review with my team to validate our preliminary findings.

Methods for data gathering

The tool I used to generate data for my study interviews. I did this by preparing an email template (see Appendix 2B) that I sent to different companies to screen which ones would be interested to learn more about the technology. The interviews I held are semi-structured because my research approach is case study, which requires an in-depth understanding of my selected company. Therefore, my objective here was to gain some market insights by interviewing facility managers and service technicians. Another tool used for generating data is Microsoft Teams which I used to facilitate virtual meetings with company representatives.

As for the procedure to collect data, I prepared a questionnaire for my interviews and allowed for an open discussion to understand the daily routine of service technicians. This is to say that the questions listed on the questionnaire are open-ended. The questionnaire used in the meetings is attached in Appendix 2C.

Data analysis techniques

The method I applied in my data analysis is grounded theory developed by Strauss and Corbin. I chose this technique to use an inductive approach to my qualitative data to answer my research question. I analyzed my data and identified statements that appeared on several instances, and then generated codes from them. So I began by comparing my data sets derived from interviewing Tivoli, DTU Campus Service, KONE, FORCE Technology, and Energinet, then generated open codes that are very specific. These codes serve as a guiding compass for developing theories that can help answer my research question.

I repeated the process and grouped the open codes based on their causal relationship to form categories to generated axial codes that grouped the open codes into categories.

I completed the process by linking the categories together based on interrelationships to form a core category that constitutes a general theory that guided me to answer my research question. A basic framework of my analytical process is outlined in Figure 2.

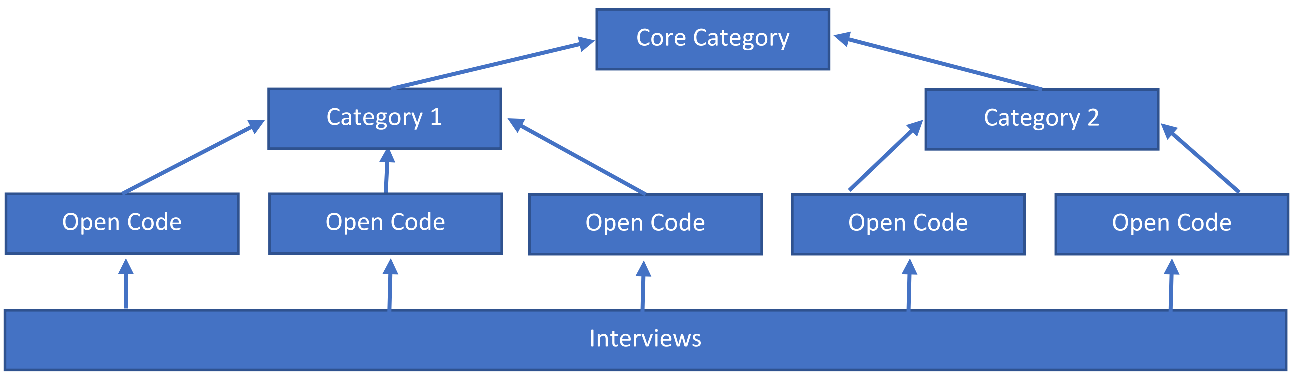

Figure 2: Analytical Framework based on grounded theory (Strauss og Corbin 1998)

Data Validity and Reliability

The interviews that I conducted are vulnerable to participant errors. This might have happened because company representatives have busy schedules that could make them want to get the interview over by providing quick and simplified answers. I worked towards minimizing this by contacting them later whenever I needed to get some facts clarified.

I also expected a certain degree of participant bias because most company representatives might have wanted to portray their organization in a way that does not damage their image. An example of this occurring is when a company representative does not admit to accidents due to loose bolts. The approach I took here is by rephrasing my questions and asking for a description of a worst-case scenario.

There are situations where I had to run interviews and, at the same time, take notes of the answers provided by the respondents. This created a risk for researcher error, and for this reason, I asked my colleague Nils to take his own set of notes which we would compare after the interview session. Moreover, the research team from DTU and I held a status meeting every 3 weeks where we discussed the project, including interview results. This enabled me to verify my notes from the interviews, which also helped me minimize the impact of researcher bias.

As for my construct validity, I aimed to find out how I can commercialize the bolt tension technology estimator. I started the process by listing the companies that conduct inspection bolted joints based on my assumptions. This was then followed by contacting these companies through email, where I gave them a brief presentation of myself and the project that I am involved in. The five companies that showed interest in learning more were invited for an interview where I presented the project and asked open-ended questions about their daily operations and other aspects relevant to my research question.

It is difficult to demonstrate the external validity of the data since it cannot be generalized to a group of companies working in the same field. This is because companies have their own individual ways of approaching innovation and embracing it. Companies are not created equal in terms of vision, resources, geographical placement, etc. therefore, this data is case-specific, and replicability is not considered relevant.

Ethical considerations

All my participants were requested to consent to recording data from the interview before the meeting. Moreover, I agreed with the interviewees that they would maintain complete anonymity when describing the process.

Delimitations

Given the short time to write this thesis, the number of industries to be analyzed in this paper will be limited to one. Based on my experience contacting potential customers, scheduling meetings can take weeks or even months, depending on the availability of key persons. The scope of my thesis excludes business analysis and prototyping because the technology being studied is still in its early stages and will require collaborating with a company to move the project forward.

Another aspect worth highlighting is that all study activities are being conducted digitally, which means access to universities is limited to critical members of staff. This continues to restrict access to facilities for conducting demonstrations for potential customers.

Chapter 3 – Theories

Research design

My research strategy for this paper is the case study research design. The reason for choosing this strategy is to conduct an in-depth study of a particular company that could potentially use the vibration-based bolt tension estimator technology. The type of case study that I will be using is a single case study that will focus on one specific company within a particular industry. This will allow me to understand how the company would interact with the technology and its experience from using it.

I am aware that making general conclusions based on how a single company interacts with the technology is weak. However, due to the time constraints for writing this paper, I shall draft some recommendations for the next steps that can aid the process of moving forward.

Open Innovation

In a university context, open innovation will be studied and applied to get the vibration-based bolt tension estimator technology out to the business world. So what is open innovation? Henry Chesbrough describes open innovation as ideas originating internally or externally whereby they get to the market from inside a given company or outside it (Chesbrough 2003). This means that new ideas are allowed to flow outside a given company where third parties can monetize them or, new ideas are allowed to flow inside a given company where they can be exploited for commercial gain. This flow of knowledge is depicted in Figure 3.

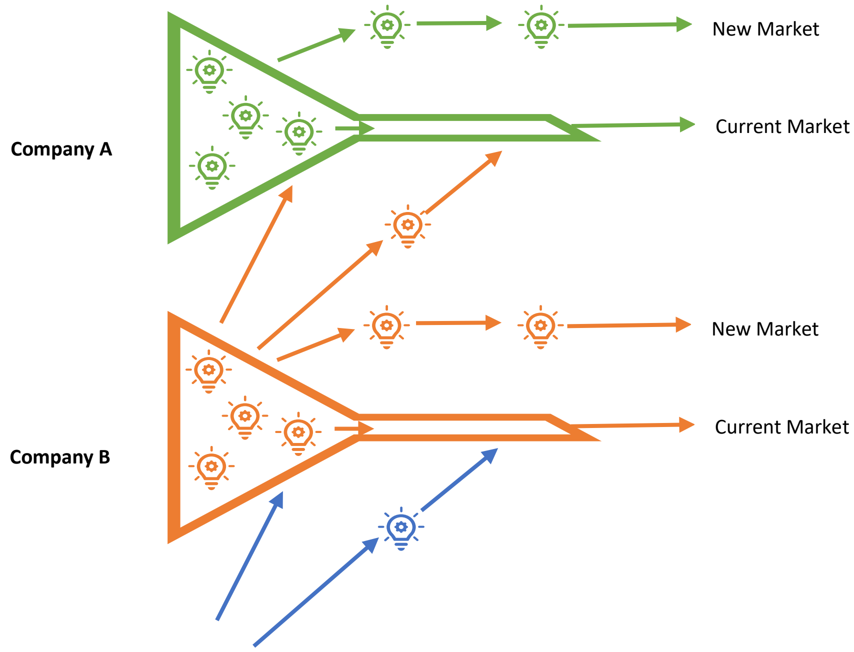

Figure 3: Knowledge landscape in open innovation paradigm (Chesbrough 2003)

With the internet providing us with access to abundant information, knowledge gathering has become inexpensive and less time-consuming. Therefore, this has resulted in government funding in basic scientific research to decline, thus paving the way for scientific research focusing on problems experienced by industries (Chesbrough 2003). When looking at the X-Tech Entrepreneurship course at the DTU, its purpose is to bring together students, researchers, and industry mentors in an incubator program. New ideas emerging from this collaboration are developed and tested with the hope of forming corporate or university spinout companies. The impact of this approach has resulted in the utility of knowledge being multiplied since it can be built upon from different use cases.

So, the role of research has changed with the advent of open innovation, where knowledge is not only created from within an organization but also sourced from the external environment. Another theory that I analyzed is the diffusion of innovation theory. Since this theory will be of particular interest during the product development stage, I shall not discuss it in this chapter. The theory is discussed in Appendix 1B.

Technology Push and Market Pull

According to a study on market pull versus technology push conducted by the University of St. Thomas, industries face a significant challenge when developing products that customers want and are willing to purchase. When taking the market pull approach, suppliers are faced with the challenge of producing products or services that are in line with market demand, whereby the problem defined by the market is translated into a solution (Dixon 2001). On the other hand, technology push presents a challenge to the producer whereby a need is learned long before the market. Thus a product that fulfills functional demands in ways not imagined before by customers is created (Dixon 2001).

In the case of vibration-based bolt tension estimator technology, our approach will be based on a combination of technology push and market pull since our potential customers have not imagined how new functionality can improve their inspection routines on bolted joints. However, this is a risky approach because the technology is developed with minimal contact with potential users or market trends. Therefore, I shall also provide a scenario where a company interested in the technology will influence its development.

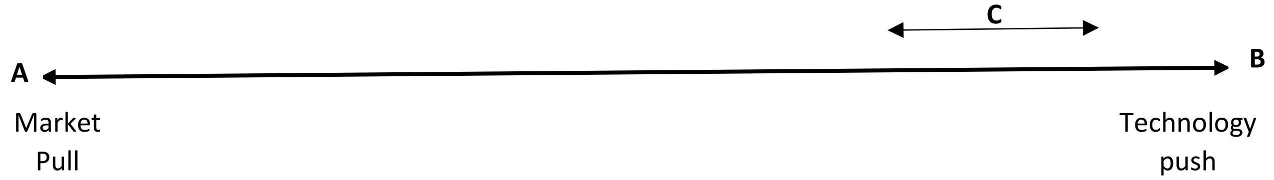

Figure 4: Market pull versus Technology push Continuum (Dixon 2001)

Figure 4 illustrates two spectrums where A represents market pull and B representing Technology push. The area occupied by C showcases where our group is currently operating. Since we are currently working on productizing our technology, the dominant approach remains on the technology push side. However, this area is likely to move towards market pull as it starts to diffuse in a given industry. By utilizing industry insights, empirical studies have shown that a de-facto standard is expected to be established once the technology's development process matures. This is covered in more detail under the new product development process later in this chapter.

Attribute	Technology push	Market pull
Technology uncertainty	High	Low
R&D costs	High	Low
R&D duration	Long	Short
Sales Marketing-related uncertainty	High	Low
Time-to-market	Uncertain/Unknown	Certain/known
R&D customer integration	Difficult	Easy
Kinds of market research	Qualitative/discovering	Quantitative/verifying
Need for change of customer behavior	Extensive	Minimal

Table 1: Technology push versus Market pull (Gerpott 2005)

Table 1 summarizes the key characteristics that distinguish technology push from market pull approach. Technology uncertainty is high because our technology is very new to the world, which exposes us to the risk of not addressing challenges experienced by customers.

Research and Development (R&D) costs are expected to be high because a lot of man-hours are put into research-related activities that require skilled labor. Furthermore, materials and components required for prototyping will be specialized and therefore incur high unit costs.

R&D duration for deep tech ventures such as the bolt tension estimator technology can take several years before it becomes commercialized. This is because our technology has to diffuse, starting with innovators and early adopters before the mass market consisting of early-late majority and laggards adopt it. This is discussed under diffusion of innovation theory in Appendix 1B.

A high level of uncertainty is expected to be experienced when selling and marketing our technology. This is because our technology will require educating potential users on optimizing their inspection routines on bolted joints. Moreover, the customers' desired outcomes have to be measured and fitted into our technology, which is likely to complicate matters.

Since the R&D duration is expected to be lengthy, the time it takes to get our technology to the market remains unknown. Several factors such as the rate of diffusion across customer groups, e.g. innovators and early adopters will influence this.

Henry Ford stated, "if I had asked people what they wanted, they would have said faster horses." This is to demonstrate that customers do not know what they want. Radical innovation requires minimal customer input on product development which makes customer integration in R&D

difficult. This type of approach aims to educate potential customers on new ways of solving functional tasks. Our objective is to involve key partners that can help develop the technology so that it can be pushed to initial customers and evaluate its performance.

The type of market research employed for technology push is qualitative. This is because we aim to understand the problem at hand and the desired outcome for the customers. Once this is understood, our technology will be transformed into a functional product with supporting technologies that can help cover the full spectrum of the problem.

New technologies require customers to change their behavior. Smartphones have changed how we interact with each other, whether online or via social media or regular telephone calls. Regarding our technology, we shall be required to train customers on how to use it when performing inspection of bolted joints. Since several industries rely on visual and audible senses when conducting such inspections, a shift in behavior will be necessary to increase the rate of diffusion of our technology.

Since new technologies need to be pushed to potential users, entrepreneurs and marketers need to understand the role of decision-making units (DMUs) in companies when devising a sales strategy. The theory of DMUs is discussed in more detail in Appendix 1D.

New Product Development (NPD)

Companies develop new products and services to grow, increase profits and remain relevant in the market. When a company plans to develop a new product, it undergoes a series of phases. Since it has been highlighted that the major causes of startup failure are wrong unfit products and no market need, the NPD process will be used to evaluate the product idea through a stage-gate process to ensure that resources are committed to feasible projects. According to Booz & company, activities associated with new product development can be managed using a framework known as the BAH model (Booz, Allen and Hamilton 1982), as illustrated in Figure 5.

Figure 5:Own depiction of BAH Model (Booz, Allen and Hamilton 1982)

New Product Strategy and Development: This phase entails laying out key strategies in line with company objectives. The role of new products is aligned with corporate interests and is a prerequisite for proceeding to the forthcoming stage.

Idea Generation: During this phase, ideas are sourced internally via employees or externally via potential customers, collaborating partners, suppliers, etc. The generated ideas must be anchored to the defined objectives in the previous phase.

Screening & Evaluation: Product ideas gathered from the previous stage are analyzed and evaluated. Ideas that demonstrate the highest potential are then qualified to proceed to the next phase.

Business Analysis: Ideas offering the greatest potential are analyzed more in detail to determine their value offering from a business standpoint. Such analyses include competitors, marketing, financial projections, etc.

Development: The product ideas that have demonstrated results that meet all success criteria are granted entry to the development phase. During this stage, products are developed and undergo a series of iterations until they meet all functional objectives.

Testing: Once the developed product is ready, it will be tested in the real world through experimentation with actual users. The users will then provide feedback based on their experience, and the product will then be iterated upon until the desired outcomes are met.

Commercialization: During this phase, newly developed products are launched into the marketplace on a large scale. Other activities that take place are generating customer feedback and course-correcting product errors. This is all aimed at meeting or, if possible, exceeding customer expectations.

By applying the BAH model in our product development process, our new product strategy and development is determined by identifying key industries that conduct periodic inspections of bolted joints. Moving on to idea generation, we shall map out different product ideas that are applicable in various industries. Such ideas will be sourced from supporting staff at DTU, potential customers, and industry experts.

Once we have held conversations with potential customers and industry experts, we shall review and evaluate their responses and determine which ideas demonstrate the highest potential. This will then be followed by conducting a business analysis where market sizing, competitive advantage, sales and marketing strategy, business modeling, etc., will be determined. Supporting theories for conducting business analysis will be covered in more detail later in this chapter.

The product idea that demonstrates a viable proposition will proceed to the development phase. Here we shall engage in a series of prototyping activities to experiment on the product's functionality, such as speed, accuracy, and integration with computer software for data storage. Once the product meets the defined success criteria, it shall proceed to the testing stage. This stage will engage potential customers by conducting experiments on the product in a real-life scenario. User feedback will then be used to iterate the product and align its performance and design to the user's desired outcomes.

Finally, once the iterative processes result in a product that meets the user's criteria, full-scale production will be commissioned. This will help standardize some of the components used, which will in turn drive down production costs. Since our product is fairly new in the market, we shall continue to remain close to customers who can provide us with valuable feedback on the product's performance and lacking areas.

NPD process also comes with its share of shortcomings, and if these are not monitored closely, we risk the likelihood of failing to address some of the underlining questions in each phase. These shortcomings are summarized in Table 2. By conducting analyses for each stage in the process, a conclusion will seek to address these shortcomings.

Like NPD theory, I also consider the Jobs-To-Be-Done theory as a supporting theory that can build on the product development process. This theory is discussed in more detail in Appendix 1A.

As part of the delimitations of this paper, I shall focus on the first step of the NPD process because of time constraints. Idea, Screening and Evaluation, Business Analysis, Development, Testing, and commercialization lie outside my analysis scope.

Area	Shortcomings
Market	The market size of the potential market is small. The product differentiation is vague. The product's positioning is poor. Misalignment with customer's needs. Lack of channel support. Competitive response.
Financial	Low return on investment.
Timing	Late entry into the market. Early entry into the market before it is developed.
Technical	The product did not work. The product design is not desired.
Organizational	Poor fit with the organizational culture. Lack of organizational support.
Environmental	Stringent government regulations. Macroeconomic factors.

Table 2: Own depiction of causes of New Product Failure (Jain 2001)

Porter’s Five Forces Analysis

As we work on positioning our technology in the market, I shall conduct a market analysis using the Porter’s Five Forces model shown in Figure 6 to map out the competitive landscape. This will help me determine the competitive strategy that should be deployed to overcome some of the common industry boundaries. Industry competitors consist of all firms that are competing against each other in a given industry. These competitors are surrounded by forces that comprise potential entrants, buyers, substitutes, and suppliers.

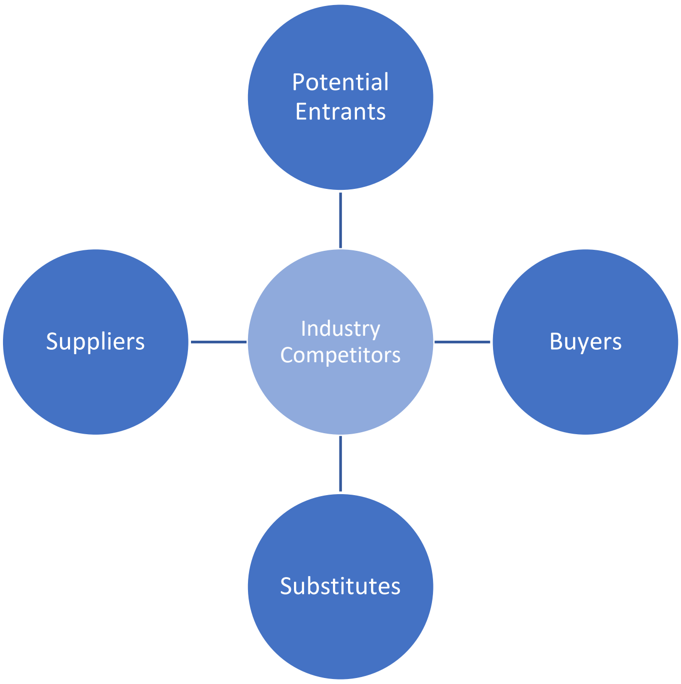

Figure 6: Own depiction of Porter's Five Forces Analysis (M. E. Porter 1980)

Potential entrants are industrial players that can enter the market with a similar offering. Here I shall analyze the level of ease for new competitors to enter the market.

Buyers with access to a large variety of competing products tend to be price-sensitive, meaning that they will not be willing to pay for a product or service that is priced above the market average.

Substitute products or services will influence how our technology will be produced and marketed. If substitute products are high-performing, then our product has to be priced competitively. Suppliers can influence the pricing of components and raw materials. In the presence of a large number of suppliers, the pricing of components will be low, while the absence of a large number of suppliers will increase supplier power and thus high prices of components and materials.

Porter’s generic strategies serves as a complementary theory which I have discussed in Appendix 1E.

Chapter 4 – Data Collection

This chapter illustrates how data collection was conducted and for what purpose. I started this process by shortlisting some companies that inspect bolt tension as part of their daily operations. I contacted them via email and phone call to ask them if they would be interested in learning about the bolt tension estimator technology. The purpose of conducting the interviews is to get an impression of whether the technology can be commercialized by certain industries and also understand the theoretical aspects surrounding innovation, competitive advantage, and product development. This is viewed as moving a step closer towards answering my research question.

Field study

Since I already have a technology that requires a market that is ready to absorb it, I need to get some industry players familiar with it and provide feedback that will indicate whether it is applicable.

I started by mapping out potential companies that inspect critical bolted joints of their infrastructure and equipment. These companies are,

Tivoli Gardens

According to VisitDenmark, Tivoli is the oldest and most visited amusement park in Denmark, located in Copenhagen. The service and maintenance team is engaged in both comprehensive and short routine maintenance. I am interested in learning about their maintenance procedures and potential opportunities to be realized using bolt tension estimator technology.

DTU Campus Service

This section of the Technical University of Denmark is tasked with all activities covering Facilities Management at the university. I was primarily interested in learning the procedures involved when inspecting elevators at the university.

FORCE Technology

They are a Research and Technology Organization (RTO) that provides Non-Destructive Testing (NDT) and inspection services. I will mainly focus on Non-Destructive Testing where the bolt tension estimator technology could potentially be value-adding.

KONE

This is a company that produces and sells elevators for both residential and commercial buildings. I am interested in speaking with them to learn whether integrating the bolt tension estimator would add value to their elevators.

Energinet
Energinet is a state-owned company that owns and operates high voltage power lines. I am interested in contacting them to find out whether the bolt tension technology can streamline their maintenance routines and save costs.

After completing this step, I shall contact the above companies to briefly introduce the technology and ask if they would be interested in learning more about it. By doing this, I can screen to identify industry players that find the technology's application relevant to their field of work.

Therefore, the candidates that are curious to learn more about the technology shall be invited to an online presentation where open discussions and questioning will be conducted. The interview are semi-structured and will be guided using a questionnaire with open-ended questions (see Appendix 2C).

Findings
After conducting interviews with the planned companies, I compiled my interview transcripts (see Appendix 3A) and broke them down into open statements. As illustrated in table 4, I developed open codes from my qualitative data by selecting statements that were of interest to my research question on commercialization.

Open Codes
We use Visual/Audible senses when conducting inspection
Normal tools such as torque wrenches are used
We have a competing technology e.g. ultra sonic
We use Software to help us run inspections
We value technology that has a high level of accuracy
We have limited time available to perform maintenance
We can help Co-developing the technology
We can help conduct Product testing
We experience some operational downtime
We incur high labor costs
Changing mechanical parts is expensive
We at times hire external companies for specialized tasks
We prefer purchasing equipment
The technology can be used for quality assurance

Tabel 4: Open codes from interview transcripts

The open codes were derived from statements highlighting themes such as costs, i.e., high labor costs. This is a common issue that managers mention. Operational downtime and spare parts are also mentioned as expenses that occur from time to time.

Other aspects of interest that I looked at are the current solutions used at the time of this writing, e.g. torque wrenches, audible and visual senses, software.

The ownership model is an area of particular interest where I learned that such companies prefer to own equipment and service it themselves. This is because the management chooses to purchase and own service equipment if its usage is very high.

The next step is to group these open statements into themes, as illustrated in table 5.

Open Codes	**Axial Codes**
We use Visual/Audible senses when conducting inspection	Competing Methods
Normal tools such as torque wrenches are used	
We have a competing technology e.g. ultra sonic	
We use Software to help us run inspections	
We value technology that has a high level of accuracy	Product Performance
We have limited time available to perform maintenance	
We can help Co-developing the technology	Product development
We can help conduct Product testing	
We experience some operational downtime	Expenses
We incur high labor costs	
Changing mechanical parts is expensive	
We at times hire external companies for specialized tasks	Business Model
We prefer purchasing equipment	
The technology can be used for quality assurance	

Tabel 5: Axial coding of my transcripts

By grouping my open codes into themes, I can integrate the competitive aspect of using the technology. Introducing new technologies is not a recipe for success in itself, so I have to understand the existing solution being used and the experienced level of satisfaction. Tivoli and DTU Campus Service use visual and audible senses when inspecting their facilities. When asked how satisfied they are doing this, they responded positively by saying that their methods are flexible and work well for them. FORCE Technology uses ultra sonic technology and discovered that the accuracy levels achieved by the bolt tension estimator are far more superior.

Moving to product performance, only FORCE Technology emphasized how important it is for them with product performance. This can be attributed to the high costs associated with product failure and/or accidents. Tivoli and DTU Campus Service mentioned that product performance is equally important since they need to pass an inspection certification process annually. However, the bolt tension estimator technology is not applicable for them since bolt inspection consists of a small percentage of the actual inspection procedure.

Product development is an aspect I discussed with FORCE Technology since it is one of their key areas. They displayed an interest in owning the technology, although they did not specify whether to purchase or license the intellectual property. Furthermore, FORCE Technology expressed their interest in co-developing the technology with DTU and providing testing facilities.

Tivoli and DTU Campus Service expressed the expenses aspect in the form of labor costs and spare parts. The feeling I got from this aspect is that these two organizations will be willing to use a given technology if it demonstrates the ability to cut costs and increase productivity. FORCE Technology is also committed to minimizing the risks of product failure, leading to additional expenses due to damages.

As for the business model, DTU Campus Service and Tivoli stated that they prefer to own machinery and equipment if their usage is high. In cases where annual inspections need to be conducted using specialized machinery, they prefer to hire external service providers. On the other hand, FORCE Technology develops and owns its equipment. Since they are hired on a contract basis, they use their equipment for the intended task. Therefore, a suitable business model will consider the ownership model that is most preferred by respective industries.

Considering the above aspects, I grouped the themes together under one category called New Product Development, as shown in table 6.

<table>
<tr><th>Open Codes</th><th>Axial Codes</th><th>Selective Code</th></tr>
<tr><td>We use Visual/Audible senses when conducting inspection</td><td rowspan="4">Competing Methods</td><td rowspan="14">New Product Development</td></tr>
<tr><td>Normal tools such as torque wrenches are used</td></tr>
<tr><td>We have a competing technology e.g. ultra sonic</td></tr>
<tr><td>We use Software to help us run inspections</td></tr>
<tr><td>We value technology that has a high level of accuracy</td><td rowspan="2">Product Performance</td></tr>
<tr><td>We have limited time available to perform maintenance</td></tr>
<tr><td>We can help Co-developing the technology</td><td rowspan="2">Product development</td></tr>
<tr><td>We can help conduct Product testing</td></tr>
<tr><td>We experience some operational downtime</td><td rowspan="3">Expenses</td></tr>
<tr><td>We incur high labor costs</td></tr>
<tr><td>Changing mechanical parts is expensive</td></tr>
<tr><td>We at times hire external companies for specialized tasks</td><td rowspan="3">Business Model</td></tr>
<tr><td>We prefer purchasing equipment</td></tr>
<tr><td>The technology can be used for quality assurance</td></tr>
</table>

Tabel 6: Selective code for my interview transcripts

New Product Development (NPD) process will form the theoretical basis for my paper because it takes into account;

- The competitive aspect of the technology
- The product performance through product testing

- The product development through prototyping
- Expenses by conducting a cost-benefit analysis of implementing the technology
- Business model development

This will in turn help me answer my research question.

The point of departure for this study is defining a new product strategy and development, as illustrated in Figure 7. This stage involves linking new product strategy with a company's mission and vision with new products.

Figure 7: NPD Process (Booz, Allen and Hamilton 1982)

In the next chapter, I shall analyze the interview findings and contextualize them to the NPD process theory. Furthermore, I shall also consider how open innovation, Porter's Five Forces analysis and technology push and market pull fit into new product development and thus lead me to answer my research question.

Chapter 5 – Analysis

In this chapter, I shall provide an in-depth analysis of my interview findings by contextualizing them using the theories discussed in Chapter 3. This will be done by conducting an in-depth analysis of the selective code developed in the previous chapter. Moreover, I shall explain how the startup failures discussed in Chapter 1 can be avoided.

1. Competing Methods

During my interview with Tivoli, I learned that their existing methods of inspecting loose bolts are done by conducting test rides on the rollercoaster to get sound signals that indicate loose bolts. DTU Campus Service also runs a test ride of their elevator and listens to sound signals that indicate loose bolts. Both Tivoli and DTU Campus Service use a computer software program that can detect misalignment of the structural build of the rails. As for FORCE Technology, they have developed an inspection device that they use to inspect bolted joints in subsea structures. The technology is based on ultrasonic technology that measures the flight time from the bolt head to the surface that it is fastened to where the time is compared to the baseline measurement. FORCE Technology expressed the need to improve its current solution and was very keen to learn more about the bolt tension estimator technology.

One fundamental question that investors tend to ask startup founders is how their competitive landscape looks like. Technicians at Tivoli and DTU Campus Service rely on their audible senses to hear sound signals that indicate potential loose bolts and other structural parts. This method works well for both companies since they did not express dissatisfaction with their inspection process. In view of Porter's Five Forces, this indicates that Tivoli and DTU Campus Service has a substitute method of detecting loose bolts that works well for them. Therefore, the competitive aspect puts the bolt tension estimator technology at a disadvantage in the amusement park and elevator industries. Despite this, the offshore industry remains an interesting area where the technology could be valuable.

In summary, the key factors that cause startup failures suggest that "being outcompeted" is one reason for this. When assessing the position taken by both Tivoli and DTU Campus Service, the current method of inspecting bolted joints is preferred to the bolt tension estimator technology.

2. Product Performance

Tivoli and DTU Campus service expressed that time is a scarce resource and if there is any way they increase their productivity when conducting maintenance, it would yield a significant value. Given the current situation, technicians at Tivoli use their audible senses to detect loose parts and then immediately fix the problem by e.g. retightening loose bolts using a torque wrench. The same is for DTU Campus Service where the technicians use their audible senses and a computer software to detect operational errors. These methods seem to work faster than what we could currently achieve with the bolt tension estimator technology at the time of this writing.

In view of Porter's Five Forces, time can be used as a performance criterion when comparing two or more substitute products. In my case, Both Tivoli and DTU Campus Service use procedures that take a relatively short time to diagnose the well-being of their infrastructure. This is a parameter that the bolt tension estimator technology cannot compete on. Therefore, this aspect hinders it from being an attractive option for both companies.

Accuracy is an important factor for companies that work in very sensitive environments i.e. elevators, amusement parks and offshore oil platforms. DTU Campus Service are required to obtain an operation certificate annually that permits them to run their elevators. This calls for maintenance procedures that adhere to strict safety requirements. Thanks to in-built technologies in elevators that allow monitoring using software. Tivoli is also required to obtain an annual operation certificate to allow them to run their park. The technicians use a software program that aids them in monitoring their infrastructure.
Conversely, the old section of Tivoli consists of bolted structures that require diagnosing the structure manually. The technicians retighten bolts straight away as a way of ensuring all bolts are fastened. From a competitive point of view, the accuracy levels of elevators and amusement parks are achieved using the software that is tailored for each. This makes the bolt tension estimator technology unfavorable for Tivoli and DTU Campus Service.

On the other hand FORCE Technology has expressed the need to improve its accuracy level when inspecting subsea structures. Furthermore, they have also expressed some interest in engaging in a collaborative partnership with DTU to co-develop the technology subject to its management's approval. From a technology push and market pull standpoint, FORCE Technology will be required to provide resources to develop the bolt tension estimator technology further. When assessing its maturity stage using the technology readiness level (TRL), it is situated between levels 3 and 4, as illustrated in Figure 8.

This means that the experiments conducted on the technology have attained proof-of-concept. Moreover, the ongoing experimental work involves the validation of components in a laboratory environment. The time interval between the TRLs vary and this could take several years to move up one or more levels. This is why additional resources i.e. funding, market expertise, potential users etc. would be required to speed up the process.

Therefore, FORCE Technology will be able to test the accuracy levels and make further improvements as the technology continues to mature.

In view of NPD process, the testing phase takes place once prototyping is complete. This is where FORCE Technology can test it at their testing facility. Since this is an iterative process, the product will be improved continuously until it meets certain criteria set by the product manager. Once the device can demonstrate a high level of performance, it can be transferred to an offshore environment where its performance will be tested. This process will be iterated upon until a satisfactory performance is achieved.

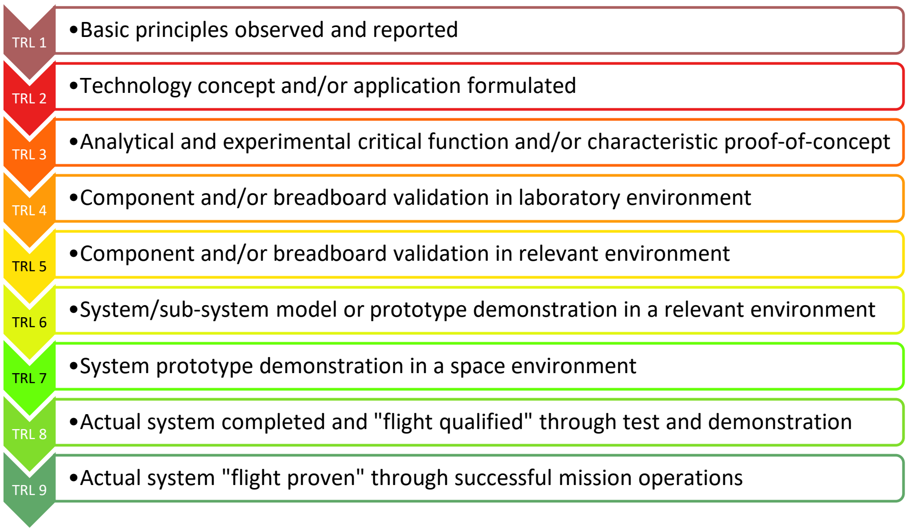

Figure 8:Own depiction of Technology Readiness Level (Tzinis 2021).

From a competitive perspective, FORCE Technology is currently using an inspection device that is based on ultrasonic technology. Given the performance of the current device, they are seeking alternative methods that can improve this. That is why they expressed a strong interest to collaborate with DTU in co-developing the technology. In line with Porter's Five Forces, the bolt tension estimator technology is a radical innovation that threatens to displace ultrasonic as a new entrant in the market. The same can be viewed as a substitute product to the ultrasonic technology.

Since one of the reasons for startup failure suggests product not being a hit, co-developing the technology with FORCE Technology can reduce the chances of producing a product that fails to solve the intended task. Through continuous development and testing ensures that the product is able to meet certain criteria before launch. No market need for product is also one of the reasons for startup failure. In this case, FORCE Technology is the potential user of the bolt tension estimator technology. If a collaborative agreement is established between DTU and FORCE Technology, that is a validation in itself that there is a market need.

3. Product Development

FORCE Technology expressed interest in collaborating with DTU to co-develop the bolt tension estimator technology and provide testing facilities and potential users to conduct product testing. During a technology push scenario, the researchers from DTU engage with the technology in isolation to validate the basic proof of concept. Regarding technology readiness level, stage four covers "component and/or breadboard validation in laboratory environment" meaning that the proof of concept is validated in a laboratory environment. Afterwards, the objective will be to work towards validating the proof of concept in a relevant environment. This is where market pull starts to take place because potential users e.g. FORCE Technology are engaged in co-developing the technology and shaping its development through feedback from product testing.

With regard to open innovation, new technologies and inventions that are developed at DTU are presented to industries that can exploit its commercial advantages. After holding initial talks with FORCE Technology about the bolt tension estimator technology, they requested a meeting to learn more about it and assess its relevance to their line of business. FORCE Technology revealed their long tradition of maintaining close contacts with universities since they present opportunities to gain new knowledge through licensing or purchasing Intellectual Property (IP). Indeed, this could help them improve their current inspection device by supplementing it with the bolt tension estimator technology.

In view of “no market need” as a reason for startup failure, this can be attributed to products not being developed in close collaboration with stakeholders who provide valuable feedback. Therefore, by DTU engaging in a collaborative agreement with FORCE Technology, the market need is verified because FORCE Technology is already a potential user of the technology. The same is true for the reason “product not a hit.”

4. Expenses

Tivoli spoke of labor costs being the most expensive aspect of their operation and if there would be a technology that helped offset these costs, they would consider it a viable option. Other costs that they incur yearly are downtime costs whereby tivoli’s rides run 97% of the time on average. Anytime a ride has to be shutdown due to operational errors, it looses the revenues it is meant to generate during that particular period. DTU Campus Service mentioned mechanical parts of the elevator as being the most expensive aspect of operating elevators. As for FORCE Technology, the most expensive aspect of their operation is labor because they sell their offshore expertise to offshore energy companies who in turn contract them to service their offshore facilities.
From a competition standpoint, the bolt tension estimator technology is not able to offset labor costs for Tivoli because a big portion of their infrastructure have welded parts and therefore have very few bolts to inspect. This would make the inspection process longer, which is costly, and training staff to use the technology will add to the existing costs. The high costs incurred by DTU Campus Service for purchasing mechanical parts for elevators is likely to remain unchanged. On the other hand, the bolt tension estimator technology is likely to save some costs for FORCE Technology that stem from technical errors. Since the nature of maintaining offshore installations is highly complicated and require a high level of expertise, technical errors and accidents can turn to extra costs or if worse, heavy penalties. Therefore, the high accuracy levels recorded by testing the bolt tension estimator technology will minimize the risk of incurring such expenses.

Startup failure resulting from no market need is caused by developing products that are not in line with user’s needs. The offshore industry demands a high level of experience and know-how from companies and its workers. Technological development is a way for companies to minimize their risk of committing errors in such a sensitive working environment. By demonstrating the accuracy level achieved by the bolt tension estimator technology, FORCE Technology is able to quantify the risk reduction level which will then translate to cost savings. This is the value proposition drives the need for FORCE Technology to pursue a collaboration with DTU to co-develop the technology.

5. Business Model

DTU Campus Service engages in purchase of equipment. When asked whether hiring equipment is exercised, they answered that state-owned entities are not allowed to lease equipment or products. If in a situation where purchasing equipment or hiring extra staff is deemed unfeasible, the normal practice would be hiring external companies to conduct elevator maintenance during peak times. The maintenance team from Tivoli said that they prefer purchasing equipment if its usage exceeds ten times per year. In a situation where this number is below ten, then they would lease the equipment instead.

As for KONE, they did not express any interest in engaging in any form of collaboration. However, they recommended that I look into leasing the technology to contractors in the construction industry for the purpose of providing quality assurance documentation. The same recommendation has been provided by Energinet who outsource maintenance of high voltage power lines to contractors.

Despite the above, I learned that FORCE Technology prefers to own the equipment that they use to service offshore installations. This is why they express the need to collaborate with DTU to co-develop the bolt tension estimator technology. In view of NPD process, FORCE Technology will align their corporate strategy with developing the bolt tension estimator technology. The screening of ideas will involve conducting an economic appraisal for the possible ventures. Since FORCE Technology is expected to use the innovation to improve the quality of inspection of bolted joints, the focus of the business analysis is likely to be based on cost savings.

Therefore, startup failure based on market need can be avoided if DTU Campus Service, Tivoli, KONE Elevator and Energinet are disregarded. This is because they did not show any interest in engaging with the bolt tension estimator technology, making them an unfit target group at this stage of development. FORCE Technology has on the other hand expressed the interest in owning an equipment based on the bolt tension estimator technology. The fact that the company is structured to develop products and test products make them a good fit. Moreover, startup failure originating from wrong business model can be avoided because FORCE Technology sells its expertise in servicing offshore installations. Their experienced workers make it applicable for them to own a technology that can improve the quality of their inspection service and reduce costs.

6. New Product Development

New Product Development is used as the study's theoretical basis because it takes fundamental aspects of innovation. The process will take me from establishing corporate goals for new products all the way to commercialization. The possibility of FORCE Technology engaging in a collaborative effort to develop the bolt tension estimator technology with DTU makes NPD process applicable. Furthermore, FORCE Technology’s product development lab, testing facilities and market intelligence sets favorable conditions for a successful commercialization of the technology.

In regard to Tivoli, DTU Campus Service and Energinet, I sensed a low interest in pursuing the bolt tension estimator technology because they are not innovators and/or early adopters. This makes the NPD process not applicable for these companies since they are mainly consumers of technology. The same was experienced when speaking to KONE where they concluded that the technology is not fit for their products.

The NPD process is essential to answer my research question since it considers an organization's product strategy before moving on to the ideation process. The product ideas will then undergo a market analysis and financial appraisal to determine their viability. Therefore, startup failure resulting from "product not a hit", "wrong business model" and "no market need" can be avoided since I am already aware that Tivoli, DTU Campus Service, Energinet and KONE are not fit to absorb the bolt tension estimator technology.

Chapter 6 – Discussion

In this chapter, FORCE Technology will be used as the center of my discussion since the NPD process is applicable in relation to its structure. I shall also account for how open innovation, Porter's Five Forces analysis and technology push and market pull fits with the NPD process, leading me to answer my research question.

FORCE Technology

In 1938, 2 welded steam boilers were sent to Switzerland from Denmark where they underwent an x-ray process and acquired documentation that permits its usage (FORCE Technology 2014). Since there was a need for conducting this process in Denmark, a private company called Svejsecentralen was founded in 1940, which would later evolve in the years that followed to become FORCE Technology (FORCE Technology 2014). FORCE Technology is the largest Research and Technology Organization (RTO) in Denmark employing 1,100 people providing counselling and training to its clients through its unique laboratory infrastructure for testing, calibration and analysis (FORCE Technology 2014). Moreover, FORCE Technology provides on-site inspection services and data acquisition of e.g. bridges, wind turbines, oil platforms etc. (FORCE Technology 2014).

Key success factors for startups

According to Bill Gross, five factors are critical to the success of a startup (Gross 2015). These factors are;

<u>Timing:</u> This is the most important component that influences the success of a venture. It is important for a technology to be understood by a broad audience that can speed up its diffusion rate. So how can I know the timing of the bolt tension estimator technology is right? One important aspect has guided me to conclude this, which is FORCE Technology expressing their interest in engaging in a collaboration with DTU.

<u>Startup team:</u> For an idea to be converted into a product or service, a dedicated team must work around the clock to reach this objective. This is viewed as the 2nd most important factor. In the case of the bolt tension estimator technology, DTU and FORCE Technology will need to establish a task force that can work on developing the technology. This can be organized in such a way both parties can leverage on each other's core strengths. DTU has the technical knowledge to develop an innovation tailored to the offshore environment, while FORCE Technology possesses a wealth of knowledge related to market intelligence.

<u>Ideas:</u> Idea generation is an important process when seeking ways to develop new products and/or services ranked at 3rd place. Not all ideas are feasible therefore it is important to align them with customer needs. During the ideation process, FORCE Technology will be required to evaluate their ideas by engaging potential users of the bolt tension estimator technology and conducting financial appraisals.

Business model: This comes in 4th place even though Bill Gross argues that startup do not need to have a business model in the preliminary stages (Gross 2015). He further stateshat startups should focus on the best product and technology (Gross 2015). With regard to FORCE Technology, the current business model for inspecting subsea structures is by selling their expertise in servicing offshore installations to energy companies. Therefore, the bolt tension estimator technology is likely to be incorporated into the existing business model.

Funding: This comes at 5th place since Bill Gross argues that startups can grow organically if it has the right timing, team, idea and business model (Gross 2015). FORCE Technology and DTU have the possibility of applying for funding via European Union's funding facility Horizon Europe, Innovation Fund, Otto Bruuns Fund and Alexander Foss' Fund to cover costs associated with prototyping, labor, legal etc.

The success factors are weighed based on importance in Figure 9.

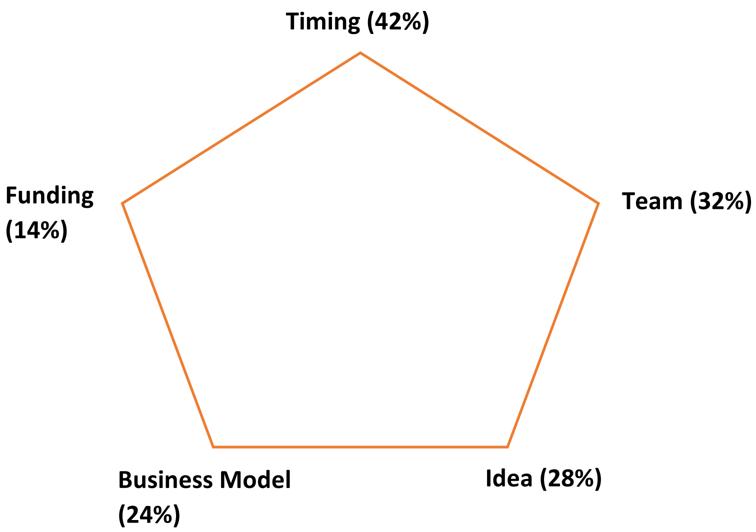

Figure 9: Key success factors for startups (Gross 2015)

The success factors for startups will form the basis of answering my research question in view of Technology Push and Market Pull Theory, Open Innovation Theory, Porter's Five Forces and New Product Development theory.

Technology push and market pull

As discussed previously in Chapter 3 I highlighted how the development process of a radical innovation finds its place at the technology push side on the right end of the spectrum. Considering that the current Technology Readiness Level is considered to be between 3 and 4, the development process is still taking place in a controlled environment with minimal contact with potential users. Once the functionality in the controlled environment is validated, the next step will be to test it in a real environment. This will require DTU to partner with some stakeholders, e.g. FORCE Technology, to conduct tests in a real-life setting. This will result in changes in the development process (represented by “C”) whereby the process starts to shift towards the left side as illustrated in Figure 10.

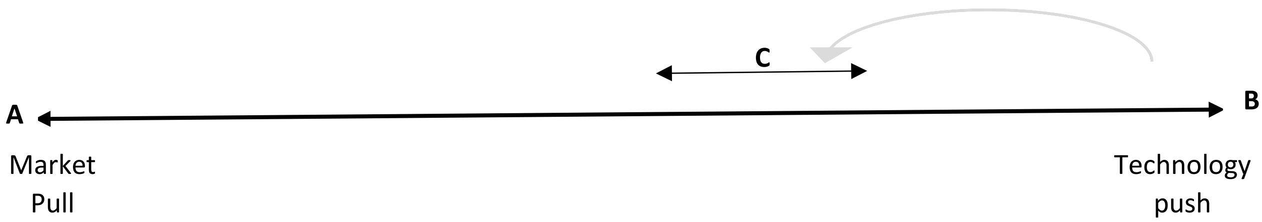

Figure 10: Market pull vs. Technology Push Continuum

This can be explained by the fact that once the technology is validated within a closed environment, the forthcoming activities will involve external stakeholders who are likely to influence the direction the technology it is to develop.

Therefore, establishing contact with potential partners came as the next step where we received some interest from FORCE Technology. After holding discussions with them, DTU might have the opportunity to negotiate for either a license agreement or sell the IP. If any of these options are pursued, the technology is expected to be developed further so that product testing can be conducted in a real-life setting to generate user feedback, which will be used to steer the technology on a user-oriented path. During this phase, the process will continue to shift towards the left side (market pull) until the Technology Readiness Level reaches level 9, indicating that the technology is fully mature.

In the context of the NPD process, technology push and market pull can be exercised during the development stage. The ideas that make it to the development stage will be prototyped and tested to record their performance. Product testing will occur in an enclosed environment where results can be measured and then used to build up on the next iteration. Once the prototyping reaches an advanced level, the product will be tested in a real environment by service technicians. This will enable DTU and FORCE Technology to develop a product that aligns with users’ needs eventually.

So how does this process increase the success rate of startups?

We have already learned that the most critical success factor is timing which requires that a broad range of audience understands the technology. The collaboration between DTU and FORCE Technology will enable the technology to be used by service technicians during testing, whereby the generated user feedback can help steer the product development towards users.

With the project team being the 2nd most important factor for success, the team will consist of researchers at DTU who have the technical competencies for developing the technology. On the other hand, FORCE Technology is an established company in the offshore industry where they can provide valuable market insights and test facilities for product development.

Good ideas are also considered critical, and is ranked at 3rd place. The process of prototyping and testing will enable FORCE Technology to validate ideas that fit well with users' needs. Other ideas can emerge through holding conversations with users' on ways to improve the prototype. With reference to the coding results outlined in Chapter 4, it is concluded that the technology has a low likelihood of "not being a hit" or "no market need." Based on key startup success factors, this can be attributed to smart ideas generated in the idea stage and during product testing, where user feedback is used in the iteration process.

Open innovation

Similar to Technology push and market pull, open innovation advocates for an open way to explore knowledge that can be integrated into new products and services.

According to Figure 11, DTU selects the bolt tension estimator technology from its vast portfolio of IP and presents it to several companies as presented in Chapter 3. FORCE Technology being the company that expressed strong interest in the technology, they shall conduct an assessment by developing and testing the technology, and then determine whether it can serve as a complementary feature on their current device.

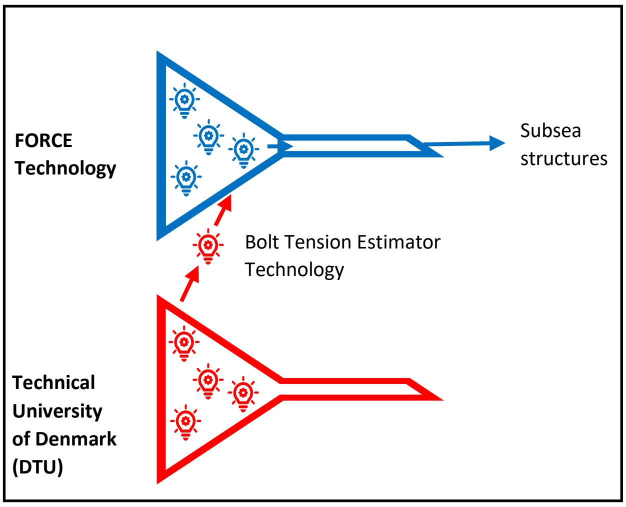

Figure 11: Knowledge Lanscape 1

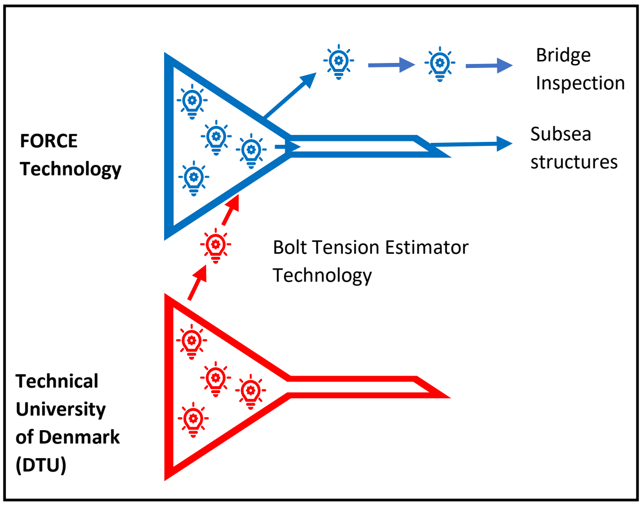

Figure 12: Knowledge Landscape 2

Assuming that we have a scenario where the technology displays great potential in key areas where FORCE Technology conducts its business e.g. bridge inspection, the knowledge landscape of open innovation will look similar to Figure 12.

The knowledge landscape shows that transfer of new knowledge takes place between DTU and FORCE Technology, where the technology is applied in the area covering inspection of subsea structures. This scenario also shows how the subsequent transfer of knowledge could take place internally at FORCE Technology. This could be the case when the application potential of the technology in other service areas is analyzed, and a new market for the technology is created e.g. bridge inspection.

So what is a typical process like when attempting to establish contacts with a potential industry player?

Below is a summary of an interview I conducted with the Technology Transfer office at DTU to learn about the process of commercializing patents.

Interview with DTU Tech Transfer
Tech Transfer office has a long tradition of working closely with certain industries, creating a thorough understanding of some industry challenges. This has enabled DTU to establish solid contacts with industry players. Therefore, whenever an invention with commercial potential is registered, an industry player that can benefit from it is contacted and presented with the new knowledge.

Another way DTU reaches out to the corporate world is by hosting an Intellectual Property (IP) Fair where industries are invited and presented with a wide range of patented technologies that have the potential to revolutionize manufacturing processes, performance efficiency, precision, etc. Additionally, DTU is considering developing a portal where their patents will be publicly listed so that interested companies can evaluate whether there might be a patent that is relevant to their industry. X-Tech Entrepreneurship course has also been used actively to bring students together with researchers and experienced mentors from a wide range of industries to commercialize patents owned by DTU. Finally, DTU approaches companies directly through cold-calling and/or emailing potential industry players.

Once DTU enters a formal agreement with an industry player, they engage in a collaborative activity to develop it further. This can be through requiring the collaborating company to provide testing facilities and mentorship. Other efforts can be realized through applying for external funding, where costs associated with labor and prototyping are covered.
During the development process, collaborating companies can opt to buy or license a patent, and if this is not the case, DTU can sell them to another interested party. If a patent does not demonstrate a commercial potential, the project will be brought to a halt and then given back to researchers.

When assessing business models for university patents, DTU only engaged with licensing and sale of patents. University spin-out companies can in special circumstances be owned partly by DTU, but this does not happen very often, and the university prefers to avoid it.
In circumstances where an industry is interested in purchasing a given patent, DTU conducts its research to determine the market value of such a patent and then sets the price accordingly.

In the context of open innovation, DTU provides industries with the platform to find new knowledge on how technology can be used to improve business processes and operations. This entails initiating contact with a potential industry hoping that the innovation can prove to be of value.

My efforts for commercializing the bolt tension estimator technology have undergone the process of initiating contacts with potential industry players through cold-calling. FORCE Technology is a good example of an industry player that I called and presented DTU's technology.

Since the engineering team at FORCE Technology has shown a high level of interest in the technology, the next step is for them to inform their management about it so that necessary arrangements can be made to demonstrate it physically in a laboratory facility at DTU.

Given a scenario where DTU enters an agreement with FORCE Technology after a successful demonstration of the technology, the two parties have to agree on sharing their resources. Since FORCE Technology is a Research Technology Organization, they have testing facilities in their laboratories to cater to experimental work. Moreover, FORCE Technology has a wealth of industry knowledge that they can leverage on to test products based on the bolt tension estimator technology. For example, FORCE Technology conducts inspections on offshore oil platforms where inspecting bolt tension is an ongoing challenge. In this scenario, the product development team can be granted access to the actual application areas where performance criteria are set and measured for analysis. The same product development process can be performed by the technical team that performs bridge inspection where monitoring bolt tension is a challenge.Given the above application scenarios, there are many resources that DTU as an academic institution can provide, such as research knowledge, know-how and intellectual property. In case FORCE Technology is unable to pursue the technology, DTU will contact other potential companies.

In view of NPD, open innovation provides organizations with the opportunity to seek knowledge that can benefit their corporate strategy concerning new products. It also encourages knowledge from different fields to be explored to give rise to new technologies. During the ideation process, FORCE Technology can generate ideas that are relevant for inspection of bolts in subsea structures and other business areas, i.e. bridge inspection. If such ideas qualify for the development stage, they can be implemented in prototypes either as a main technology or supporting technology.

Through open innovation, I can conclude that timing of the bolt tension estimator technology is right because after approaching FORCE Technology with a proposal to consider licensing or purchasing the patent, they have so far given a positive response. Since DTU collaborates with numerous companies to develop products, FORCE Technology has the possibility to leverage on DTU's technical competencies while at the same time provide market insights and laboratory facilities for prototyping and testing. Last but not least, DTU and FORCE Technology can use the feedback from user testing to generate new ideas on how to improve the product to fit users' needs. In reference to the coding results under product development, the potential collaboration of FORCE Technology and DTU decreases the probability of creating a product that is not a hit or has no market need since FORCE Technology is a potential user. This will increase the chances of success through open innovation because of its timing, project team, and ideas.

Porter’s Five Forces

Potential Entrants

In reference to product and process innovation outlined in Appendix 1C, I have learned that the competitive landscape changes in line with the maturity stage (fluid, transition, and specific) of the technology in question. This is to say that during the early stages of product development, the process is fluid, which results in producing multiple innovations. Competing technologies discovered at this stage can be radical and can render non-performing innovations obsolete.

The bolt tension estimator technology finds itself in the early stages of product development which is fluid and thus making the process flexible. If I take a scenario where FORCE Technology takes part in developing the technology, there might be subsequent discoveries that complement the primary technology. This can help make the technology more advanced, thus giving it a competitive advantage. On the other hand, there might be new entrants with radical technologies that can outcompete the bolt tension estimator technology since competitors at this stage mainly focus on product differentiation.

During the transition stage of the product and process development, the innovation is based on feedback concerning customers’ needs thus, a product standardization is established. As I discussed earlier concerning technology push, if FORCE Technology pursues the bolt tension estimator technology, they will conduct experiments in a real-life setting where learnings will be used to improve the innovation to fit users’ needs. During this process, a dominant design is expected to be established, which is likely to eliminate some competitors and thus giving FORCE Technology a huge advantage. Dominant designs can be patented which will then be able to generate revenue streams via royalties. This can be a good way of having some level of control on competitors or new entrants. Furthermore, FORCE Technology can continue to develop complementary products to fit the dominant design which could eventually result in establishing a new standard in the future.

The final phase, the specific stage, tends to be rigid, and innovations that stem from this stage are incremental. Potential entrants will likely be rival technologies that are brought into the market, which can influence licensees to jump ship.

To conclude this, potential entrants are likely to be on the low side. This is because the technology is made to fit B2B customers who offer specialized services within inspection of bolted joints. FORCE Technology could in this case choose to either purchase or license the technology to enable them to develop a product that can improve their inspection services. However, it is expected that potential entrants might appear in other areas where FORCE Technology operates e.g. wind industry. This will not be a disadvantage to DTU because they are interested in expanding their licensing agreements with companies operating in other industries. On the contrary, FORCE Technology can instead opt to purchase the IP from DTU, giving them more control with regard to managing it in both the short and long term.

Buyers

Since the bolt tension estimator technology will either be licensed out or purchased, a strategy for determining buyer selection has to be deployed. In a scenario where the technology is purchased by a given buyer, DTU will have to price it accordingly to recoup their investment money. In a licensing scenario, a lot of aspects need to be considered to ensure that a favorable outcome is achieved. Therefore, DTU needs to license the technology to favorable candidates that have high growth potential.

Determining the quality of buyers requires scrutiny of the following;

a) <u>Purchasing needs versus company capabilities:</u> This is achieved by matching buyers' needs with the competencies of a seller. In my case, understanding the bolt tension estimator is paramount to sell the idea to potential customers. The conversation with FORCE technology focused primarily on their area of expertise, where I contextualized the functional properties of the technology in relation to their challenges. By introducing a potential solution for inspecting bolted joints that is very targeted to their challenges made them enthusiastic.

b) <u>Growth potential:</u> The potential growth rate of FORCE Technology is an important parameter for DTU to consider when entering into a license agreement. If FORCE Technology demonstrates growth in their market, then it means that their revenues will also grow, resulting in increased volume of DTU's royalty collection.
   Figure 13 shows that the annual turnover of FORCE Technology has been on a steady decline. In 2016, they experienced a turnover of 1.3 billion DKK, while in 2020, the numbers dropped to around 1.1 billion DKK. In 2016, the turnover was at a record-high 1.3 billion DKK because FORCE merged with Delta in January 2016. They continued to do well in 2017 in the areas concerning calibration and metrology, accredited testing, consulting, and electronic products. From 2018, FORCE Technology had some non-performing subsidiaries, mainly within inspection services.
   And in 2020, the declining turnover is due to the global pandemic that has slowed down all their service areas. Moreover, FORCE sold off some of their non-performing service areas, contributing to a decline in their turnover. In summary, FORCE Technology is a diverse company, and its turnover stems from all their service areas. Therefore it is difficult to pinpoint the exact performance numbers that are derived from inspection of subsea structures. The above is supposed to give a rough picture of the size of turnover and growth potential. A decline in turnover does not necessarily mean that the area of subsea inspection is declining. Its diverse core areas perform differently. Some are high-performing while others are not. Assuming DTU and FORCE Technology agree on a licensing deal, then it is recommended that a thorough economic analysis of subsea inspection is conducted to evaluate whether FORCE meets certain criteria that qualify them as a good buyer.

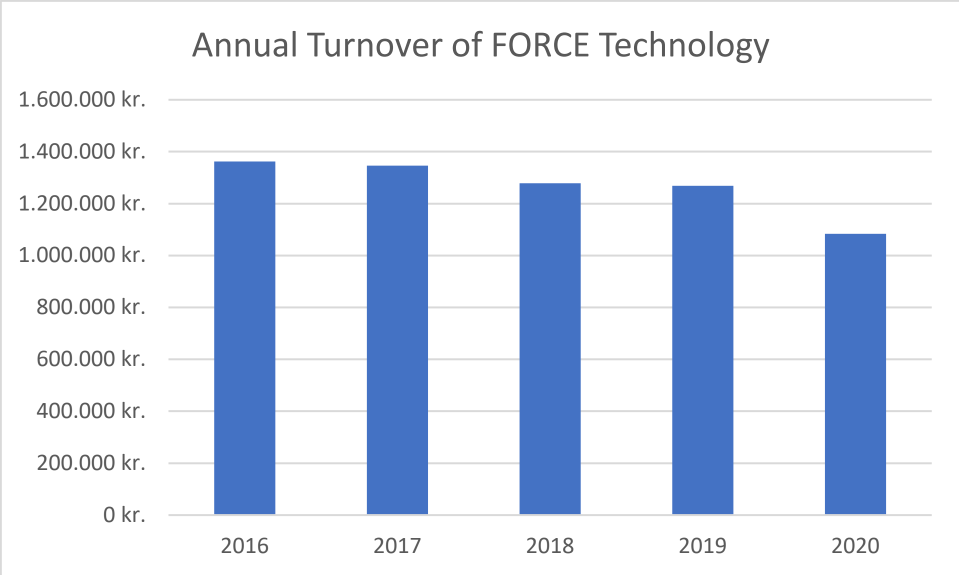

Figure 13: Annual Turnover (FORCE Technology 2020)

c) Intrinsic bargaining power: As mentioned earlier, FORCE Technology is currently experiencing challenges in conducting inspection of bolted joints in subsea structures. This positions them as a buyer that is seeking a technology that can help them improve the level of accuracy of their work. Since the market offers few alternatives, FORCE Technology has limited leverage to use for bargaining. Moreover, developing a product using the bolt tension estimator technology will incur retraining costs of employees and investment costs in new equipment thus making switching costs high.

d) Price sensitivity of buyers: Since FORCE Technology has the objective to improve the effectiveness of their inspection service of subsea structures, their level of price sensitivity is expected to be low. This is because the consequences of product failure are servere which makes them more concerned about reliability and performance.

In summary, qualifying good buyers to license the technology will be a helpful way to determine the candidate that can provide the most value in terms of the volume of royalties collected as well as striking a healthy balance when bargaining. FORCE Technology is one of the companies that have shown interest in the offshore sector and supposing another competitor expresses the same level of interest, both firms have to be evaluated to determine the most favorable option. Therefore, the possibility of experiencing buyer power being exercised is low because there are limited alternatives in the market. Furthermore, product performance is perceived as an important parameter.

Suppliers

During the fluid stage of the product and process innovation, the bolt tension estimator technology will be expressed in different forms and shapes until a dominant design is established. This will require unique designs and components that are not readily available from suppliers.

Therefore, it could take some effort to convince suppliers to produce unique components and if it succeeds, it is likely that they will charge a premium price for it.

Once the technology has a standard design, the focus will shift towards cost and performance. During this phase, the production will be ramped up, bringing the unit costs down thanks to economies of scale. Suppliers will in turn invest in specialized equipment to produce the product. This might increase the power of suppliers because the product based on the bolt tension estimator is highly specialized and might carry a high level of switching costs.
Since the inspection of bolted joints in subsea structures is a highly specialized service with a few players in the market, the quantity produced is expected to be low. These companies can build a few devices that can be used on the sites where they are contracted to conduct inspections. Through its R&D facility, FORCE Technology is able to build its products internally and thus minimize its reliance on suppliers. However, since the components required to create a product will be unique and produced in small quantities, the price is likely to be high. Furthermore, It is expected to bear switching costs concerning supplier relations, certification, equipment, etc.

Based on the aspects above, it is expected that the supplier power will be medium in both the short and long term.

Substitutes
As we learned in Chapter 3, products and services that perform similar functions are considered substitutes. Substitutes provide buyers with an alternative that is either cheaper or better performing compared to their previous solution. Therefore, identifying substitutes requires seeking products or services that solve similar functional tasks.

The bolt tension estimator technology can be a better alternative to the current solution used to inspect bolted joints on subsea structures developed by FORCE Technology. Since their current solution does not yield satisfactory results, they seek alternative solutions that can help them improve their current performance and costs.

So what could be the possible threats the bolt tension estimator technology could face?
Relative value compared to price: This is defined as the value a buyer receives from using a particular product or service compared to the cost of acquiring it.
The cost for financing the purchase of the bolt tension estimator technology could be very high since the technology is applicable in several industries.

FORCE Technology could only be interested in buying it to use it for its core business units so an alternative technology that bears a lower market value because of its limited field of application could be of interest to them.

Technology performance could also be a reason for FORCE Technology to be in favor of a substitute technology. Since the bolt tension estimator technology has not yet been tested in windy and submerged environments, alternative technologies might be a better option if its performance does not meet these criteria.

Switching costs: These are costs associated with switching from one supplier to another or from one technology to another. Suppose we have a scenario where FORCE Technology purchases the IP from DTU. The switching costs will be very high because switching to an alternative technology will require the bolt tension estimator technology to be abandoned due to changes in functionality. In a scenario where FORCE Technology licenses the IP, the switching costs will also be high because their product designs will be based on the bolt tension estimator technology. The impact of this will be due to expenses associated with retraining staff and sourcing new suppliers.
Buyer propensity to substitutes: The likelihood of a buyer switching to a substitute product is dependent on different factors that influence making such a choice. Some of these choices might have something to do with resources, e.g., time, money, labor, etc. It is highly uncertain how FORCE Technology will respond to investing in a new technology that can improve their subsea inspection. Given the situation with the global pandemic that has harmed its business units, it remains to be seen whether they would be willing to invest in a substitute technology.
FORCE Technology is an organization that is known to invest in state-of-the-art technologies in various industries. Since innovation is integrated within their organization, an appraisal of the technology will be conducted.

Finally, since FORCE Technology faces a lot of competition from rival firms, this has made them invest heavily in innovation over the years. Therefore, the bolt tension estimator technology could give them an unfair advantage for a couple of years. As soon as a new and improved technology is available, we might see them switching to the alternative as long as they see potential value that will help them stay ahead of their competition.

Based on the above account on substitutes, it is unlikely for FORCE Technology to be lured by new technologies, given that they are still recovering from the financial hit caused by the global pandemic. Therefore, I anticipate a minimal threat from substitutes in both the short and long term because they will have invested many resources in a technology that bears high switching costs.

Competitive Rivalry
This consists of competing companies that serve FORCE Technology's target customers. They comprise companies that conduct maintenance services of subsea structures such as SIEMENS Gamesa, Aibel and SKANSKA.
Siemens Gamesa is a company headquartered in Spain that produces and installs wind turbines both onshore and offshore. It also conducts maintenance services of offshore installations.
Aibel is a Norwegian company that specializes in construction and maintenance of oil, gas and offshore wind installations.

SKANSKA is a project development and construction company that is headquartered in Sweden and operates internationally. It has an offshore division where it specializes in maintenance of offshore installations.
The above companies are established within their markets and could influence the manner in which FORCE Technology grows. The offshore industry is a highly specialized and regulated area which is a feature that raises the entry barrier. Therefore, this presents a great opportunity for FORCE Technology to improve its service and, at the same time, minimize the associated costs of rendering these services. This indicates that the threat from rival firms is currently medium and will remain to be so in the near future.

Company	No. of Employees	Industry
SIEMENS Gamesa	24,500[1]	Offshore wind power
SKANSKA	32,500[2]	Construction, Oil and Gas, Offshore wind
Aibel	4,000[3]	Oil, Gas and offshore wind
FORCE Technology	1070[4]	Testing products and structures

Table 7: Competitors in the offshore industry

Given that FORCE Technology only serves the Scandinavian market, I shall limit the competitive rivals to 3 established players outlined in table 7.
The factors influencing the competitive rivalry are;

- Size of competitors
- Growth of industry
- Product differentiation
- Exit barriers

As mentioned earlier in the previous chapter, the number of competitors in the offshore industry is likely to be low due to the nature of the industry with respect to know-how, capital intensity and regulatory implications. The offshore industry has been growing steadily since 2019, as illustrated in Figure 14 and Figure 15.

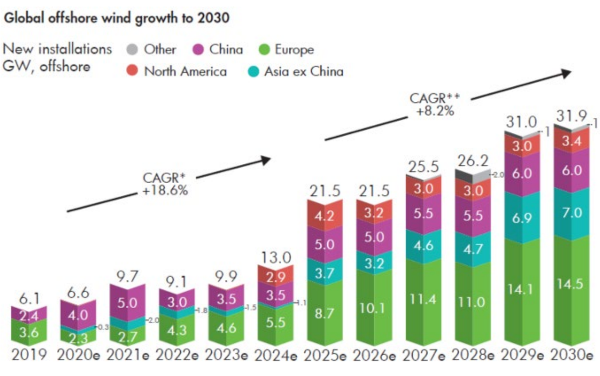

Figure 15: Growth projection for offshore wind (Lee and Zhao 2020)

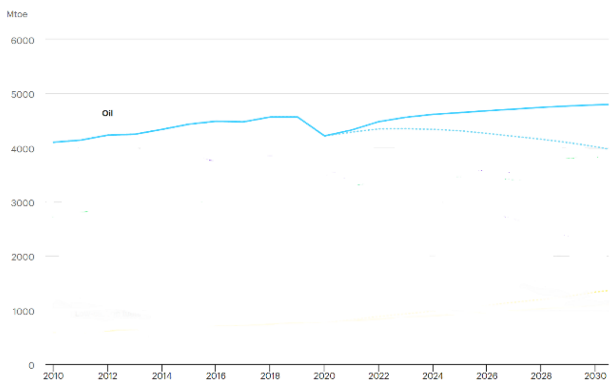

Figure 14: Growth Projection for oil demand (IEA 2020)

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[1] Data retrieved from SIEMENS Gamesa website https://www.siemensgamesa.com/sustainability/employees
[2] Data retrieved from SKANSKA website https://group.skanska.com/about-us/skanska-in-brief/
[3] Data retrieved from Aibel website https://aibel.com/company
[4] Data retrieved from FORCE Technology website https://forcetechnology.com/en/about-force-technology/economy

The wind industry has been growing since 2019, with an unexpected drop in installed capacity in 2022. This might be due to the global pandemic that has sent the global economy to a recession. Concerning the European offshore wind industry, the growth decreased in 2020 and is expected to gradually peak from 2021. The same applies to global demand for oil. The demand has been steadily growing since 2016 and then it takes a dip in 2020 because of the global pandemic that has curbed its demand worldwide. As the large economies start to show signs of recovery, demand for oil is expected to peak again. On the contrary, a scenario showing negative growth rate of oil demand has been also prognosed in the event of renewables starting to replace oil powered industries.

Nevertheless, it can be deduced that the offshore industry will continue to grow where FORCE Technology is able to cease the opportunity to improve its services in inspection of offshore installations.

As for product differentiation, the bolt tension estimator technology offers a unique way of conducting tests on bolts with a high level of accuracy. According to Aries Group, the largest Engineering, Inspection and Maintenance company in the middle east, a typical inspection procedure of bolts involve conventional ultrasonic testing (Aries 2020). Furthermore bolts are also inspected by testing them using Dye Penetrant Inspection (DPI) method or Magnetic Particle Inspection (MPI) method (Aries 2020). Since ultrasonic technology is used to detect possible deformation of bolts by passing sound waves through it and measuring the travel time, it can also be used to measure bolt tension levels.

Measuring bolt tension levels using ultra-sonic technology remains a common practice. The bolt tension estimator level is yet to demonstrate itself as a more efficient and accurate technology. During our conversation with FORCE Technology, they mentioned that they are working on developing an innovation powered by ultrasonic technology for inspecting bolted joints. The response I received after demonstrating the bolt tension estimator technology is positive. This is because the technology does not require calibration for different bolt heads, which was regarded as an added advantage together with the reported accuracy level. Therefore, the fact that testing bolt tension is done differently between the ultra-sonic technology and bolt tension estimator technology, the area is not expected to turn into a red ocean anytime soon. Additionally, the bolt tension estimator technology is patented, limiting the number of companies that are allowed to use it. So threats posed by competitive rivalry are expected to be low.

Exit barriers are formed when companies have the inability to exit a market due to declining profits that result from a saturated market. FORCE Technology are already active in the offshore inspection service market and are looking for ways to improve their service delivery with improved performance. However, conducting such services require FORCE Technology to enter into a service contract with a client operating in the offshore industry. Such contracts vary in length, and the stated contract terms oblige service companies to honor its service commitments regardless of the market forces. As discussed previously, the projected increase in the number of offshore installations in the coming years indicate that competing firms will not engage in price wars. These installations will increase the demand for inspection services despite the exit barriers that are posed by service contracts.

Porter's Five Forces is an important analysis to conduct when evaluating the attractiveness of the bolt tension estimator technology. As we have already learned,

- Threats posed by new entrants is low
- Threats posed by buyers is low
- Threats posed by suppliers is medium
- Threats posed by substitutes is low
- Threats posed by competitive rivalry is low

In view of NPD, Porter's Five Forces can be used in the screening stage where ideas that display a low level of market attractiveness are disregarded.

With regard to critical success factors for startups, Porter's Five Forces suggests that the timing of the bolt tension estimator technology is right. This is because the threat posed by buyers is low given that there are a limited number of alternative technologies that can measure the bolt tension level with the same level of precision. Since working in the offshore industry is governed by strict rules and regulation, a company like FORCE Technology will prioritize product performance over product costs. Moreover, due to low competitive rivalry, FORCE Technology is focused on distinguishing itself from competitors based on performance. And with the expected growth rate of the offshore industry, the timing for bolt tension estimator is likely to fit perfectly. In line with the coding results analyzed in the previous chapter under competing methods, this suggests that the bolt tension estimator has a low probability of being outcompeted because of limited alternatives that can match the same performance criteria set by it. Therefore, this makes its timing suitable that is puts in favor of a successful commercialization.

New Product Development

As detailed in Chapter 3, I have gone through the first step of the NPD process which is defining a new product strategy and development. I have also discussed some theories connected to how FORCE Technology could go about developing a new product based on the bolt tension estimator technology spanning from technology push and market pull to Porter's Five Forces. The next stage is Idea Generation which is outside the scope of my study but I will discuss the possible scenarios.

Once FORCE Technology defines its corporate strategy, the next step would be to generate ideas on how the new product would meet their objectives. This involves generating ideas, incubating and transforming them into successful ventures. It is not as easy as it sounds because not all ideas will lead to success. According to Figure 1 for every 100 ideas generated in the idea stage, only 25 will be commercialized and around 15 will be successful. These findings were first documented by Booz, Allen and Hamilton in 1982 and then replicated by Product Development & Management Association (PDMA) in 1995 and 2004 (Barczak, Griffin og Kahn 2009).

So how can ideas be generated? FORCE Technology can utilize its internal resources to generate ideas. This can be through employees, customers, network organizations, project collaborators i.e. DTU. This can be exercised by identifying challenges that are common in the offshore industry and welcoming suggestions on how to solve them. A study conducted by William Souder states that ideas that are sourced internally via R&D, management and suppliers demonstrated a lower success rate compared to the ones sourced externally via marketers and customers (Souder 1987). What this means is that FORCE Technololgy as a customer can provide user feedback in its development process while at the same time, ideas can be sourced externally via DTU who have an extensive knowledge base in different fields of technology.

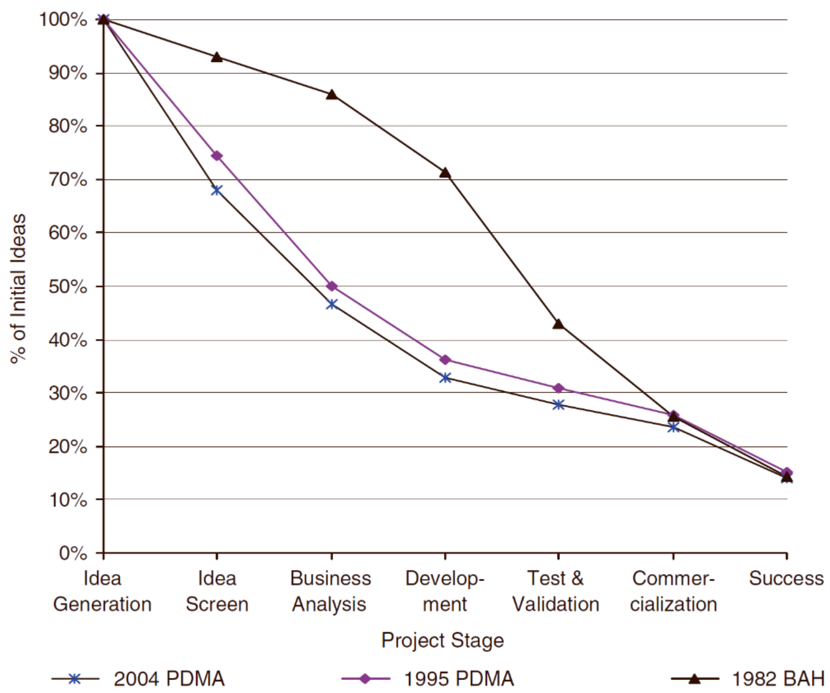

Figure 16: Idea generation and maturation (Barczak, Griffin og Kahn 2009)

As the product ideas proceed to the screening stage, an analysis is made to appraise its feasibility, where shortlisted ones will be qualified to proceed to the next stage. What I imagine happening at this stage is that FORCE Technology will take all their ideas and screen them using competitor analysis and calculating quantified value proposition and R&D costs just to name a few.

Competitor analysis can be performed using Porter's Five Forces analysis as I have done earlier in this chapter. Another analysis relevant to this is the blue ocean strategy where the technical specifications of the bolt tension estimator technology is compared head-to-head with a competing technology such as ultra-sonic.
As for quantified value proposition, a comparison of current costs is made based on the current solution versus a future solution based on the bolt tension estimator technology.

This process is said to be critical since it influences the success of the company. According to Booz, Allen & Hamilton, the costs associated with product development increase as one advances to the next stage (Booz, Allen and Hamilton 1982). Therefore, FORCE Technology must review the screened ideas with its management to agree on the criteria set for the preceding stage.

Moving forward, the shortlisted ideas from the previous stage will be analyzed further in the Business Analysis stage. This stage is somehow similar to the previous one except that a deeper analysis concerning financial performance is analyzed here to verify its attractiveness. This stage entails conducting financial analysis such as Net Present Value (NPV), Internal Rate of Return, Profitability Index (PI) etc.

The Net Present Value for these ideas can be determined by calculating the cost of developing the idea and discounting the expected future cash flow from each of them. This should provide a clear indication on whether the investment is financially viable before committing more resources in product development.

During the development phase, the business case prepared in the previous stage is transformed into a physical product within the set budget and specifications. As mentioned earlier in Chapter 3 concerning technology push versus market pull, the process in the development stage will shift from technology push towards market pull. This is because, technology push stage will involve the research team from DTU working in a closed environment focusing solely on the technology. As soon as FORCE Technology is involved in co-developing the technology, the process will shift the technological development towards meeting customer needs.

The process will start by developing prototypes that simulate the actual functionality when conducting inspection of bolted joints. This process is iterative and requires developing a series of prototypes where each is built upon learnings from previous experiments. For example, if during the first round the prototype malfunctions because the material used is sensitive to cold temperatures, the iteration in this case will be on using materials that are less sensitive to cold temperatures.

Once the development of a prototype is complete, it will be moved to the testing stage where its design features and actual performance are measured. FORCE Technology will have the opportunity to take the technology to an acutal environment where it can be put into use by field technicians. These technicians will measure their experience handling prototype as well as how well it performs the task that its set to do. The results from user feedback will be sent to the product manager who can then plan the iteration process which sends the prototype back to the development stage. Several rounds of iteration is expected to take place before the prototype is able to perform flawlessly. Therefore, once the prototype is able to meet the success criteria, it will then move to the commercialization stage. This is where FORCE Technology will plan how the final product is to be manufactured as well as logistical implications.

One of the major risks during this process is when a competitor introduces a radical innovation that can render the bolt tension estimator obsolete. Since this is something external and cannot be contained, the solution will need to be developed fast so that FORCE Technology has a product that can quickly diffuse in the market and rip profits from it.

So how does the development process look like? NPD process is very much a stage gate process where each stage needs to be completed and approved before advancing to the next one. The challenge with this approach is that screening of ideas and appraising them need to take place in the preliminary stages before getting to the development stage. Assuming a competitor introduces a radical innovation for monitoring bolt tension, the work that led to the business case becomes obsolete and will require FORCE Technology to go back to the drawing board and start ideating all over again.

The key is to shorten the development cycle so that the product can be at the hands of customers as fast as possible. An example of a development process is the lean startup methodology illustrated in Figure 17.

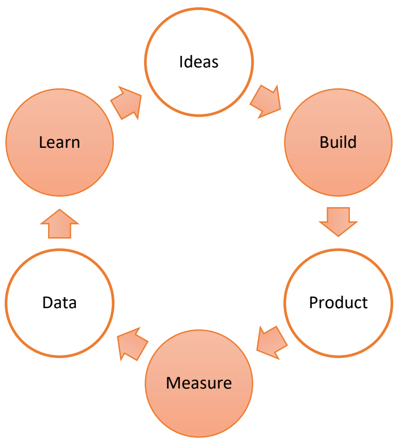

Figure 17: Build-Measure-Learn Feedback Loop (Ries 2011)

By using this model, the qualified ideas for development are shared and the ones that qualified will be transformed into products. The data from usablility tests will then be quantified and measured against the success criteria. The lessons learned from the experiment will be passed on to the ideas stage and then suggestions for improvements will be used to refine the prototype. And the cycle will be repeated until the results satisfy the set criteria.

Given the above, FORCE Technology can develop a hybrid system that consists of NPD process and the build-measure-learn feedback loop. Corporate strategies concerning new product development can be performed using the NPD process while the development and testing stages could be based on the lean startup methodology since it focuses on actual users of the prototype. This will shorten the feedback loop that will speed up the product development process.

In line with critical success factors for startup success, NPD process shows that the timing of the bolt tension estimator technology is right. This is due to the fact the screening stage entails the analysis of the competitive landscape of the offshore industry. As mentioned previously, the bolt tension estimator technology has limited competitors in the market which makes it unlikely for FORCE Technology to switch to a substitute. Moreover, the offshore industry is projected to grow in the coming years which indicates that there will be a demand for new technologies to support this growth.

NPD process is also likely to give rise to good product ideas provided FORCE Technology seeks them externally via users, DTU and competitors. This is because ideas that are aligned with market insights and trends stand a better chance of being transformed into successful products.

Finally, the NPD process will facilitate the formation of a competent team derived from FORCE Technology and DTU in the product development stage. Market insights and trends can be gained through FORCE Technology's experience in the offshore industry while product development and testing can be conducted in collaboration with offshore workers.

Chapter 7 – Conclusion

This paper aims to answer the research question ***”In view of new product development theory, what are the key factors for a startup to consider in order to commercialize the vibration-based bolt tension estimator technology?”***

Therefore my answer deems the following factors as critical.

Timing

With timing regarded as the most critical factor for startup success, my findings suggest that through the NPD process, idea screening and business analysis reveal that the competitive landscape is favorable for the bolt tension estimator technology. By conducting Porter’s Five Forces analysis, the results show that there are limited alternatives in the market while the projected growth of the offshore industry is expected to increase in the next years. This makes the timing right since FORCE Technology is interested in investing in new technologies to help sustain this growth.

The NPD process through new product strategy and development facilitates open innovation by engaging with the external environment to find new product ideas. What I found out here is that the timing of the bolt tension estimator technology is right because by approaching FORCE Technology with a proposal to consider licensing or purchasing the patent, they have reacted positively to it.

Team

With the project team being the 2nd most important factor for success, it will consist of researchers at DTU who have the technical competencies for developing the technology and FORCE Technology who have market experience in the offshore industry. Moreover, they can provide test facilities for product development and potential users of the technology. Through the NPD process, both parties can engage in a collaborative agreement at the idea stage to form of a competent team that can develop the bolt tension estimator technology. In view of technology push and market pull, the collaboration will result in the technology development shifting towards market pull since market insights are incorporated.

Ideas

Ideas are also considered as critical ranked at 3rd place. Through the NPD process, good product ideas can emerge if FORCE Technology seeks them externally via users, DTU and competitors. This is because ideas that are aligned with market insights and trends stand a better chance of being transformed into successful products. By leveraging on Open Innovation approach, FORCE Technology can generate rich ideas that can potentially improve their inspection of bolted joints in subsea structures.

Last but not least, DTU and FORCE Technology can leverage on user feedback received from product test and use them to generate new ideas on how to improve the product to fit users' needs.

Reflections

I believe the case study approach has enabled me to answer my research question because of conducting an in-depth study of how a given company can potentially benefit from using the bolt tension estimator technology. Furthermore, by applying judgemental sampling, I was able to select Tivoli, DTU Campus Service, FORCE Technology, KONE and Energinet for screening in order to determine which of these companies will find the technology applicable. The screening process took place when conducting semi-structured interviews, which allowed for an in-depth understanding the needs of the companies being studied.

During data gathering and analysis, I used grounded theory to compare data sets from my interviews and generated themes which I grouped into categories which then formed NPD as my theoretical basis. While conducting interviews, I did not manage to collect a lot of data because the interviewees preferred not to be recorded via audio. What I did instead was to note down the most important points from our conversations. Moreover, I held short phone interviews with managers from KONE and Energinet because of their busy schedule. Fortunate enough, they were able to share their thoughts about the technology and gave recommendations.

NPD process has enabled me to evaluate whether the bolt tension estimator technology has all the ingredients for success. I applied open innovation from the first stage of the NPD process where corporate goals in relation to new products are defined and all the way to product development and testing. The NPD process covered the first stage only and the rest of the stages were discussed with the assumption FORCE Technology licensed the technology. The actual activities in these stages can be defined once FORCE Technology and DTU begin to work together. Porter's Five Forces has also been helpful to me when determining the market attractiveness for the technology which is conducted in the idea and business analysis stage in the NPD process. Technology Push and Market Pull provided me with the essential understanding of moving the development process from isolation to an area where product testing is done in close collaboration with potential users. This process can be incorporated into the NPD process from the idea stage to the commercialization stage.

Case studies require a large volume of data for analysis, and since this has been a constraint in this paper. Therefore, the results are not to be generalized since it is specific to this particular case. Moreover, it is also important to point out that KONE and Energinet are keen on the bolt tension estimator technology being used to provide quality assurance documentation for the installation of elevators and high voltage power lines.

My expectations for writing this thesis were to identify a company that can benefit from the bolt tension estimator technology and establish a collaboration agreement. As per the end of my thesis period, I have managed to identify FORCE Technology as a potential candidate to commercialize the technology, but is yet to enter a formal agreement with DTU.

Recommendation and further work

In order to gain a better understanding of the scope of commercialization potential of the bolt tension estimator technology, future studies could consider diving deeper into managing intellectual property. This is because some companies could find themselves patenting novel technologies and then shelving them for later use. Moreover, business model as part of managing IP could also be considered.

As for ownership model, future studies could address the benefits of licensing versus purchasing the IP and vice versa. Holding further talks with FORCE Technology would shed some light on the type of ownership model they prefer to move forward with. Lastly, Funding options is also an area that practitioners could consider analyzing.

Research Contribution

The bolt tension estimator technology is an invention from DTU that was patented in January 2020. My research has contributed with knowledge on how this invention can be commercialized using key factors for startup success.

Moreover, my results confirm that New Product Development remains a reliable theory in developing new products and services that are in line with market needs.

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Appendix

Appendix 1A – Jobs-To-Be-Done Theory

This theory is coined by Clayton M. Christensen, a professor at Harvard Business School. He states that "When we buy a product, we essentially 'hire' something to get a job done. If the job is done well, when we are confronted with the same job, we hire that same product again. And if the product does a crummy job, we 'fire' it and look around for something else we might hire to solve the problem."

Since we are working towards commercializing the vibration-based bolt tension estimator technology, this theory will serve as a guide when analyzing what potential customers are trying to get solved as well as the aspects that influence their buying decisions. Additionally, applying jobs-to-be-done theory will set me on a predictable path towards innovation and effective marketing.

According to Tony Ulwick, jobs-to-be-done can be characterized using these core principles,

People buy products and services to get a job done.
In our everyday lives, people are constantly faced with challenges when conducting activities and turn to products or services that can help them overcome this.
Putting this into context, facility managers and service technicians are often inspecting their buildings, machinery, or infrastructure whereby checking of bolt tension is an important task. Since these tasks are already performed manually using visual and audible senses, hiring a product or service to do the job might prove to be more efficient and accurate.

Jobs are functional with emotional and social components.
Normally when someone is conducting a task, he/she wants to feel in a particular way when using a product or service that they have hired. This can be expressed through the ease at which the hired product or service helps them overcome a challenge or it could be how they are perceived by their friends and acquaintances. In my situation, service technicians are tasked with inspection of bolts that require a high level of vigilance. Performing this task manually can be monotonous and susceptible to human error. Therefore, introducing vibration-based bolt tension estimator technology can improve the overall output of inspection tasks thus likely to make one feel that he/she is good at their job.

Jobs-to-be-done is stable over time.
For decades and even centuries, humans have been trying to solve the same functional jobs. The only different thing is the type of product and/or service that is used to get a particular job done. For decades if not centuries, service technicians have always had the duty to inspect bolt tension in either buildings, machinery, or infrastructure. This task has always been conducted manually by visually inspecting bolted joints and listening closely sound frequencies that indicate the tension level of bolts. This method continues to be applied today in some industries i.e. railway which opens up a window of opportunity to develop a solution that can perform this more efficiently.

A job-to-be-done is solution agnostic.
Functional jobs should be approached in a manner in which a devised solution is independent of them. This is to say that there is not a single way of performing a functional job. This emphasizes understanding the job that a customer is trying to get done. Once this is clear, possible solutions can be drafted focusing on how to get the job done with relative ease. In my case, I shall conduct exploratory interviews with potential customers to understand the job they are trying to get done when conducting a routine inspection on bolted joints. The acquired knowledge from the interviews will enable me to define different parameters of which the new solution should be able to address concerning the functional job.

Success comes from making the job the unit of analysis.
By mapping out the desired outcome of potential customers, I shall be able to quantify the level of satisfaction experienced. In case the level of satisfaction is not good enough, it should be possible to pin down the metrics that can be tweaked. Putting this into context, I shall study what my potential customers' desired outcomes are concerning the inspection of bolted joints. Desired outcomes can be expressed as efficiency, cost reduction, accuracy, flexibility, etc. Once the major metrics are mapped out, the solution will be designed to meet these outcomes.

A deep understanding of the customer's job makes marketing more effective and innovation far more predictable.
Company employees need to be in sync when defining a potential customer's need. This makes it possible to work towards developing a solution that meets the customer's desired outcome. Failure to do so can lead to false expectations, wasted resources, loss of potential revenues, etc. On the other hand, if a company can agree on all dimensions of customer's desired outcomes this will put them in a position to,

- Sell existing products and services.
- Improve existing products and services.
- Develop new products and services.

By developing this understanding, I can approach marketing in a way that is relatable to service technicians that have the same desire. As for predictable innovation, customer insight will always help me to stay ahead regarding the areas that need to be improved.

People want products and services that will help them to get a job done better and/or cheaply.
Globalization has enabled us to gain access to a variety of products and services, some available locally and others having to be sourced from outside. This in itself has made consumers less loyal to products and services thus making them select what meets their needs best. As soon as a product or service does not perform the job satisfactorily, they quickly seek an alternative solution that can perform the underlying job better.

By understanding the key metrics that drive the customer's desired expectation, I shall focus on building a product that can meet these expectations. This is in most cases the speed at which a job is performed and the cost. Time is money and if my solution can offset the number of hours consumed by service technicians, I shall be better positioned to argue for the potential saving that can be realized by adopting the vibration-based bolt tension estimator technology.

People seek out products and services that enable them to get the entire job done on a single product platform.

When customers purchase a product, they do not want to be faced with the task of seeking 3rd party products or services to help get their entire job done. They instead wish to complete their entire job on a single product platform. In my case, the task of inspecting bolted joints can be performed by adopting the vibration-based bolt tension estimator technology. Our potential customers might also seek additional services such as cloud services to store data, automated filing, and reporting, etc.

Innovation becomes predictable when 'needs' are defined as the metrics customers use to measure success when getting the job done.

The customer's desired outcomes should be maintained as a constant when evaluating competing ideas against each other since these outcomes are stable over time. By doing this, innovation becomes predictable since the success criteria are already pre-defined. This is because,

- The underserved and overserved needs can be quantified.
- The underserved needs of specific customer segments are identified.
- Product ideas can be tested against a set of key metrics before developing a product.

By conducting interviews with potential customers, I shall be better positioned to identify the industries with overserved and underserved needs and thus use this information to propose solutions to customers with unmet needs before developing a product.

Appendix 1B – Diffusion of Innovation Theory

Another theory that is complimentary to jobs-to-be-done theory is the diffusion of innovation theory developed by Everett Rogers. The theory states that for an innovation to be adopted by society, it must undergo a communication process through different channels over some time (Rogers 1983). The innovation can be expressed in the form of a product or an idea, while communication takes place when information is exchanged between 2 or more individuals. (Rogers 1983).

This process is important because I need to segment the target market to establish my beachhead strategy. Since I am going to develop a series of prototypes before committing more resources to develop a finished product, my beachhead market should consist of customers that are willing to try out unproven products with a high degree of errors. Once our product matures, I can then expand its user base to validate our value proposition and iterate accordingly until I achieve product-market fit.
According to the innovation adoption life cycle in Figure 18, communication of new ideas or product innovation usually go through 5 stages.
Innovators: These are individuals that are fascinated and eager to try out new technologies. They normally have a high-risk appetite which drives them to want to be the first to try out new technologies. These individuals make up 2.5% of a given social system and have financial resources to undertake such endeavors.

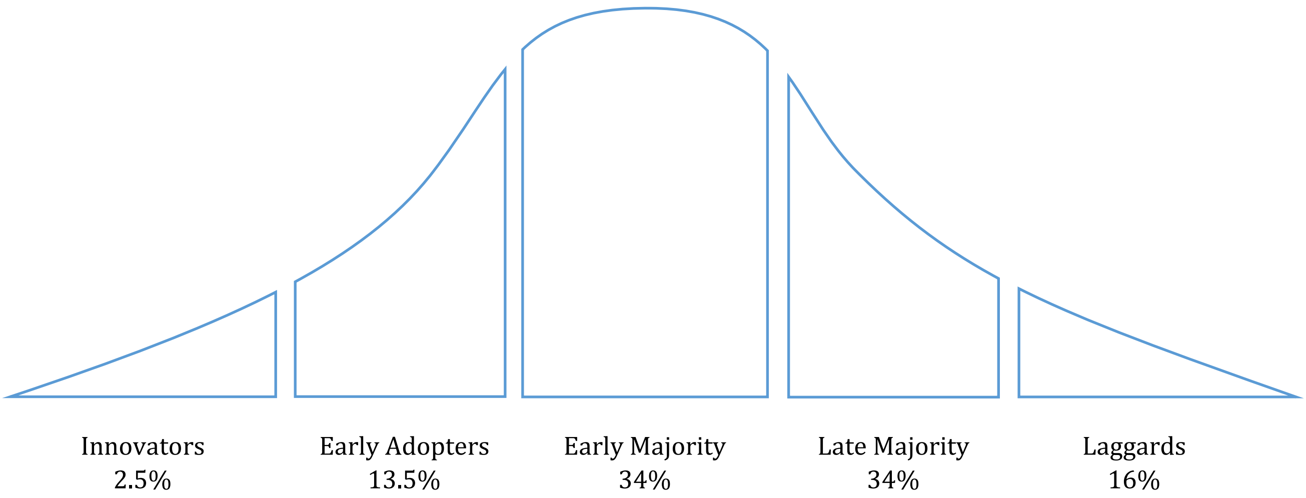


Figure 18: Own depiction of Innovation adoption life cycle (Rogers 1983)

Early adopters: These individuals are opinion leaders and consist of 13.5% of a given social system. Potential adopters in a social system normally seek opinions and information from early adopters before making any decisions. Early adopters serve as agents of change since they try out innovations and then pass their opinions to their social networks.

Early majority: These are the individuals that adopt an innovation or new ideas just before the mainstream market. They make up 34% of a social system and are not opinion leaders. They tend to be pragmatic and rely on opinions from early adopters.
Late majority: These individuals are skeptical by nature and tend to adopt new ideas and product innovation once people form their social system have adopted them and start to persuade them to do so as well. This is because the late majority are resource-constrained people that want to adopt a technology that is proven and has few errors. They make up 34% of a given social system.
Laggards: These are conservative individuals that consist of 16% of a social system and are normally the last ones to adopt an innovation. They are generally suspicious of new technologies given their limited resources. Therefore, laggards adopt an innovation once they are certain that it is worthwhile.

Given my task to commercialize the vibration-based bolt tension estimator technology, I shall start by identifying a beachhead market. Since the technology is still in its early stages, a series of product development shall take place until we satisfy performance and design requirements. This makes the innovators segment our primary target since they are generally interested in new and promising technologies and are likely to accommodate product flaws and shortcomings. In a Business-to-Business (B2B) context, companies that invest heavily in innovation will be suitable for us to approach with our technology.

Appendix 1C – A-U Model

The product development process is visualized using a model developed by William Abernathy and James Utterback known as the Abernathy and Utterback model (A–U Model) see Figure 19. The model shows that product innovation is highest during the fluid stage whereas in the transitional and specific phases there will be a decrease in the rate of innovation.

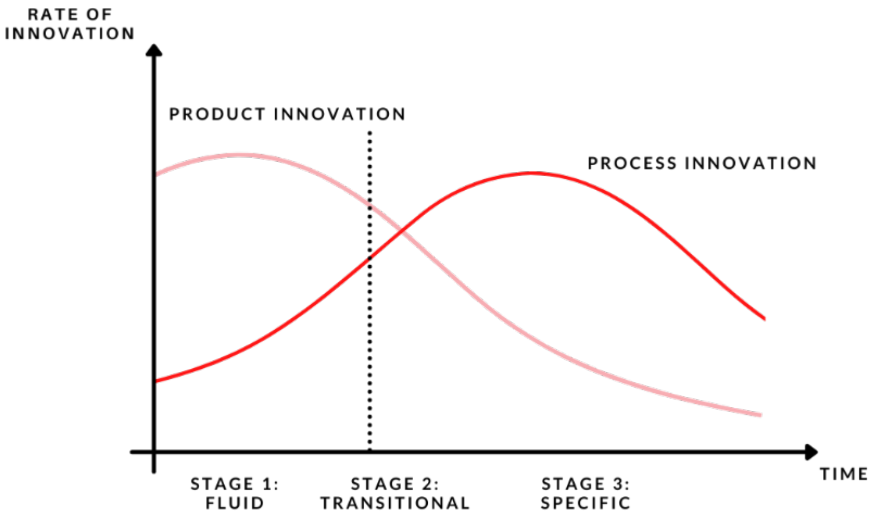


Figure 19: Own depiction of Abernathy and Utterback Model (Utterback og Abernathy 1975)

During stage 1, the product undergoes a vigorous process of trial and error because the level of uncertainty is very high concerning the market and technology. The resource consumption at this stage is very high due to the extensive use of high-skilled labor. Furthermore, suppliers are not likely to offer competitive pricing of components and parts because of small-scale production and high product specialization.

The competitive landscape is known to be limited since competing technologies look for ways to differentiate their core offerings. This makes existing technologies and radical technologies the likely threats at this stage.

Stage 2 concerns the transition of the product which transpires once the customers' needs are learned and adhered to. Once producers get to learn about the technology and the associated customer needs, a level of product standardization will be established. And as diffusion of the technology continues, its acceptance starts to increase which indicates that the transition phase is underway.
As its development continues, process innovation and product innovation will eventually converge and form a dominant design of the product. A dominant design usually has its key components and underlying attributes as constants across product models which is adopted as an industry standard.

As one enters stage 3, the focus shifts from differentiation to cost and performance benefits because a dominant design has already been established. Producers will then move on to segment their markets and develop products that can serve them. Moreover, production costs will drop since the dominant design paves way for mass customization and commoditization.

When assessing both the innovation adoption life cycle and the A–U model, it can be deduced that the former helps to form a framework that can identify and map out a beachhead market. Putting this into context, innovators are suitable candidates for us to approach to develop our product further while it is being put into use. The A–U model gives a glimpse of how the product development process is likely to take place whereby the core technology undergoes a series of stages before a universal concept of a given product is established. What this means for our technology is that, once we identify a potential market and a customer group consisting of innovators, we can start developing a series of prototypes through a process of trial and error. Therefore, the aforementioned models are geared towards introducing and spreading the vibration-based bolt tension estimator technology through established channels and thus serve as a guide for testing the diffusion of innovation theory.

One theory that I do not find suitable for my paper is disruption innovation theory which is coined by the late Clayton M. Christensen. The theory states that while incumbent companies focus on serving their profitable customers with improved products and services, smaller companies (new entrants) will react by only serving customer segments that are overlooked thus creating a new market (Campbellsville University 2017). Since serving such a newly established market doesn’t yield high returns, incumbent businesses tend to ignore them and focus on the mainstream and profitable customers (Campbellsville University 2017). As time passes by, the new entrant will then move upstream and start delivering high-performance products and services to mainstream customer segments while continuing to serve the lower segment they started with (Campbellsville University 2017). Disruption will then take place once the mainstream customers start adopting the entrant’s offering in large volumes (Campbellsville University 2017).

The reason for not applying this theory is the fact that we have a radical technology that can potentially revolutionize how service technicians inspect bolted joints on their facilities. Moreover, our focus will be to approach an industry that sees potential in utilizing our technology for conducting inspections efficiently and cheaply. Since disruptive innovation tends to democratize existing products and services that are exclusively accessible to a wealthy customer segment, this makes it unfit to serve as a guideline for receiving answers to our research question. However, this is not to completely dismiss the theory. I imagine the theory being applicable in a situation where our technology is productized to fit a particular industry, and then new entrants approach underserved customer segments and after some time move upstream to serve mainstream customers.

Appendix 1D – Decision-Making Unit (DMU)

Identifying people that are involved in deciding which products and services to acquire for end-users is essential to conduct business successfully (Aulet 2013). Newly proposed products can either be approved or rejected which results from opinions shared in a DMU (Aulet 2013). A decision-making unit consists of the following characters,

Champion: This is the person that is in favor of the product or service being proposed and is not necessarily an end-user.

End-User: This is the person the product is targeted for. Therefore its intended use has to be appealing to him/her which can result in the person taking up the champion role.

Primary Economic Buyer: This is the person that controls the budget spending and is the primary decision-maker. Depending on the organization's setup, this person can be the end-user and might take up the champion role.

Primary and secondary influencers: These are people with expert knowledge in a subject area and their opinions are highly valued. Some primary influencers can have veto power if they believe the proposed product or service is not worth spending money and other resources on. Secondary influencers do not necessarily have veto power but their opinions play a major part in decision-making.

A person with veto power: These are people that have the power to block a purchase for whatever reason. They normally occupy a top seat in a hierarchy where they outrank champions or end-users.

Purchasing department: The department's concern is to handle logistical matters of purchases. Their area is very sensitive and can result in blocking a purchase decision if the costs go against their cost-cutting measures.
When approaching potential customers, we shall ensure that the person we request for an interview is an end-user and if possible a primary influencer. This will be done by seeking contact information from company websites and/or LinkedIn.

Appendix 1E – Porter's Generic Strategies

Companies need to define their positioning within their industry to be able to compete. This helps indicate whether a company's profitability is above or below the industry average.

	Lower cost	Differentiation
Broad Target	Cost Leadership	Differentiation
Narrow Target	Cost Focus	Differentiation Focus

Figure 20: Own depiction of 3 generic strategies (M. E. Porter 1985)

As illustrated in Figure 20 companies can position themselves by striving to be the leader of low-cost products in their industry. This is known as a cost leadership strategy. This can be realized through economies of scale achieved by mass production, exclusive access to raw materials, propriety technology, etc.

In the case of differentiation strategy, a company will choose to differentiate its product or service offering by including key features that are valued by customers. The company positions itself as being unique whereby the extra costs incurred are levied to customers at a premium rate. Competitive strategy can take a narrow approach where a company can focus its efforts on serving a customer segment with very specific needs to the exclusion of others. This can focus on cost whereby a company chooses to provide low-cost products that are very specific to a particular customer group. Or, a company can choose to focus on differentiation whereby products or services are created to meet the specific needs of customers.

When analyzing the adoption of our technology by potential industry players, we shall deploy a competitive strategy that best suits our situation.

Generic Strategy	Commonly Required Skills & Resources	Common Organizational Requirements
Overall Cost Leadership	• Sustained capital investment and access to capital. • Process Engineering skills. • Intense supervision of labor. • Products designed for ease in manufacture. • Low-cost distribution system.	• Tight cost control. • Frequent, detailed control reports. • Structured organization and responsibilities. • Incentives based on meeting strict quantitative targets.
Differentiation	• Strong marketing abilities. • Product engineering. • Creative flair. • Strong capability in basic research. • Corporate reputation for quality or technological leadership. • A long tradition in the industry or unique combination of skills drawn from other businesses. • Strong cooperation from channels.	• Strong coordination among functions in R&D, product development, and marketing. • Subjective measurement and incentives instead of quantitative measures. • Amenities to attract highly skilled labor, scientists, or creative people.
Focus	• Combination of the above policies directed at the particular strategic target.	• Combination of the above policies directed at the particular strategic target.

Table 8: Own depiction of requirements of generic strategies (M. E. Porter 1980)

Appendix 2A – Company list

1. Tivoli A/S
2. SKS Kraner A/S
3. DTU Campus Service
4. KONE A/S
5. Banedanmark
6. BMS A/S
7. Metro Service A/S
8. FORCE Technology
9. Energinet
10. KIWA Inspecta A/S

Appendix 2B – Meeting Request Template

Til rette vedkommende

Mit hold og jeg er studerende på DTU og arbejder med en boltspændingsteknologi.

DTU Mekanik har opfundet en teknologi der kan aflæse boltspænding i forskellige anlæg f.x. broer, jernbaner m.m.

Teknologien kan integreres med en robot eller et håndholdt værktøj som kan bruges til at generere data om anlægenes boltspænding, hvorefter jeres hold kan tilrettelægge eftersyn og evt. reparationsarbejde.

Vi anser teknologien som et hjælpemiddel, der potentielt kan nedbringe jeres vedligeholdelsesomkostninger og samtidig sikre nøjagtig boltspænding.

Hvis I vurderer at vores teknologi kan være relevant ift. jeres arbejde vil vi meget gerne forberede en målrettet præsentation.

Lad mig vide om det kunne have jeres interesse.

Jeg ser frem til at høre fra jer.

De bedste hilsner

Peter Githii

Appendix 2C – Sample Questionnaire

1. How would you describe your inspection procedure?
2. What challenges do you face when performing inspection on elevators?
3. How do you inspect bolt tension on the overall infrastructure?
4. How often do you experience downtime due to errors or failure of the elevator system?
5. Which types of equipment do you use when performing inspection? What is your experience using these?
6. If we develop an inspection device that meets your need how would you like to own it? (buying, leasing etc.)
7. How many workers conduct inspection of elevators and how often is this done?
8. What is the average hourly rate for people working with elevators including pension?
9. What is the most expensive aspect when conducting inspection of elevators?

Appendix 3A – Interview with Tivoli

1. **How would you describe your inspection procedure?**

Tivoli has comprehensive and smaller routined maintenance. Tivoli uses Mobaro software program to conduct maintenance tasks

2. **What challenges do you face when performing inspection on elevators?**

A big challenge is the available time to conduct maintenance tasks which is runs from 6 am to 11 am. Tivoli also closes only in January and February each year

3. **How do you inspect bolt tension on the overall infrastructure?**

Bolt inspection is not a task that takes a lot of their time. Most inspection is done visually and audibly and this has produced great results over the years. Force Technology is usually hired by the police to conduct certified inspection on the rides. They have their mechanical team that go on each ride and inspect the structures.

4. **How often do you experience downtime due to errors or failure of the system?**

The average operation time is 97% per year. There are some rides that operate 100% and others that run 90%. Our efforts are concentrated on the rides that operate 90% without failure.

5. **Which types of equipment do you use when performing inspection? What is your experience using these?**

Tivoli uses normal tools to fix their rides e.g. torque wrench.
In cases where they have to use an advanced machine to conduct maintenance, they will prefer to hire an external company to do it as long as it is a task performed less than 10 times per year.

6. **According to Tivoli's CSR report 2019 there is an outlined strategy to reduce work-related accidents. What is the nature of these accidents?**

The accidents that workers encounter at work is skidding because of slippery surfaces or fall due to old ladders with loose steps.

7. **How many workers are involved in conducting inspection of the amisement park and how often is this done?**

There are 20 workers working with maintenance where 14 are mechanical workers and 6 are eletricians.

8. **What is the average hourly rate for people working with elevators including pension?**

The average salary is 205kr./hour with a 55% extra cost on shoes, sick leave, equipment.

9. **What is the most expensive aspect when conducting inspection of elevators?**

The most expensive aspect of our operations is labor costs?

Appendix 3B – Interview with DTU Campus Service

1. **How would you describe your inspection procedure?**

I normally plug in my work computer to the elevator and then it displays technical information that I need to know about in real time.

2. **What challenges do you face when performing inspection on elevators?**

People tend to push the elevator doors with force such that the door alignment is affected thus resulting in faulty operation. Other than this, I spend time on the switch board where I ensure everything is working properly and remedying registered errors.

We own different elevator brands which means every time a new technology is rolled out by a specific manufacturer, I must keep myself up to date by enrolling for professional courses.

3. **How do you inspect bolt tension on the overall infrastructure?**

I normally use a torque wrench to retighten bolts. This is not done very often because the volume of traffic at the campus is low. I normally inspect bolts every 5 years where we retighten them. A good place to target is hospitals and train stations where elevators are constantly running.

4. **How often do you experience downtime due to errors or failure of the elevator system?**

We experience this hundreds of times per year. This is because during semester start, students tend to move around with large and heavy bags that knock doors. Other times can be that the doors are pushed when one is trying to stop it from closing.

5. **Which types of equipment do you use when performing inspection? What is your experience using these?**

I use a torque wrench and a computer.

6. **If we develop an inspection device that meets your need how would you like to own it? (buying, leasing etc.)**

We would probably purchase it because government organizations are not allowed to lease equipment at the moment. Alternatively external companies can be hired to provide services.

7. **How many workers conduct inspection of elevators and how often is this done?**

I inspect all the elevators on my own. During peak times an external company is hired to inspect a given number of elevators.

8. **What is the average hourly rate for people working with elevators including pension?**

40,000 kr. Per month

9. What is the most expensive aspect when conducting inspection of elevators?

Changing mechanical and electrical parts.

Appendix 2C – Interview with FORCE Technology

1. **Is there anything specific you would you like to see the technology perform?**

Additional tests have to be performed in different environments such as windy, submerged etc. Otherwise the test results are very impressive.

2. **Which devices do you normally use to conduct inspection for subsea structures?**

There isn't much competing products for measuring bolts on sub-sea structures.
We have developed a product for conducting such measurements but has its challenges with calibration and accuracy levels.
+-5% accuracy level of the bolt tension estimator technology is a very impressive performance.

3. **Is there anything specific you like about the technology?**

One does not need to know the type of bolt and calibration which is very positive
The technology is a direct competitor to an ultra-sonic technology they are already working on.

4. **What are the next steps moving forward?**

We shall speak with our management about the technology and a possible collaboration with DTU concerning co-development of it. Apart from that, we are also interested to visit your facility for a tech demonstration.

5. **What do you use your labs for?**

We use it to provide our customers with prototyping facilities and our own research activities. In a situation where we collaborate with DTU, we can help in co-developing the prototype in our facility. We usually create our own products at our lab. For instance, the current device we use for inspection of subsea structures is developed at our lab.

6. **Where else do see an application potential of the bolt tension estimator technology?**

We have bridge inspection division which I can imagine showing some interest.

7. **How does FORCE Technology generate revenue from offshore inspection?**

We sell our knowledge and know-how of servicing offshore installations to energy companies. These are usually service contracts we are awarded for a period of time.

Appendix 2D – Interview with KONE A/S (Telephone conversation)

Hej A***

Tak for en behagelig samtale.

Som nævnt er vi 2 studerende på DTU der arbejder med en boltspændingsteknologi.

DTU Mekanik har opfundet denne teknologi som kan aflæse boltspænding i forskellige anlæg eller maskiner f.x. elevatorer.

Teknologien kan integreres med en robot eller et håndholdt værktøj som kan bruges til at generere data om anlægenes boltspænding, hvorefter jeres hold kan tilrettelægge eftersyn og evt. reparationsarbejde.

Vi anser teknologien som et hjælpemiddel, der potentielt kan nedbringe jeres vedligeholdelsesomkostninger og samtidig muliggøre forbyggende vedligehold med øjet nøjagtighed.

Hvis I vurderer at vores teknologi kan være relevant ift. jeres arbejde vil vi meget gerne forberede en kort præsentation om det.

Lad mig vide om det kunne have jeres interesse.

Jeg ser frem til at høre fra dig.

De bedste hilsner

Peter Githii

Answer

KONE has read about your exciting project with great interest but can unfortunate not see a fit for it in our product range. I can personally advise you to consider fitting your technology in an inspection robot that can perform quality checks inside elevator shafts for newly installed elevators. I believe that the quality assurance documentation for this will be valuable for building owners.

Appendix 2E – Interview with Energinet (Email correspondence)

Hej S****

Tak for en behagelig samtale i fredags.

Som nævnt er vi 2 studerende på DTU der arbejder med en boltspændingsteknologi.

DTU Mekanik har opfundet denne teknologi som kan aflæse boltspænding i forskellige anlæg eller maskiner f.x. højspændingsmaster, gasledninger m.m.

Teknologien kan integreres med en robot eller et håndholdt værktøj som kan bruges til at generere data om anlægenes (elmaster eller gasledninger) boltspænding, hvorefter dit hold kan tilrettelægge eftersyn.

Vi anser teknologien som et hjælpemiddel, der potentielt kan nedbringe jeres vedligeholdelsesomkostninger og samtidig muliggøre forbyggende vedligehold med øjet nøjagtighed.

Hvis I vurderer at vores teknologi kan være relevant ift. jeres arbejde vil vi meget gerne forberede en kort præsentation om det.

Lad mig vide om det kunne have jeres interesse.

Jeg ser frem til at høre fra dig.

De bedste hilsner

Peter Githii

Answer

Hej Peter,
Jeg har haft materialet forbi mine kollegaer.

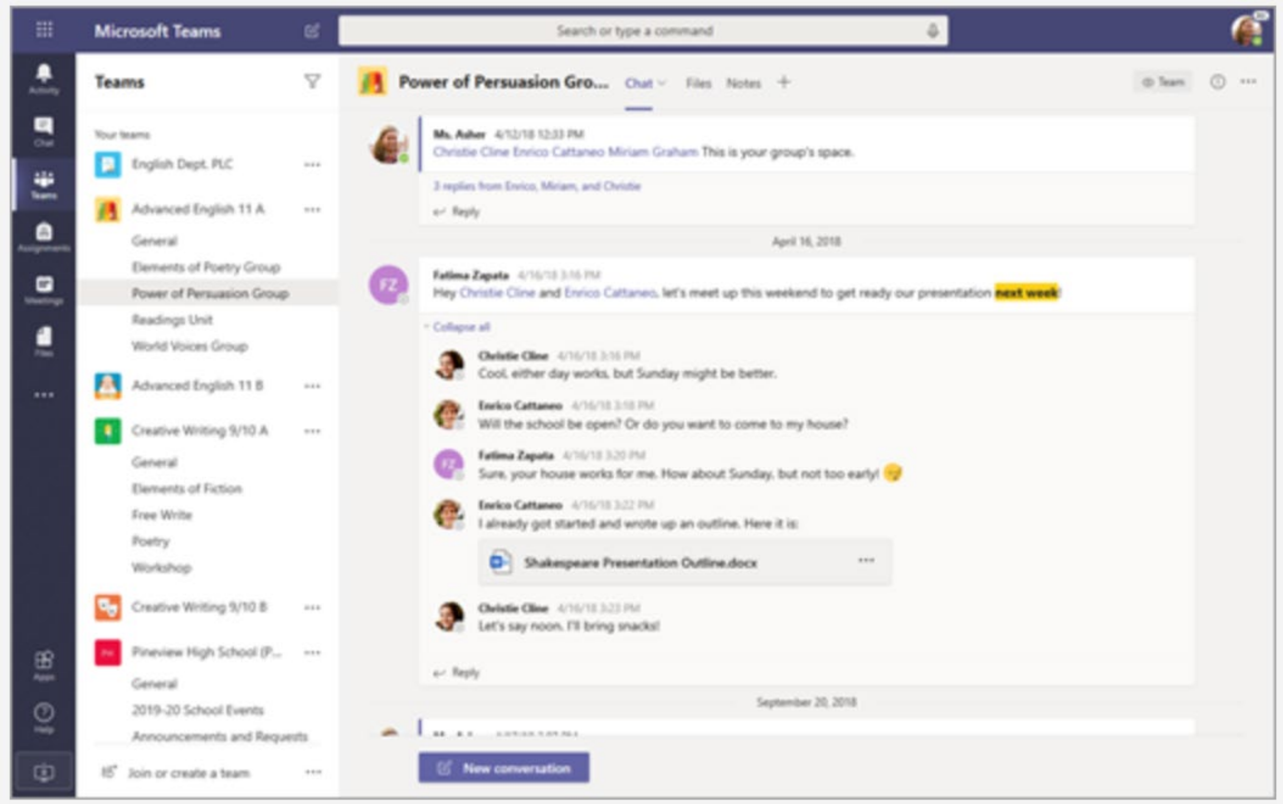
Vi ser ikke umiddelbart anvendelse af teknologien direkte i vores hverdag, men mere indirekte via de indkøb vi foretager i vores projekter.

Derfor vil jeg anbefale at I tager fat i enten entreprenører eller leverandører, der har behov for at levere dokumentation for kvalitetssikring i forbindelse med deres leverancer til kunder som Energinet.

Held og lykke med jeres teknologi, som helt sikkert kan finde anvendelse som en god dokumentation af foretaget kvalitetssikring.

Venlig hilsen
S****

Appendix 3A – MS Teams Screenshot



Figur 21: Screenshot of MS Teams for video conferencing (Microsoft 2021)