Internet of Things-enabled Servitization for Small to Medium Sized Enterprises

INNOVATION REPORT

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Abstract

Servitization has been a recognized business phenomenon since the late 1980s to innovate a business's capabilities and processes to create value for their customer through service. Recent technological advances, particularly in the capabilities being developed by the Internet of Things (IoT) could be an enabler for a servitzation transition at an organization. Servitization, enabled by the Internet of Things (IoT), has not been considered in the context of Small to Medium Sized Enterprises (SMEs). Due to the traits of SMEs, the potential opportunities from effectively servitizing their business models and the accessibility and affordability of IoT sensors, equipment and tools, there is a gap to be explored.

This research provides an understanding of the many challenges SMEs face to remain competitive. Additionally, the research develops a framework that can help to overcome some of these challenges through the utilization of a Servitization business model and IoT technology and capability. The investigation and development of IoT-enabled Servitization for SMEs could potentially lead to new knowledge and innovation.

Initially, main traits of SMEs were identified and then aspects of IoT and servitization were ascertained to find those that best align with the SME unique traits. From this understanding, a framework was developed that will allow Small to Medium sized Enterprises to utilise the technology and capabilities from the IoT in order to develop servitization within their business. This framework was then further developed through a longitudinal case study with an SME and validated by a range of industry stakeholders.

The outcome resulted in a conceptual framework, based on academic literature, evolved in a real-world case study, and validated by professionals and stakeholders. This validation was conducted through the dissemination of the material on a professional program MSc module, presentation of the research at international conferences, and an event held with regional SMEs to gain insight on the final version of the framework. The framework can be used by SMEs or those consulting SMEs to help them develop strategy that creates value added services in their business that are enabled by the IoT.

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Glossary of Terms

CAD	Computer Aided Design, a type of software
CFW	Conceptual Framework, sometimes used to describe the innovative framework created
IoT	Internet of Things, a core theme to the research
MSc	Abbreviation for Masters of Science
PLM	Product Lifecycle Management, a type of software
PTC	The sponsor company of the research, formally Parametric Technology Corporation
SLM	Service Lifecycle Management, a type of software
SME	Small to Medium-sized Enterprise, a core theme to the research
WMG	The university department where the Engineering Doctorate was based, formally Warwick Manufacturing Group

Chapter 1: Introduction

1.1 Research Question, Aim and Objectives of the Engineering Doctorate

This chapter serves to introduce the statement of the problem, the main research question, and the research aim and objectives. Additionally, it will present the context of this aim, as well as introducing the structure of the degree, the portfolio of work and the Innovation Report. It will place in context the development of the submissions and introduce the innovative framework that was developed in this Engineering Doctorate.

1.1.1 Statement of the Problem

The growing infrastructure of information allows for an increasing awareness of available technologies and business models which can lead to innovation for businesses (Henderson, 1994). Some of these technologies and business models have shown great potential for some businesses and industries, particularly Servitization (Baines, Lightfoot, Kay, & Benedettini, 2009; Toivonen & Tuominen, 2009; Vandermerwe & Rada, 1988) and The Internet of Things (Porter & Heppelmann, 2014; Skipper, 2014), two unique and currently relevant concepts. Today, 75% of the world's population accesses the internet and there are six billion connected devices globally. This presents many opportunities and challenges. In particular, the aspect of adding service to existing products for many large companies, such as the Daimler group, GE, LG and Bosch, has gained momentum (Ferber, 2013). How opportunities can further be explored by Small to Medium Sized Enterprises (SMEs) is still a challenge.

1.1.2 Research Question and Context

Considering the increasing opportunities and challenges being presented from both the phenomenon of IoT and Servitization, how could SMEs best be equipped to understand these opportunities and challenges? How would they be able to develop the needed capability to best take advantage of the opportunities and mitigate risks?

Since Servitization was first recognized, it has become a key business strategy for various sectors, particularly manufacturing (Lightfoot, Baines, & Smart, 2013; Vandermerwe & Rada, 1988). Servitization is the process through which, if done successfully, an organization can increase the value it delivers to its customers through providing service. This process can be entirely unique to an organization, depending on its business model, competencies and strategy. Benefits can include a competitive advantage in the market, improved customer relationships and retention and more predicable cash flow (T. S. Baines, Lightfoot, Benedettini, & Kay, 2009).

Equally of interest for business is the "Internet of Things (IoT)," where the technology and connectivity of devices allows for data and information to be exchanged between them (Ashton, 2009; Ning, 2013). This could allow for products to be monitored, controlled, optimized or even automated (Porter & Heppelmann, 2014). The IoT has been described as ubiquitous, embedded or pervasive computing because it has the potential to affect nearly every aspect of human life (Kellmereit & Obodovski, 2013). Utilizing the opportunities available from the IoT could potentially enhance or enable new opportunities for Servitization, especially for SMEs.

Implementing new technologies and ideas can be a challenge for any organization, no matter the size, and often requires a great deal of expertise, planning and road-mapping to be successful (Phaal, Farrukh, & Probert, 2010). This challenge can be even more difficult for Small to Medium sized Enterprises (SMEs) due to limited resources of people, time, expertise and money (Garengo, et al., 2005; Morabito, Pace, & Previtali, 2005). However, the ability to implement new ideas and technologies allows companies to remain innovative and competitive (Parrilli & Elola, 2011). SMEs accounted for nearly half of all employment and approximately a third of all private sector turnover for the UK in 2014 (BIS, 2014). It is therefore critical to find practical methods to enable SMEs to successfully innovative as technology evolves.

Many SMEs share common traits, such as lack of human resource and limited capital resource, which can inhibit an SME's ability to grow, measure their performance or plan (Garengo et al., 2005). These traits present a variety of challenges to SMEs and their ability to translate technologies and business models that have shown success in larger counterparts.

Nevertheless, there are also many SME traits that positively affect the business. The managers often have a strong commitment to innovation, decision making is quicker, they can focus on small market niches and communication is less formal (Storey & Greene, 2010).

SMEs in newly formed industries also face the challenge of entering a new and potentially risky market (Gudlavalleti, Gupta, & Narayanan, 2013). The developing fuel cell technology industry in the UK is an example. This industry is mostly comprised of SMEs. While fuel cells face technical challenges, an equally difficult challenge is the ability for businesses to have

success in a competitive energy market. Utilizing complementary technologies and business models can help fuel cell suppliers cut costs (Skipper, 2014), be competitive (Porter & Heppelmann, 2014) and reach new markets (Gudlavalleti et al., 2013).

1.1.3 Research Aim and Objectives

The initial aim of this Engineering Doctorate was to understand key needs of stakeholders, namely the sponsoring company and a potential new industry for them, Small to Medium Sized Enterprises (SMEs). From this understanding, it was discovered that there was an opportunity to consider two main competencies of the sponsor company; Servitization and the Internet of Things; as they might relate to exploiting this new industry. The overall aim, then, was to create a framework that could allow for the exploitation of opportunities that allow for innovation and growth to be obtained. This was achieved by the completion of the following objectives:

1. To understand the sponsor company and their main customers (Submissions 1 and 2).
    - Developed an understanding of the direction and goals of PTC (Submission 2).
    - Researched the current major industry of manufacturing, which is the main consumer type of the sponsoring company, PTC (Submission 1).
2. To identify the main issues and commonalities relevant to potential customers, in a specific industry (Submission 3).
    - Explored a new industry in the UK in energy (fuel cell technology) and identified commonalities from the needs of this industry and the competencies of both servitization and the Internet of Things (IoT), both particularly relevant to the direction of PTC.

3. To develop a tool from both academic sources and real world data (Submission 4).
    - Undertook a longitudinal, two-year case study with a London SME to understand how servitization was occurring and how this servitization was utilizing IoT technologies. Then, using both academic resources and this data, developed a framework that can aid SMEs in their decision making when considering these themes for their expanding business.
4. To disseminate this framework to key stakeholders to demonstrate the innovation of the concept and to collect feedback on the value of the research (Chapter 5 of Innovation Report).
    - Presented framework to a diverse group of SMEs and industrialists in the UK to measure interest and potential use of the framework.

The original project objectives were around the themes of Open Source Hardware Design and SMEs. Both of these topics were explored from the beginning of the program, but ultimately decided to follow a more relevant path to the sponsor company, particular around SMEs and the competencies being developed by PTC, namely, Servitization and the Internet of Things (IoT). The reasoning behind this shift is explained in further detail in Chapter 2.

The first objective established the current situation, for both existing PTC customers and PTC. The second objective explored a new situation; a new industry (fuel cells) in an existing market (energy) was explored as a potential use case for exploration. From this research, it was established that a combinations of themes; the Internet of Things and servitization could lead to innovation for SMEs. Next, the third objective critically analyzed these three themes and studied them further in context in an in-depth case study at an SME undertaking an

evolution in their offerings of products to services. Three total iterations of a framework were developed. The first iteration came from the current literature and theories of these themes, and the second from the collection and understanding of various types of qualitative data from the case study. Finally, this framework was presented to other SMEs and industrialists in other industries to generate feedback on the potential innovation and possible application of the idea. This resulted in the third and final iteration of the framework.

1.2 The Sponsoring Company, PTC and its relevance to the direction of the Engineering Doctorate Research

This research was considered from the perspective of the sponsoring company, PTC. PTC is a global software company based just outside of Boston, Massachusetts in the United States of America. PTC was founded in 1985 and was a market leader in Computer Aided Design (CAD) software with the product Pro/ENGINEER, which was the first parametric, associative feature, solid based modeling software. In more recent years, the company has diversified their offerings through the acquisition of several software packages. Most relevant to the research was the acquisition of Servigistics in 2012 and ThingWorx and Axeda in 2014. Servigistics is software that allows manufacturers to implement service-led growth within their company and ThingWorx and Axeda are two software packages that enable capabilities, such as secure connectivity and application building, in the IoT space. ("PTC History and Acquisitions," 2015).

The research for the Engineering Doctorate has focused to capture the requirements of the evolution of PTC's focus throughout the course of the research. Initially, the research was

focused on collaborative networks, Product Lifecycle Management (PLM) and SMEs, but quickly grew to consider aspects of Servitization and the IoT. As PTC's focus has shifted recently to become leaders in the IoT (Business Wire, 2015), the research conducted has become increasingly relevant. Ultimately, this research will help the sponsoring company to consider how its current competencies in Servitization and the IoT may create new opportunities with SMEs.

1.3 The Structure of the International Engineering Doctorate Program

The International Engineering Doctorate program is both a research and taught degree that is portfolio based. It is meant to focus on industrial issues and develop an innovation that can be utilized in industry, stating that the major aim of the degree is to "develop engineers who are capable of demonstrating innovation in the application of knowledge to the global engineering business" ("International Doctorate Centre Handbook," 2013). Additionally, it is meant to develop a diverse range of competencies, which are shown in the personal profile. The Innovation Report is the culminating document that is structured to show the path of research taken and connect the common themes from the different projects, ultimately outlining the core innovative contribution.

Table 1: Timeline of the Engineering Doctorate

	Jan-Dec 2012	**Jan-Dec 2013**	**Jan-Dec 2014**	**Jan-Dec 2015**
Areas Explored / Main Events	-Understanding SMEs, Formula Student -Collaboration: FS collaborative network -Open source hardware design -Manufacturing in the UK -Open Innovation -Engineering YES competition	-Internship at PTC, cloud and software -Engage with PTC on lean startup, working like an SME -Servitization -International placement at Monash University, Melbourne, Australia	-Relationship established with Arcola Energy -Big Data, data analytics -Supervision of 2 MSc students -IoT Monitoring -Bringing together IoT and Servitization for SMEs -Presentation on Formula Student Collaboration Network for WMG Innovation Conference	-Case study project with Arcola Energy -Conference presentation at the International Conference of Business Servitization and at the WMG Innovation Conference -Presentation and dissemination of innovation to UK SMEs
Submissions	Submission 1: "Engineering the Future: Manufacturing in the UK"	Submission 2: "PTC Internship – CAD and SLM in the Cloud" International placement report	Submission 3: "Fuel Cell Technology and the UK Industry"	Submission 4: "IoT-enabled Servitization for SMEs" Publication in ASME Journal of Fuel Cell Science and Technology
Modules	1) Collaborative product development 2) Financial Analysis and Control Systems 3) Service Design and Delivery	4) Product Design and Development Management	5) Lean Principles and Applications 6) Service Support Technologies	Six Sigma: Green belt certification and Black belt training through the Bourton Group

Table 1 shows the timeline of the Engineering Doctorate, highlighting modules and training undertaken, submissions to the portfolio and the areas explored and main experiences of the degree. The first year was spent exploring and understanding a variety of topics, namely

open source hardware design, open innovation, collaboration and SMEs. This was completed through reviewing literature and engaging with the Warwick Formula Student team.

An internship at PTC in early 2013 contributed focus on the topics of their software solutions, cloud technology and understanding their market, which coupled with the understanding of both SMEs and collaboration, contributed to the final research and innovation. The focus on IoT-related topics, such as Big Data, cloud computing and sensors, was started in 2013. Additionally, the modules taken about service, Service Design and Delivery and Service Support Technologies, furthered knowledge and understanding about Servitization. Finally, engaging for two years with the SME, Arcola Energy, as well as the initial research with Formula Student and literature-based understanding of SMEs in general contributed to knowledge of SMEs.

Additionally, the international aspect of the degree was achieved by both the internship at PTC at their headquarters in Boston, Massachusetts, USA and by the international placement at Monash University for three weeks in late 2013. The international placement at Monash allowed the researcher to discuss some of her early research ideas with other researchers on topics like Big Data, eResearch and Bayesian Modeling. These topics all feed into the overall topic of IoT and helped to provide a foundation in that aspect of the EngD research. This foundation was particularly useful in understanding the similarities in challenges by the institutions and organizations faced in the three main countries (Australia, US, and UK) visited and engaged with, both in the international visits and over the course of the Engineering Doctorate. One of the main lessons from all three experiences showed a need for improved data understanding, interpretation and visualization, which resulted in being a

key theme in the Engineering Doctorate for the utilization of the IoT. These experiences are further explained in separate documents in the portfolio, namely Submission 2 and the International Placement Report.

1.4 The Structure of the Portfolio

The portfolio highlights the main journey of the research. The structure is shown in Figure 1. Much of the research that occurred in the first eighteen months of the program culminated in defining the problem and is covered in submissions 1 and 2. This was completed through first developing an understanding of the sponsor company's main customer base and sector, manufacturing, and the structure and culture of the sponsor company through internship work. A main priority of this research was to develop an innovation that was currently relevant to both the sponsor company and current and potential customers of PTC, as well as SMEs more broadly.

Further investigation into the research problem of the needs of SMEs occurred in submission 3, where a specific industry, the fuel cell industry in the UK, was researched. Simultaneously, there was a relationship being built with a corresponding SME in this industry to conduct a case study. It was in this submission that it became clear that a solution that addressed the challenges in implementation that SMEs faced with servitization and utilization of new technologies related to the IoT would be innovative. Additionally, this potential solution would help the sponsor company utilize new competencies in both servitization and the IoT in a potentially new market. Submission 4 shows both the development of the solution from main literature sources and the testing and modification of the proposed innovative solution through the qualitative case study analysis conducted with Arcola Energy.

Finally, the personal profile highlights the main competencies developed or enhanced through the activities and research completed with the Engineering Doctorate.

Other submissions to the portfolio are all module assignments, the international placement report, a publication in the Journal of Fuel Cell Science and Technology titled "Depositing Catalyst Layers in Polymer Electrolyte Fuel Cells: A Review," and the conference paper from the International Conference of Business Servitization, titled "Internet-of-Things-enabled Servitization for UK SMEs."

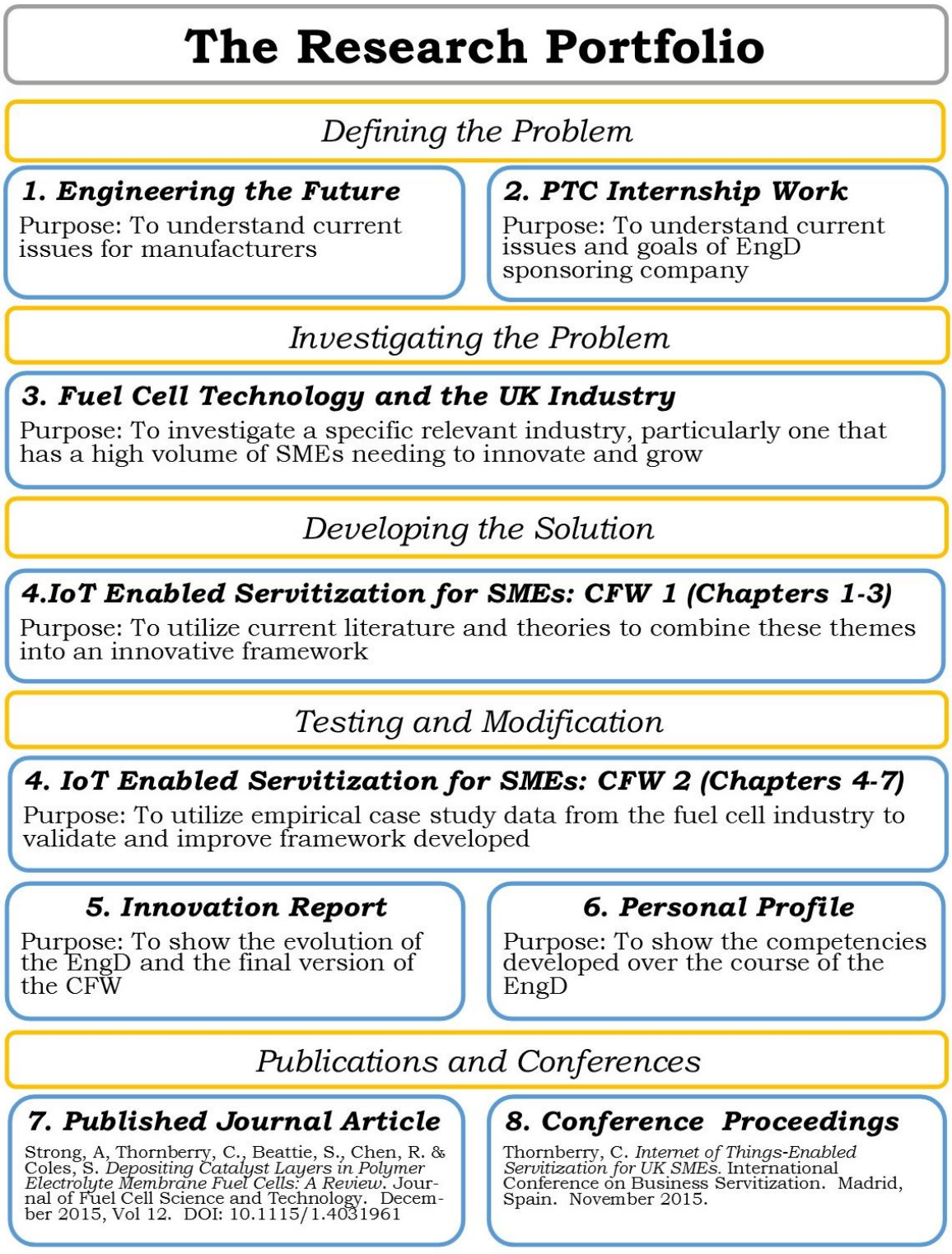


Figure 1: The Research Portfolio

1.5 The Structure of the Report

This report summarizes the research undertaken over the last four years and demonstrates the connection between projects that have all contributed to the final innovative framework that fulfills the requirements of the Engineering Doctorate.

Chapter 2 highlights much of the background research conducted leading up the final innovation and clarifies its significance. In particular, this background research includes what was conducted with the Warwick Formula Student team and research of the UK Fuel Cell industry.

Chapter 3 begins with defining the SME and specific drivers and barriers faced by these businesses. Then, the report discusses the Internet of Things and how this technologic revolution acts as a potential enabler to Servitization. This chapter shows the logical progression of merging these three main areas, SMEs, the IoT and Servitization, into a main focus of study as an opportunity for innovation.

Chapter 4 reiterates the main findings from the central case study, in order to justify the methodology that was developed to analyze the case study organization and their operations, which took place over the course of approximately two years.

Chapter 5 develops the formation of the innovative framework and discusses the advantages of SMEs servitizing their potential to clients, enabled by the IoT. It discusses feedback given by other SMEs about the framework and presents a cost analysis of the potential value of the innovation to the sponsor company.

Chapter 6 confirms the innovation, discusses final thoughts about the research conducted and presents ideas for further work in this area.

Chapter 7 reflects on the body of literature, the empirical research made into SMEs operations and the adoption of the innovative framework into their future developments. Proposals are made for extending and future research in the adoption of servitization and IoT by SMEs.

1.6 Summary of the Innovation

The body of work conducted through the entirety of the Engineering Doctorate research program has resulted in contributions into current aspects of servitization and IoT for SMEs. It has also produced a framework that has structured these themes together with consideration of both academic and industrial inputs.

The notable contributions of the program are listed below, as well as the location of this research within this report.

- Combining the research areas of SMEs, the Internet of Things and Servitization (Chapter 3).
- Development of a conceptual framework from these three literature themes to enable them to be considered together (Chapter 3).
- Modification of this framework based on industrial case study data (Chapter 4).
- Dissemination of the research to produce a final framework, based upon both literature and empirical data, that can be used as a tool by SMEs to servitize their

offerings, utilizing the IoT, or used by the sponsor company to better serve existing and new customers. (Chapter 5).

These contributions are significant, both academically and in their application. This innovation report will present and explain the significance of these aspects in detail.

Chapter 2: Background Research and its significance to the Engineering Doctorate

2.1 Introduction

From the beginning, the central theme to this Engineering Doctorate was SMEs; understanding how they work and finding ways to improve the way these types of companies create value. This chapter serves to discuss the research conducted in the first 18-24 months of the Engineering Doctorate, including research undertaken, how it laid the foundation to address this central theme, and the development of a conceptual framework. There were four distinct areas explored in this initial timeframe;

1) The Warwick Formula Student Team
2) The UK Manufacturing Industry (Submission 1)
3) Sponsor company PTC's direction and requirements (Submission 2)
4) The WMG High Value Manufacturing Catapult and the UK Fuel Cell Industry (Submission 3)

The Formula Student team is an academic and extracurricular project for fourth year Engineering undergraduates at the University of Warwick. In an academic year, the team must design, manage, and build a race car to compete in an international competition at Silverstone with over one hundred other university teams. It is a comprehensive project that combines many of the aspects of running a small business, including technical developments, supply chain, finance and project management. Over the course of this Engineering Doctorate, three different Warwick Formula Student teams were engaged with by the researcher. Initially, this involvement was focused around finding a method or technique

that engaged professional engineers with automotive expertise to contribute to the design of the car. However, close involvement with the teams showed more interesting issues around how the student members collaborated and worked together for knowledge transfer. This knowledge transfer and sharing was seen in three ways; within the university (for each new team), among UK-based teams, and internationally, with some select teams from India and Australia.

Understanding the sponsor company's main customer and industry practices in manufacturing, was also an important exercise within the first few months of the degree, resulting in Submission 1 in November 2012.

Closely following this, two months in early 2013 were spent based in Boston, Massachusetts, USA, on an internship with PTC. Two areas were explored; Computer Aided Design (CAD) in the Cloud and Service Lifecycle Management (SLM) in the Cloud, which were compiled for Submission 2.

Additionally, there was engagement with the High Value Manufacture Catapult centre at WMG, starting in July 2012 and continuing throughout the doctorate program. This engagement explored the developing fuel cell industry in the UK and resulted in Submission 3. Engaging with the Catapult also led to the development of the relationship with the case study SME, Arcola Energy. These areas are summarized in Table 2.

Table 2: Areas explored during initial phases of Engineering Doctorate

Area	Significance to the Engineering Doctorate
Warwick Formula Student	-Understanding SMEs -Importance and mechanics of collaboration and knowledge transfer
UK Manufacturing Industry	-Current issues faced by sponsor company's main customer base -Highlighted need for solutions in technology and innovation
PTC Internship	-Clarified current direction of sponsor company -PTC was/is moving beyond CAD and PLM- focusing on Service and IoT (in 2013, cloud)
WMG Catapult & UK Fuel Cell Industry	-Relationship with Arcola Energy -Industrial connections, understanding of a currently relevant industry; fuel cell technology

2.2 Understanding SMEs

There has been increasing support in recent years from the UK government to support SMEs, as their value to the economy is realized (Elster & Phipps, 2013). SMEs have many defining traits, namely;

- Size and budget (European Commission, 2005, 2015)
- Operations that rely on key individuals and small management teams (Elster & Phipps, 2013)
- Limited resources (Time, money, expertise)(Buckley, 1989)
- Flexible, simple decision making processes (Gelinas & Bigras, 2004)

There were three main reasons that the Warwick Formula Student project was identified as a case study for this Engineering Doctorate; comparability, accessibility and repeatability. It was initially thought that the Warwick Formula Student team would be a comparable case study to an SME, as the team exhibited some aspects of the above traits; especially with

regards to size and budget, operations relying on key individuals and limited resources, especially expertise. Additionally, it was an accessible project with which to get involved. Finally, it was a repeatable project, in which the competition, team formation and delivery occurred annually. It was thought that this repeatable pattern in events could allow for testing of variables in a more controlled environment.

For the first few weeks, the researcher engaged with the project in a mostly observational role, attending meetings and engaging with members to understand the project and how the team managed to meet deliverables and work together. This observation quickly progressed into tangible participation in the technical deliverables for the project, including the machining of parts for the car and preparation of components such as the brake calipers. The researcher also engaged in other deliverables for the team, such as preparing for the business presentation at the international competition. However, the most engagement was with the issue of knowledge capture and transfer.

The first team the researcher worked with already was showing momentum for coordinating knowledge transfer from year to year. This was a significant challenge to the project, as the team members all changed with each academic year. In 2012, there was some communication between the team alumnae and existing members, on a very informal basis. This was in the process of being formalized by key individuals, as the value of the knowledge gained year on year was recognized. This work to pass on knowledge from team to team also lead the researcher to the develop a collaborative network to exchange knowledge between competing teams in the UK.

2.2.1 The UK Collaborative Network for Formula Student

In 2012, interviews were held by the researcher with five other UK- based universities to understand the potential for collaboration. While the UK is home to the largest competition in the world, a UK team has yet to win the competition at Silverstone. In July 2012, at the UK competition, five other universities were approached to discuss the challenges they faced. From these interviews, a formal online community for the sharing of ideas, questions and thoughts concluded to be a potential way to address some of the challenges. This group, established on Facebook by the researcher towards the end of 2012, started with 62 members from the six main universities (Oxford-Brookes, Liverpool, Brunel, Warwick, Sheffield and Portsmouth) and now has 269 members from 13 different UK universities. The group continues to grow and engage new members nearly three years after it was created, which is a tangible achievement by the researcher during her work with the Formula Student team.

Data Analysis on the Collaborative Network

In June 2014, the communications from the online group were captured and exported using NVivo software, capturing data from October 2013. The communications, which considered both the original post and the discussions that followed the post, were read and categorized in Excel. From this analysis, seven main themes of discussion emerged:

1) Supplies and suppliers (how to get certain supplies and what suppliers were helpful)
2) The UK competition (namely, rules and logistics)
3) Social events

4) Design comments and questions
5) Testing (logistics of finding places to test, questions about testing the car, and ideas to find better ways to test)
6) Manufacture (logistics about how to manufacture components, questions about how to manufacture, and ideas to improve manufacturing of components)
7) Sponsors (funding for the project)

After the themes of discussion were established, key words and short phrases were identified in each of the themes and NVivo was used to do a frequency word count of these key words and phrases under each theme, shown in Figure 2 and 3.

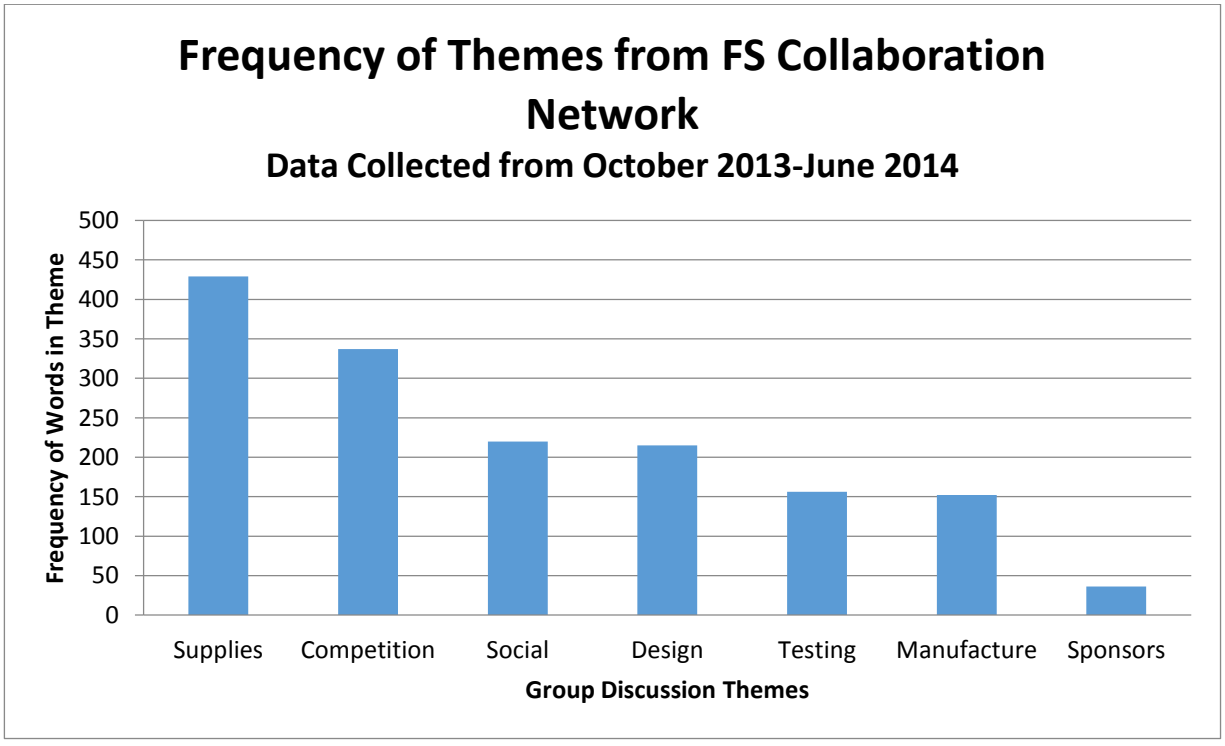


Figure 2: Frequency of themes for the UK Formula Student Collaborative Network (Thornberry, 2014).

Theme	Words	Example
Design	Assignment, concepts, design, figures, pattern, specified, idea	"…trying to work out the 2nd Moment for the welded tube with inserts. ….could anyone point us in the direction of how to do it for the complex shape formed with the insert? I know the tube one so wondered if it was a combination of that with another."
Manufacture	Construct, industrial	"…question about throttle cables, does anyone know how to shorten them and what type of cables do you use, like what kind of inner cable and what type of sleves"
Testing	Prove, MIRA, tested, test	"Where do you guys test? we are REALLY struggling to get testing days when Bruntingthorpe is booked, so we would like to know any alternative testing locations"
Competition	Silverstone, comp,	"Hi Everyone, just wondering what did teams submit regarding cost yesterday for FSUK as the rules were a tad confusing"
Suppliers & Supplies	Material, source, tyres, companies, cheap	"Can anyone give us a hand regarding tube benders please. I have been told there is a guy in Solihull (our back door) who does this cheap and accurately. Could someone pass us a contact or point us in the right direction please"
Sponsors	Support, patron, sponsorship	"How does your team deal with advertising costs for sponsors etc. At our uni this year they are having a big push that we make ALL sponsors sign agreements 'to protect us'"
Introductions & Social	Cheers, hi, hello, good luck	"Just like to introduce myself as team leader of ……On behalf of the team and I thanks for letting us join and we look forward to working with you."

Figure 3- An example of the text used to categorize the Formula Student communication into categories.

The most frequent topic of conversation in the collaborative network was around sourcing supplies and finding high quality suppliers. The topic discussed the least was sponsors. This makes sense, because obtaining and maintaining adequate sponsors is a challenge for teams and there can be sensitive information around the agreements teams and universities make with these industry partners. Furthermore, this can be a highly competitive area for teams.

2.2.2 Value from Formula Student

The initial reasoning for studying Formula Student was due to the team's perceived comparability to SMEs, the accessibility to the team by the researcher and the repeated activities of the team on an annual academic basis. However, there were aspects of the team that did not relate to how an SME would behave; namely that the team was comprised of

young, university students with little industrial knowledge and they were doing the project while also having many other obligations, such as their coursework. Unfortunately, these issues were not fully realized until engaging with the teams for approximately 12-18 months into the Doctorate. The decision was then made that a case study with an actual SME would be necessary to fulfill the objectives of the Engineering Doctorate. However, the experience, understanding, and knowledge gained from engaging with the teams proved valuable.

The only portfolio submission that includes the work with Formula Student is in the International Placement report, where the researcher was engaged in helping one of the Warwick teams at the Australasia competition in December 2013. A singular formal submission on the research was not written, as the focus quickly shifted to the case study with the SME, Arcola Energy in late 2013. However, the learning from the work with Formula Student did provide underlying value to this Engineering Doctorate, namely;

1. ***SMEs and Collaboration***: engaging with the Formula Student teams emphasized the importance of collaboration and the role it would later play in the Arcola Energy case study, which had a collaborative element with two other companies.
2. ***Conduct formal ethics paperwork***: The semi-structured interviews and viewing online posts of the team members meant that an understanding of and preparation of the proper BSREC documentation was necessary for this sort of data collection. The final approved application is shown in Appendix D.
3. ***Qualitative Data Analysis***: This was the first experience the researcher had with collection, analyzing and interpreting qualitative data. Also, it was the first-time semi-structured interviews were planned and unstructured qualitative data (from the

collaboration group) was collected. This experience later proved valuable when working with Arcola Energy. Additionally, it was valuable in learning qualitative data analysis software (NVivo)**.**

The engagement and research with the Formula Student team helped to lay the foundation of understanding the value of qualitative research and build confidence to carry out the case study later in the Engineering Doctorate. Additionally, this experience helped to develop the Engineering Doctorate knowledge and tacit understanding, which is expanded upon in the Personal Profile.

2.3 The UK Manufacturing Industry

The first aspect of defining the overarching research problem was completed in Submission 1. This submission develops an understanding of the manufacturing industry, which is the main industry of PTC's customer base. This submission focused on the current state of manufacturing in the UK, and considered reports and data produced between 2010 and 2012. This submission also contributed to a collaborative venture by the Institute of Mechanical Engineers (IMechE), the Institute of Electrical Engineers (IET), and the Royal Academy of Engineers (RAE). These organizations used the resulting review to conduct further research with UK manufacturers. This submission was completed with the help of two other researchers, who were project managed by the researcher in order to quickly turn around the research, to meet a deadline set by the Institutions to carry out further research.

This exercise had two main valuable outcomes for the doctorate;

1. The development of project management skills

2. An understanding of the current state of the manufacturing industry.

There were seven main themes discussed in the submission:

1. Health of manufacturing sub-sectors
2. Skilled workforce
3. Regulation and legislation
4. Supply chain, trading environment and collaboration
5. Business confidence, economic and financial and fiscal issues
6. Technology and innovation
7. Exporting and tapping into global markets

Of these seven, the researcher personally explored the following; themes 1, 2, 6 and 7, while 3, 4 and 5 were explored by other researchers. These themes have contributed to the understanding of the research problem. These contributions are specifically:

1. *Health of manufacturing sub-sectors:* the main issue in recent declines of most of the sub-sectors was due to a lack of the needed skilled workforce, the lack of adapting to global influences and the need for more high value manufacturing.
2. *Skilled workforce:* this was one of the main health issues of the manufacturing industry that became apparent in the first topic. While there was a long term (since 1994) doubling of manufacturing employees with degrees, the UK is still behind leading countries such as Japan and Germany. There was an emphasis found in manufacturing SMEs, as they make up a large proportion of the UK manufacturing industry and lack resources to provide the needed training to update and develop employees.

3. *Technology and Innovation:* this theme emphasized the need for advanced manufacturing in the UK and the ability for firms to innovate to meet the requirements of both their current markets and customers and potentially new markets.
4. *Exporting and tapping into global markets:* the research around this theme showed there was a lack of UK manufacturers exploiting opportunities fully on a global scale, which could help them to diversify skills and offerings and mitigate risks.

Overall, the submission found a need for the manufacturing industry to innovate, improve skills, and globalize to remain viable and competitive. The recommendations made included investing in new technology and finding innovative ways to exploit new markets, especially abroad. This submission helped to lay the foundation for later research in the Engineering Doctorate as it developed background theory behind the main issues faced in industry, especially by manufacturing SMEs.

2.4 PTC Internship

The second aspect to defining the research problem was to develop an understanding of the requirements, characteristics, and direction of the sponsor company. In February 2013, two months were spent in Boston, Massachusetts, USA to intern with sponsor company, PTC. This internship focused on two main topics; CAD in the cloud and SLM in the cloud. (A full definition of the cloud is found in Submission 2; essentially, cloud computing is a term that covers applications delivered as services, via the Internet and the hardware and systems software that provide the services.)

In addition to the outputs of work from the internship, the researcher engaged in actively learning about the business through attending meetings (both internally and externally with customers) and networking in different areas and networking with different departments, such as the CAD development team, the Servitization team and the ThingWorx (PTC Internet of Things software product) team. The main value from this experience that contributes to the overall project can be summarized into three main aspects:

1. *The history and legacy of PTC:* this was facilitated through working with the Computer Aided Design (CAD) group that was in charge of the product Creo. Creo was the rebranded product of the original CAD software package, Pro/Engineer, on which the entire company was based in 1985. While the company has lost market share in this area in recent years due to competitors, the CAD group was still very focused on innovating the product and engaging with customer needs.
2. *A glimpse at the future direction of the company:* half of the internship was spent in a fairly new group of the business in the Service Lifecycle Management (SLM) division. This was created out of the acquisition of the company Servigistics in 2011 ("PTC History and Acquisitions," 2015). This gave good insight into how PTC was working with the concepts of servitization for its customers. Additionally, for both groups, the theme of cloud computing was central. This later evolved for the broader interest of the company into the IoT, after the end of the internship and with the acquisition of additional IoT-focused companies.
3. *An understanding of company culture:* working in the main headquarters of PTC allowed the introduction and engagement with several different employees. Contacts

were made that were kept throughout the course of the Engineering Doctorate program. A follow-up visit was made in September 2015, to feedback the Engineering Doctorate research and to gain insight from key PTC employees.

Ultimately, the internship at PTC was instrumental in the understanding of the research problem for the Engineering Doctorate and allowed for a holistic understanding from both company and customer perspectives.

2.5 The UK Fuel Cell Industry

In the first two submissions, the research problem was partially defined, in that these submissions showed the needs and characteristics of SMEs, the requirements of PTC customers around technology and innovation and the direction of the sponsor company in the areas of servitization and cloud computing. However, on their own, these problems are complex and fundamental. It was critical at this stage to specifically define the problem within tangible working parameters. This was completed through considering the themes that had presented themselves from the first two submissions, exploring main opportunities and deciding how these themes and opportunities could come together to help solve a real industrial problem.

In the third submission, the opportunity was presented to engage with the WMG High Value Manufacturing Catapult to focus on a particular industry in the UK; the fuel cell industry. The in-depth technical and market analysis of the industry was an important exercise because it showed that, while this was a unique technology, it still faced many of the broader challenges faced by many other industries, as found in Submission 1. Most important was the fact that this industry has a strong need for innovation if it is to survive and grow.

Innovation can cover a wide range of meanings, but in this context, it means that the industry must find a way to be competitive in an existing energy market. This must, at its core, happen first and foremost with cost. Cost reduction can occur in a myriad of ways, but some particularly tried and tested methods include differentiating the business model (Chesbrough & Rosenbloom, 2002; Osterwalder, Pigneur, & Tucci, 2005) and using new technology in creative ways (Porter & Heppelmann, 2014). It was towards the end of this study that it was realized that there was an opportunity for a potential solution to be developed that utilized these two key concepts, particularly around servitization for a differentiating business model and the utilization of IoT technology in a creative way. The research question was further developed in the next submission; but the foundational research to understand the problems faced by the UK fuel cell industry- namely cost and competition- were established in this third submission.

2.6 Significance within the context of the Engineering Doctorate

This chapter provided a brief synopsis of the first three submissions of the portfolio and the significance this research had in the overall development of the Engineering Doctorate project. These submissions were imperative to the definition and development of the research question; Considering the increasing opportunities and challenges being presented from both the phenomenon of IoT and Servitization, how could SMEs best be equipped to understand these opportunities and challenges? How would they be able to develop the needed capability to best take advantage of the opportunities and mitigate risks?

Further developing and defining of the question, and subsequent testing of the solution, was then conducted in Submission 4.

Chapter 3: The Internet of Things as an enabler of Servitization for SMEs

3.1 Introduction

This chapter will present an abbreviated literature review of the three main themes studied for the innovation. It will consider each theme individually, then discuss how they interrelate. Finally, the first iteration of the conceptual framework, which was based upon a much more in depth literature review presented in Submission 4, will be shown. This was the first output of the innovation developed for the Engineering Doctorate.

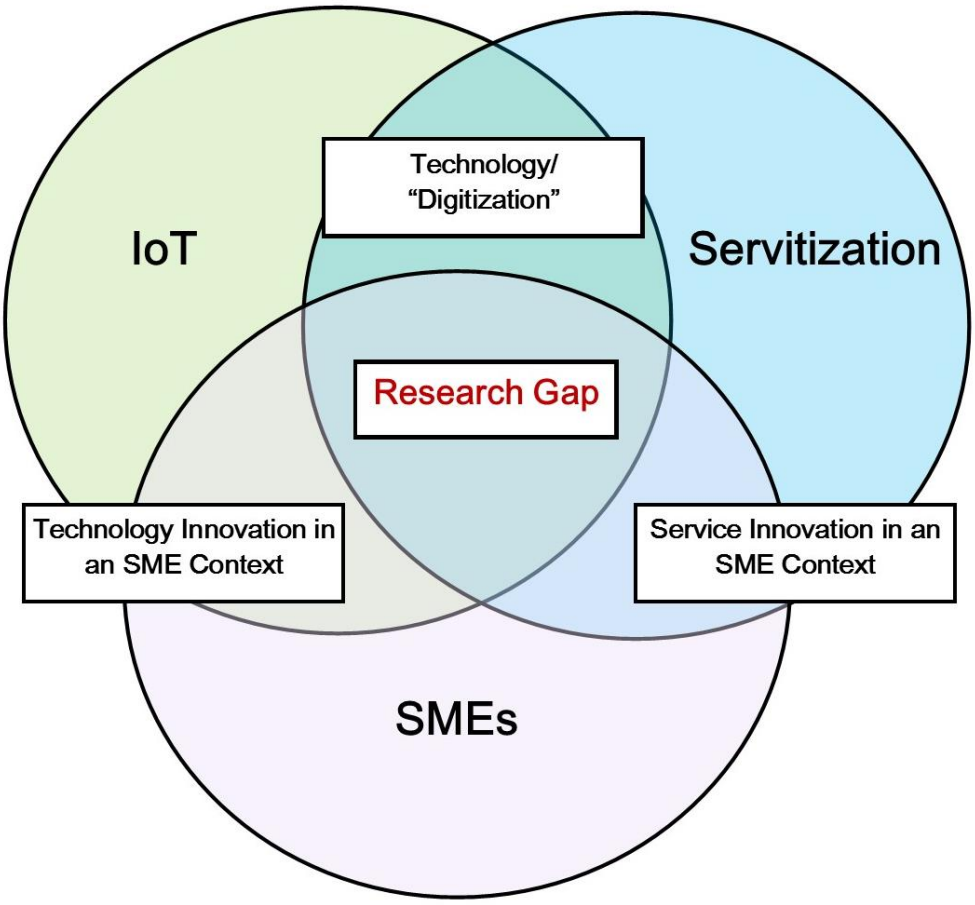


Figure 4: The Research Gap

The chapter will present how the research gap was established, as shown in Figure 4. This gap exists at the interface of the three main themes; Servitization, SMEs and the IoT. Whilst there was existing literature in the individual themes; IoT, Servitization and SMEs, as well as some literature that explored two of the themes together (such as the impact of the IoT on SMEs, for example), there was no literature that explored the effect that the IoT would have on Servitization for an SME. This gap; consideration of the impact that the IoT might have on Servitization for an SME, was what was explored by the researcher.

3.2 Defining the SME and establishing drivers and obstacles

The first theme considered for this research was SMEs. SMEs are critical to the UK economy in many respects, namely that these types of businesses account for nearly half of all employment and a third of all private sector turnover (BIS, 2014), as shown in Figure 5.

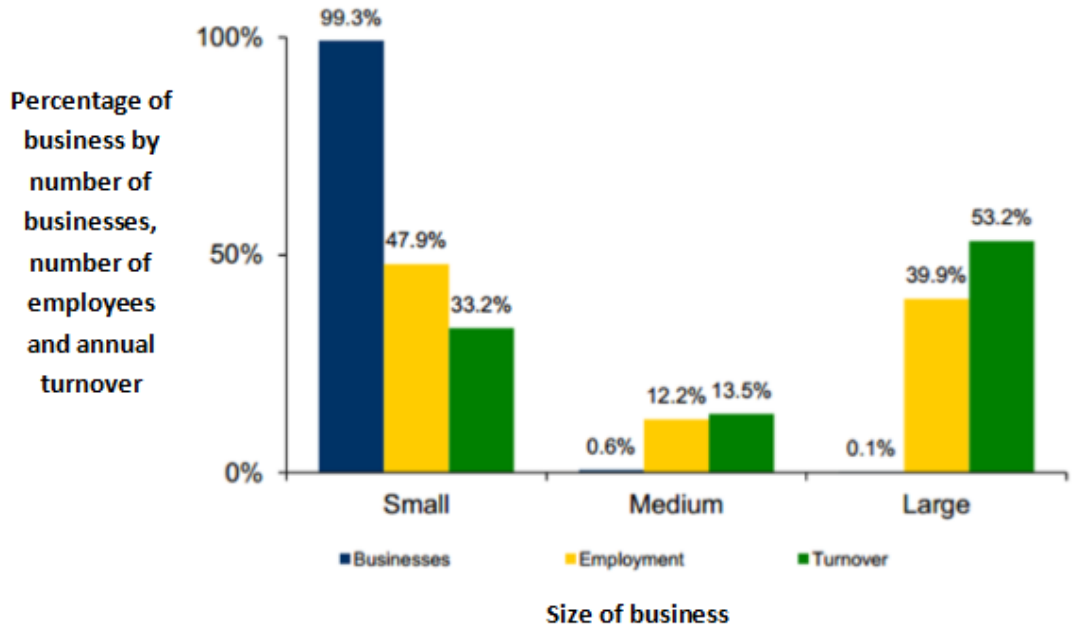


Figure 5: The impact of SMEs on the UK economy (BIS, 2014)

The importance of SMEs is recognized by government (European Commission, 2005) and academics alike (T. Baines, 2013a; Elster & Phipps, 2013; Salavou, H., Baltas, G. and Lioukas, 2004), but it remains difficult to identify and provide the right support (Directorate-General for Research and Innovation., 2013; Nieto, M. J., & Santamaría, 2010) . The need to clearly define and understand the drivers and obstacles for SMEs thus proves to be a logical first step in any research venture to develop new methods of improving their processes and business. Further impact of SMEs is explored in an analysis in Chapter 6 of this report.

3.2.1 Defining competencies and traits of the SME

Various governing bodies, such as the European Union and official government departments of countries such as the United States, have outlined definitions to categorize SMEs. This research is focused on the UK in particular, but the EU and US definitions were also considered, as these definitions are relevant in the context of the sponsor company. The EU classifies SMEs based on number of employees, annual turnover and annual balance sheet, as shown in Figure 6.

Category	Number of Employees	Annual Turnover	Annual Balance Sheet total
Medium	50-250	Less than €50 million (~£36 million)	Less than €43 million (~£31 million)
Small	10-49	Less than €10 million (~£7.2 million)	Less than €10 million (~£7.2 million)
Micro	1-9	Less than €2 million (~£1.4 million)	Less than €2 million (~£1.4 million)

Figure 6: Sub-classifications of SMEs according to the European Commission (2005)

The UK's Department for Business, Innovation and Skills are more simple in their definition; an SME is any business employing less than 250 people in their publications (BIS, 2014; BMG

Research, 2013). In the United States, the Small Business Administration defines small businesses mainly by average employee number and turnover, but this varies depending on the industry or sector (US Small Business Admistration, 2014).

Beyond basic metrics, it is important to consider the sectors or industries that SMEs are in. BIS classifies 16 main industries (BIS, 2014), which can be categorized by whether they provide a product, a service or a mix of both. Nine of these industries could be classified as service, four as product and the remaining three a mix of both. The biggest industries in terms of employment were: 1) wholesale retail and trade, repair of motor vehicles and motorcycles; 2) professional, scientific and technical activities; 3) construction; and 4) manufacturing.

In addition to exploring quantitative measures of an SME, other aspects for consideration are the capability for innovation and the desire for growth. Innovation and growth are two concepts that are usually linked; in order to grow, a business can employ innovation to enter new markets, gain new customers or add value to current offerings (Low & Sanguinetti, 2012; OECD, 2007a). The first criteria to be established by an SME is if the company has a desire to grow, as most are happy to continue a sustained business (Garengo et al., 2005).

In the UK, only about 13% of SMEs are classified as "growers," from the criteria that the number of people employed or annual turnover has increased by 5%, or a minimum of three people and £50,000, respectively (BIS, 2014). Actual growth and the desire to grow are two distinctly different measures, however. Further research shows that the desire to grow is very sector dependent, with the most interested sectors in growth being manufacturing (77%), information and communications (75%), business services (76%) and administrative

services (79%) (BMG Research, 2013). This shows that while many SMEs express interest in growth, only a small number are actually able to achieve it.

This can be partly explained by the companies' ability to innovate, as growth in a business is fueled from innovating the offering to the customer (OECD, 2007a). According to Laforet, (2011), innovation can only occur within a company if the capacity for innovation exists.

Literature shows several indicators that are positively correlated to innovation in an SME, such as their ability to collaborate and be flexible (Love & Roper, 2015), the quality of their research and development process (Parrilli & Elola, 2011) and their ability to develop and introduce new products and service (BMG Research, 2013). Figure 7 shows eight of the main capabilities found from research that seemed to indicate whether an SME will have the capability to successfully innovate and therefore grow their business.

	Innovation Capabilities for SMEs	
1	Ability to develop and introduce new products and services	(BMG Research, 2013)
2	Ability to enter new markets	
3	Quality of research and development process	(Parrilli & Elola, 2011)
4	Strategy of technology acquisition	
5	Development of methodology and tools to support innovation	
6	Strong in-house technical skills	(Love & Roper, 2015)
7	Ability to collaborate	
8	Flexibility	

Figure 7: Innovation Capabilities for SMEs

The first two capabilities focus on the ability to develop and introduce new products and services and the ability to enter new markets. Both of these abilities showcase the need for a business to have clear development processes, understand appropriate risk taking and

understand current market forces and requirements (BMG Research, 2013). These abilities could be measured based on past experience and the level of success the business has had in achieving these.

The next three capabilities focus on the quality of the research and development, the strategy used to acquire new technologies and the methods and tools used within the company to support innovation (Parrilli & Elola, 2011). Measuring these capabilities is more subjective, but can be considered again from previous success in these areas. The quality of the research and development can be seen through the skills of the workforce involved in those particular activities and from outputs. The strategy of technology acquisition can be measured on a return on investment basis, both in a predictive or a reflective manner (have certain acquisitions been worthwhile? What is the potential from acquisitions?). The methods and tools used for innovation can be assessed on any success at the company or in wider applications (for example, the Minimum Viable Product from lean thinking (Blank, 2013)).

The final three capabilities are more inherent to the core skills and culture of the company, and consider the technical skills of the workforce, their ability to collaborate and how flexible they are (Love & Roper, 2015). The technical skills can be proved from the qualifications of the workforce, alongside any previous evidence of technical expertise. Collaboration and flexibility can be shown through observational data, as well as a reliance upon any previous evidence, such as past successful collaborations. These eight capabilities from the literature later helped to guide the assessment in the case study analysis, discussed in Chapter 4.

3.2.2 Establishing SME Drivers

It could be argued that the desire for growth itself is a driver, but there are further underlying motivations that are particularly interesting to understand. These drivers can be classified as either externally or internally motivated, and the classifications are shown in Figure 8. In particular, external drivers could originate from new technology developments, customer wants and needs and needing to remain competitive and relevant in the market (Laforet, 2011; Salavou, H., Baltas, G. and Lioukas, 2004). Internal drivers include the culture of the company, particularly around how flexible and creative it is, the desire to adapt and the willingness to increase turnover and skill of the workforce (O'Regan, N. and Ghobadian, 2005).

External Drivers for SMEs to Grow and Innovate		
1	Competition	(Laforet, 2011; Salavou, H., Baltas, G. and Lioukas, 2004)
2	Operating Environment	
3	Technological Developments	
4	Customers	
5	Developing and launching new products and services	
Internal Drivers for SMEs to Grow and Innovate		
1	Drive to seek out new opportunities	(Laforet, 2011; O'Regan, N. and Ghobadian, 2005)
2	Flexible culture	
3	Creative culture	
4	Desire to adapt	
5	Reduce costs (by increasing productivity of workers)	
6	Increase turnover (through exploiting new markets)	
7	Increase skill of the workforce	

Figure 8: External and Internal Drivers for SMEs

It is important to consider that an individual company may have a few or many of these drivers and that they may have varying impacts on the overall ability of the company to grow and innovate. However, the presence of these drivers does help to establish whether or not an SME fits into the category of companies that would benefit from the outcome of the Engineering Doctorate.

Drivers versus Capabilities

It is important to note that capabilities are considered as traits of a company, while drivers consider the motivations of the company. While some of these drivers also appeared in the consideration of capabilities, such as flexibility, in section 3.2.1, they were considered slightly differently in both the literature analysis and the case study analysis. The consideration of drivers analyzes the motivations of the company to innovate and grow whereas the consideration of capabilities analyzes existing traits that can be measured through either a quantitative or qualitative analysis.

So, for example, while a company may possess a strong flexible culture, this flexibility may or may not actually be a main driver for supporting innovation within the company; they may in fact be more strongly motivated by an external force, such as customers or competition. The capability of being flexible may help them to better innovate, but the actual driver to that innovation is the customer or competition. Capabilities and drivers do not need to be exclusive either, they can support one another. A flexible culture in a company may be motivated to be so to be flexible in the market, thus giving the company a unique selling point.

3.2.3 Understanding SME Challenges

As well as knowing what drives an SME, it is important to consider the factors that negatively impact these businesses. In their review paper, Garengo et al., (2005), listed the main traits that indicate significant challenges, as shown in Figure 9. Out of these five traits, four center on limited resources of capital, staff, time and knowledge. The other trait is a result of those limited resources; the lack of being able to sufficiently plan means that the company depends on a more reactive approach to their business. Similar to the way capabilities relate to drivers, these traits of a business also relate to obstacles the business may face.

Trait	**Challenge to SME**
Lack of human resource	Staff are involved in operational activities and do not have time to engage in other strategic and management activities.
Managerial capacity	Staff have broad roles and responsibilities which leads to a neglect of management activities
Limited capital resource	Lack of cash flow can inhibit the ability for long term planning or implementation of potential cost-saving and efficient processes
Reactive approach	Constant fire-fighting to maintain the business makes strategic planning difficult
Tacit knowledge and little attention given to the formalization of process	Due to a lack of management capacity, processes and systems are not always documented as well as they could be, making future knowledge transfer very difficult.

Figure 9: Common challenges to SMEs, adapted from (Garengo et al., 2005)

As with the drivers, the obstacles for SMEs can also be categorized into external and internal. The traits presented earlier are considered to be internal obstacles for the business. Other literature indicated external obstacles as well, particularly around exporting and being able to compete on an international or global scale (Lane, Pearson, & Aranoff, 2010; Love & Roper, 2015). This factor is connected to other external obstacles an SME might face as well, including the level of competition, the state of their current economy and any

legislation that helps or hinder the process of expanding trade. Figure 10 categorizes the obstacles considered by external and internal. These obstacles have many parallels to the drivers presented earlier; these parallels are discussed in the following section.

External Obstacles for SMEs		
1	Competition	(Lane et al., 2010; Love & Roper, 2015)
2	Current economy	
3	Legislation	
4	Globalization and exporting	
Internal Obstacles for SMEs		
1	Lack of human resource	(Garengo et al., 2005; Salavou, H., Baltas, G. and Lioukas, 2004)
2	Managerial capacity	
3	Limited capital resource	
4	Reactive approach	
5	Lack of tacit knowledge / limited attention to formalization of a process	
6	Inadequacies in the organizational framework	

Figure 10: Obstacles for SMEs

3.2.4 Comparing Drivers and Obstacles

What motivates a company and becomes a barrier to a company can have many parallels to consider. The drivers and obstacles are shown side by side in Figure 11. Some are relatively obvious to compare; such as competition, which can be both a motivator but also an obstacle. Others require more consideration, such as the driver of customers, which can all be negatively affected by competition, the state of the current economy, legislation and regulations, and the impact of an increasingly global market. The customer may be motivating the company to innovate based upon some of these external obstacles.

Considering the internal factors, it can be seen how the lack of being driven to adapt, seek new opportunities, and be flexible and creative could lead to a reactive approach. Additionally, these motivators can be limited or stifled by poor managerial capacity. Therefore, in a real-world application, it is difficult to isolate the consideration of drivers without understanding potential and current obstacles to these drivers.

External Drivers	External Obstacles
Competition	Competition
Operational environment	Current economy
Technological developments	Legislation
Customers	Globalization and exporting
Developing & launching new products & services	
Internal Drivers	**Internal Obstacles**
Drive to seek new opportunities	Lack of human resources
Flexible culture	Managerial capacity
Creative culture	Limited capital resource
Desire to adapt	Reactive approach
Reduce costs (by increasing productivity of workers)	Lack of tacit knowledge / limited attention to formalization of a process
Increase turnover (through exploiting new markets)	Inadequacies in the organizational framework
Increase skill of the workforce	

Figure 11: Side by side comparison of drivers and obstacles for SMEs

3.2.5 SME Summary

This section briefly introduces the main concepts considered for the aspect of SMEs; how they are defined, what drives them and what obstacles they face, which are visually summarized in Figure 12. The first key outcome of this section focused on developing a comprehensive definition for an SME that considers not only basic quantitative measures,

such as size and sector, but other more qualitative traits of the company, such as their ability and desire to grow and their capability for innovation. The second key outcome considered the main motivators for an SME and classified them into external and internal, based upon current literature. The third and final key outcome was to identify and classify common obstacles, and then to relate those to the drivers and consider how these could impact these drivers.

There was an innovative capability, the development of a methodology and tools to support innovation that could be considered as a common theme to explore further. This development of a methodology and tools could support the company's capability to also create new products and services and enter new markets, so it becomes a significant capability to develop and maintain. For an SME that faces obstacles related to resource; around capital resource, knowledge and human resource, having simple and easy tools and methods to use could be a factor in helping to improve their ability to innovate and introduce new business models, such as servitization.

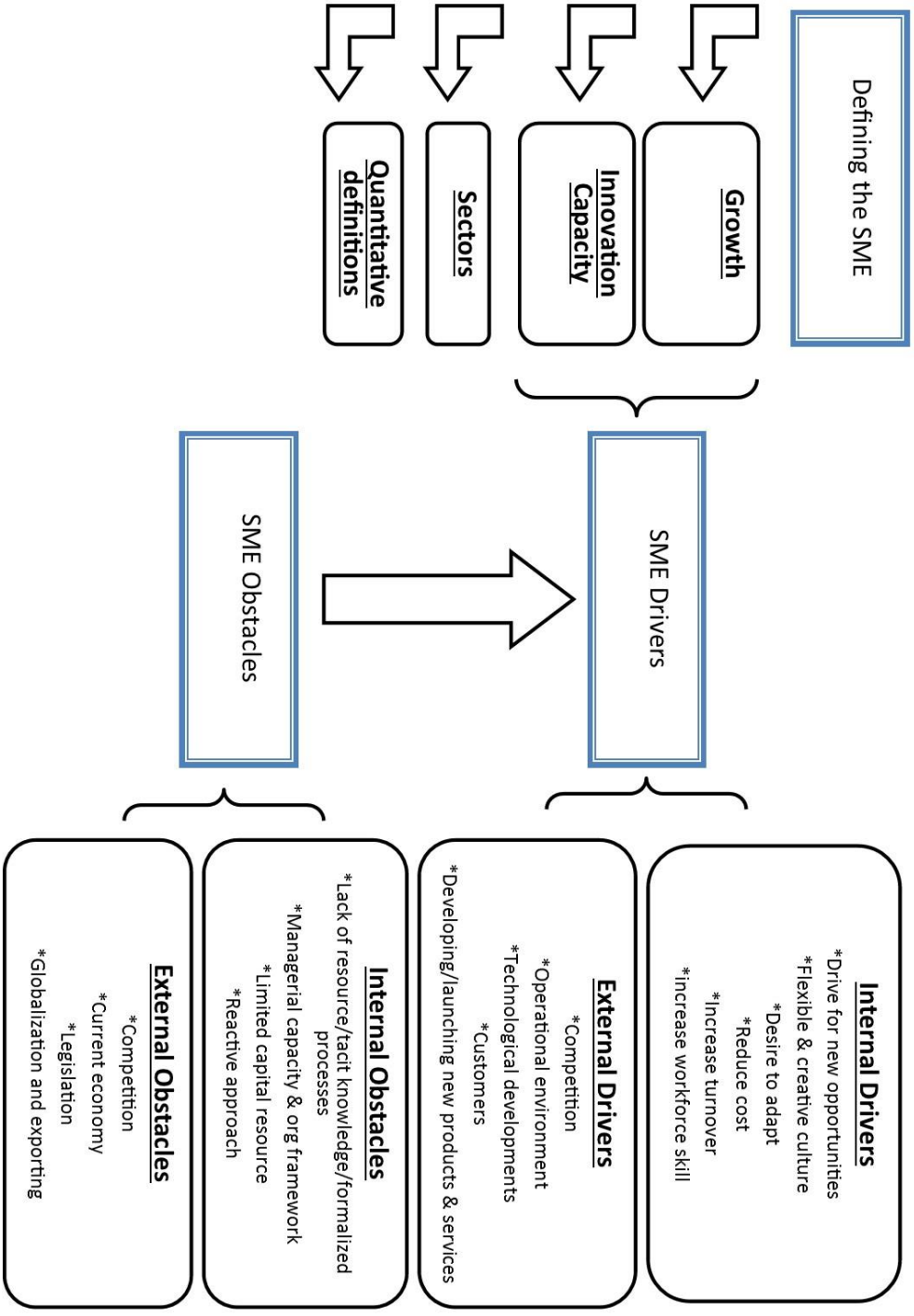


Figure 12: A summary of the key concepts considered for SMEs

3.3 Understanding Servitization in an Industrial Context

The second theme considered in the literature review was servitization. Servitization has become an increasingly valuable business activity in recent decades as well as a growing field of academic research (Neely, 2013). The concept first appeared in the literature in the late 1980s and has evolved since; starting as an intangible value creation aspect to a business (Vandermerwe & Rada, 1988), into a more complex relationship between goods and services that is presented in both academic and industrial literature (T. S. Baines, Lightfoot, Kay, et al., 2009).

3.3.1 Definitions of Servitization

The term "servitization" was put forth by Vandermerwe and Rada (1988) as a way to describe their observation of "increased offering of fuller market packages or bundles of customer focused combinations of goods, services, support, self-service and knowledge in order to add value to core product offerings." The evolution of delivering not just products, but solutions to customers shows a strong customer centricity in mindset of businesses (Davies, 2004; Miller, Hope, Eisenstat, Foote, & Galbraith, 2002). Many researchers have studied the phenomenon over the past few decades and have contributed various ideas and thoughts to the discussion of how to define it. The idea that there is a blurring between the concepts of product and service and that all offerings lie on a "product-service continuum" shows that there are different and innovative ways that businesses are attempting to add value (Leonard T. Berry, G. Lynn Shostack, 1983; Rogelio Oliva & Kallenberg, 2003).

A large focus has been on the manufacturing industry; a traditionally product based industry for which it can be argued has quite a large need in recent decades to add value and innovate

to remain competitive and relevant in many markets (T. Baines & Lightfoot, 2014). The academic community, in recent years, has established a category of research known as Service Science, which takes an interdisciplinary approach to understanding the ways a company can servitize its offerings by considering people, technology and business in a holistic way (Chesbrough & Spohrer, 2006). Figure 13 summarizes some of the main definitions found in the literature around this concept.

	Definition/Description	Source
1	*Value creation that is performed rather than produced*; essentially intangible; increased offerings/bundles.	(Vandermerwe & Rada, 1988)
2	*Strong customer centricity*, delivering not just products to customers, but solutions	(Davies, 2004; Miller et al., 2002)
3	A product-service continuum	(Leonard T. Berry, G. Lynn Shostack, 1983; R. Oliva & Kallenberg, 2003)
4	Innovation of an organization's capabilities and processes to better create mutual value through a shift from selling product to selling *Product-Service Systems*	(T. S. Baines, Lightfoot, Kay, et al., 2009)
5	*Service science*: people + technology + business	(Chesbrough & Spohrer, 2006)

Figure 13: The main definitions and descriptions of servitization from the literature

3.3.2 Motivators and Enablers of Servitization

Motivations for adding or creating new services within a business can be categorized as financial, strategic and marketability. Financially, servitization can both regulate cash flow and contribute to higher profit margins. Strategically, it can help a company gain a competitive advantage. Finally, marketability allows for a stronger relationship with the customer (T. S. Baines, Lightfoot, Benedettini, et al., 2009). These motivators are summarized in Figure 14.

Motivators for Servitization	
Financial	Regulate cash flow and contribute to higher profit margins
Strategic	Gain a competitive advantage
Marketability	Develop a strong relationship with the customer

Figure 14: Main motivations for servitization

Enablers of successful implementation of a service can also be categorized into three main areas. First, technology is a strong enabler (T. Baines & Lightfoot, 2014). Second, development tools, such as service blueprinting, have shown to have a positive impact (Kostopoulos, Gounaris, & Boukis, 2012). Finally, the overall viewpoint of the business in terms of how it considers its products and services in relation to the customer is arguably the most important enabler to a successful implementation of servitization (Smith, Maull, & Ng, 2014; Vargo & Akaka, 2009). These enablers are highlighted in Figure 15.

Enablers of Servitization	
Technology	Particularly, recent advances in information and communication technologies, are creating new opportunities to engage with the customer and provide better services and solutions
Development tools	Development tools, such as service blueprinting, can aid in the planning and creation of new services
Service-oriented viewpoint	How does the business see their products and services in relation to the customer

Figure 15: Main enablers for servitization

For this research, all three of these enablers are key in the later consideration of how the Internet of Things enables servitization, because the IoT has aspects that go beyond just the development of new technology that can enable servitization for a business.

3.3.3 Barriers to Servitization

Service implementation does not always go as planned within the company, as reflected in the literature. In a survey of 123 European industrial companies, many reported problems with the services they were developing or offering to their customers. There were six main problems reported. Over half the companies surveyed reported high development costs and long development periods to get the services ready for market. Once these services went to market, again over 70% of respondents reported that the sales of the service were lower than they predicted and that they struggled to establish an appropriate selling price of the provided service. Finally, issues were reported in the overall quality of the service, in that the service did not meet the customer requirement and there was an overall lack of quality (Fischer, Gebauer, Gustafsson, & Witell, 2009).

Enablers that were presented in the previous section were considered as to how they relate to the problems reported from companies attempting to servitize their businesses. Another study of eleven large German capital equipment manufacturers was also considered. This presented a specific issue in transitioning from a product-centric mindset to a service-centric mindset, which had further ramifications in the success of the developed services and the expectations placed on them (Rogelio Oliva & Kallenberg, 2003). The results of this consideration, along with justification are shown in Figure 16. For all of the problems, better development tools are needed to minimize the issues faced later on. Additionally, the service-oriented viewpoint is also critical in addressing four of the reported problems, particularly around developing a service that meets the customer requirement.

Problem		Main Enablers Needed	Justification
1	High development costs	• Development tools • Technology	Both time and cost can be better managed with the right technology and development tools.
2	Long development time		
3	Sales lower than predicted	• Development tools • Technology • Service-oriented viewpoint	Better development tools may help the company predict sales better alongside the right technology to manage those sales. It is also important that the mindset to develop what the market requires is present
4	Unable to bill for service	• Development tools • Service-oriented viewpoint	Better planning and understanding of the market need can clarify what is adding value to the customer
5	Lack of quality in developed service		Better initial project planning can improve quality, but the viewpoint of the company is important to make sure they are addressing their customer's needs.
6	Service does not match customer requirement	• Technology • Development tools • Service-oriented viewpoint	The viewpoint is critical here, to properly understand the customer, then to have the right tools & technology to develop the appropriate service

Figure 16: Main problems of servitization and possible enablers to solve these problems

3.3.3 Servitization in the Context of an SME

While a large focus of study has been on the manufacturing industry, there is a particular relevance, considering that manufacturing SMEs were one of the most likely SME industries to want to innovate and grow their businesses (BMG Research, 2013). However, there is little literature on servitization within SMEs currently. Aston University has conducted research since 2011, focusing on SMEs in the manufacturing sector to determine the reasons that SMEs are motivated to servitize. From recent engagement with about twenty SMEs

located in the West Midlands, Baines (2013) concludes that the motivations for smaller businesses are mainly parallel to motivations seen from their larger counterparts. These motivations, discussed in Section 3.3.1, were financial, strategic and marketability.

The case studies published from the research group indicate that the SMEs involved were largely focused on developing and understanding their own competencies and their customers. The case study reports available from the research group report the reasoning for servitization includes predictable cash flow (financial enabler), better relationships with their customers (marketability enabler) and advantages to understand and being able to predict issues with the technology and products (strategic enabler) (Musson & Forrest, 2015).

3.3.4 Summary

This section discussed servitization; how it is defined, what motivates and enables companies to servitize their offering and key challenges that are faced during this process. Servitization is a phenomenon that has grown in recent years, mainly in manufacturing, but also in other industries. There is a potential for great positive gain for a company, financially, strategically and in their market. Servitization, if conducted effectively, can help predict and normalize cash flow and improve company reputation and customer relationship. Many barriers still exist, however, and can possibly be addressed by introducing the consideration of key enablers.

There is not much literature or study on servitization at an SME, but it is thought that the motivations are much the same, though the challenges may vary. Case study research being conducted at Aston University (T. Baines, 2013b; Musson & Forrest, 2015) is starting to confirm the idea that motivations and enablers are similar. However, the application of the

process may need to be simplified to be able to be successful with the limitations faced by SMEs but not by their larger counterparts.

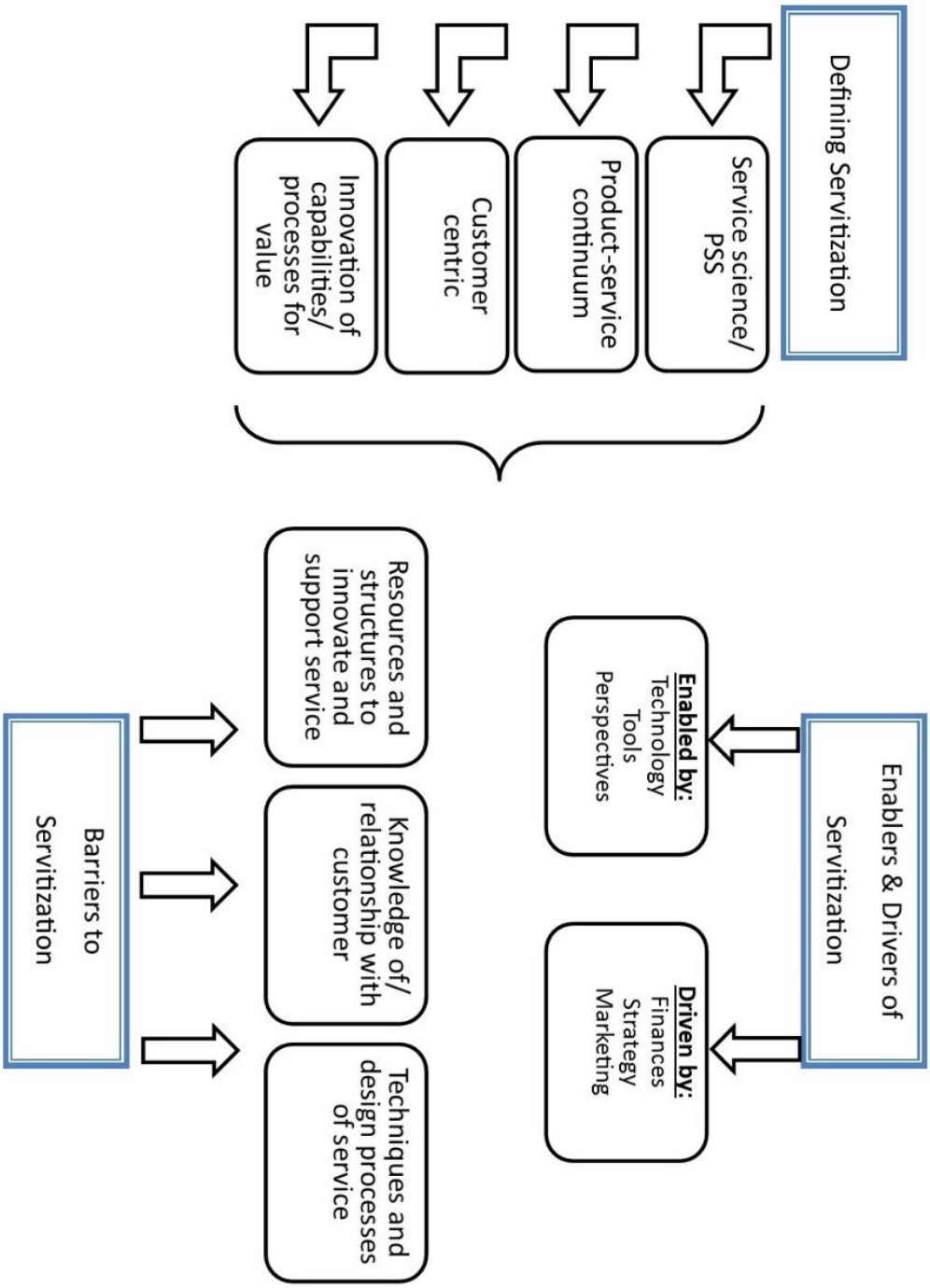


Figure 17: Summary of key concepts considered for Servitization

3.4 The Internet of Things

The third area of interest in this research is the Internet of Things. The term was first used at MIT in 1999 with the development of Radio-Frequency Identification (RFID) tags (Ashton, 2009). It has grown as an area of interest in recent years in both industrial and academic areas (Ng, Scharf, Pogrebna, & Maull, 2014; Porter & Heppelmann, 2014). Initially, it was viewed as a potential technology enabler for servitization in this research, but a clearer understanding of its ubiquitous nature indicate that the IoT has many further aspects with which to enable servitization within an SME.

3.4.1 Defining the Internet of Things

In its most simple definition, the IoT is the ability of objects to connect to the internet; allowing people to connect to objects, or objects to connect to other objects, or even people to connect to other people (Morgan, 2014). The aspect of connecting objects to other objects is known as Machine to Machine (M2M) (Skipper, 2014). On the whole, the ubiquitous or even pervasive nature of the IoT has the potential to affect nearly all aspects of human life (Kellmereit & Obodovski, 2013). This is due to the fact that the ability to collect data on this scale presents several opportunities and use cases to be explored by businesses and individuals.

The IoT is comprised of devices and sensor technology, the software that manages the data and devices and the infrastructure through which information can be transmitted (Ashton, 2009). The IoT is related and includes other corollary technologies, such as Big Data and Cloud technologies and services (Bessis & Dobre, 2014). The IoT in the near future is also

predicted to exceed people as the largest consumer and producer of information (Mukhopadhyay, 2014).

To fully define the IoT, however, the technology of devices and sensors that drives it is only one aspect. Other defining features of this new phenomenon are the network and infrastructure that are supporting the devices and software. Finally, the most important consideration for the IoT is understanding the opportunities and challenges the combination of these features present.

Aspects Defining the IoT	
Devices & Sensors	Devices ("things") that create data about use, status, and environment Sensors that collect and transmit this data
Infrastructure	How data is transmitted, this can be through wireless networks, mobile networks, or satellites
Software	Software that collects, compiles, interprets and analyzes the data into useful information, it can also be part of coordinating two way communication with devices (control)

Figure 18: Defining features of the IoT

3.4.2 Beyond Technology: Opportunities and Challenges

While technology is a main driver; it is the development of the sensors and the infrastructure that have allowed for this concept to exist, there are many more aspects that must be considered to fully understand the IoT, namely the opportunities it allows and the challenges it creates.

The main capabilities of the IoT, as outlined by Porter & Heppelmann (2014) are:

- ***Monitoring:*** comprehensively monitor an object and/or person's condition, operation and environment
- ***Control:*** control objects remotely through connectivity and embedded software
- ***Optimization:*** Use data analytics from in use or historical data to improve output, utilization and efficiency
- ***Autonomy:*** Objects work independently to complete tasks and coordinate with other objects and/or systems

These capabilities can allow for a wide range of opportunities for innovation within a business. Current literature suggests many possible opportunities from these capabilities, which include:

- The ability to understand product/service usage better (Kennedy, 2014)
- The ability to predict failures (Skipper, 2014)
- The ability to decrease costs (Skipper, 2014)
- The ability to use more aspects of data to make business decisions, develop and evolve the business model. (Hartmann, Zaki, Feldmann, & Neely, 2014; Turber & Smiela, 2014)

There are real world examples of how these capabilities are facilitating these above opportunities. A logistics company may remotely be tracking its fleet to reduce costs in transport routes or a manufacturer may monitor its equipment to understand the signs of potential failures so it may better suggest maintenance (Skipper, 2014). These can then lead to the acquisition of data that can allow for further long term business decisions to be made.

However, challenges do exist. These challenges can be categorized into three main areas; social and government, technical and business aspects. A main issue for the IoT currently exists around privacy and security (Spiekermann, 2013). How governments respond and regulate this rapidly evolving technological area is a massive challenge (Dutton, 2014). The technical challenges exist around the development of not only appropriate devices, but software and systems to properly manage these devices that allow them to successful achieve what is needed. Finally, the business challenge is around understanding the two previous challenges and how they impact the potential opportunities, so that the end user can have the best possible experience (Tsai, Lai, & Vasilakos, 2014).

IoT Challenges	
Social and Government	Data privacy and security Government legislation and regulation on how data may be used
Technical	Software, device and infrastructure development limiting what is possibly; capabilities of the technology itself
Business	Understanding how to work with the two previous challenges to create opportunities and value

Figure 19: Challenges for the IoT

3.4.3 Summary

The IoT is a rapidly evolving area that includes devices, infrastructure and software and the corresponding opportunities and challenges these aspects create. There are capabilities already proven with the existing technologies that allow for monitoring, control, optimization and autonomy. These capabilities already produce tangible benefits to businesses, such as failure prediction and decreasing costs. However, challenges still exist that need to be addressed, particularly with the social ramifications of such capabilities and how these will be

regulated by government – and then how businesses must respond to this. The technological challenges also provide limits that need to be addressed and considered.

Section 3.3 presented the enablers for servitization. These were classified as technology, development tools and a service-oriented viewpoint. While the IoT itself is driven by technology, there are other aspects to what it can provide and do that make it more than just a technology enabler for servitization. The IoT can create useful tools to help develop and innovate a service, such as through the capabilities discussed earlier. The IoT can also facilitate an evolving mindset as it allows for many ways for requirements to be met. For example, receiving real time data of product or service usage can allow a company to better understand that product or service in use, which can evolve the mindset into realizing that the customer is a co-producer of the overall value of their business. To reiterate, the IoT goes beyond just a technology enabler for servitization, allowing for development of tools and mindset change as well. This should be kept in mind throughout the presentation of the research.

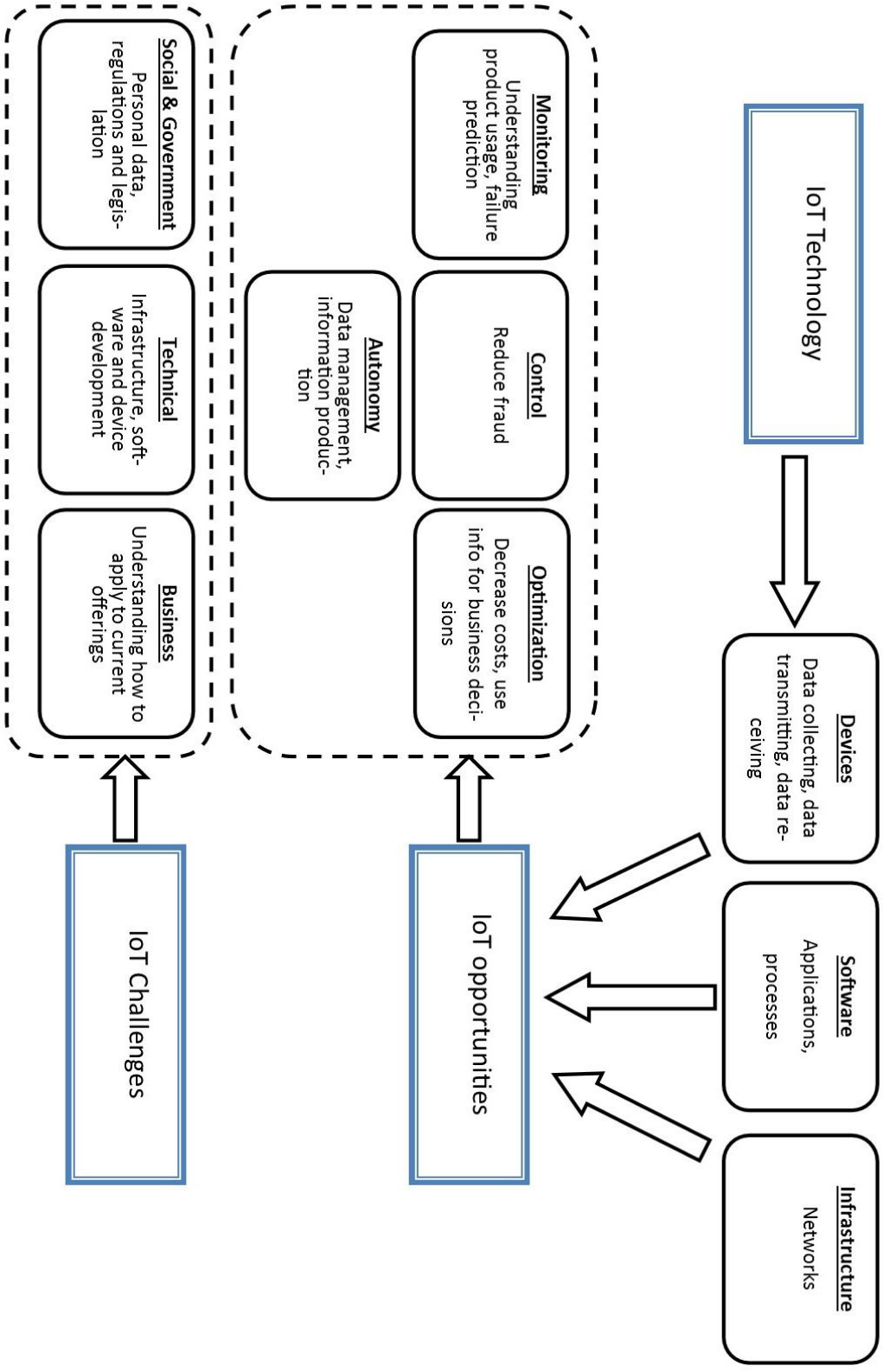


Figure 20: Summary of key concepts considered for IoT

3.5 How SMEs, Servitization and the IoT can be integrated to add value

Submission 4 (Chapter 2, section 5) showed an in-depth cross theme analysis of these themes. First, the relationship between each of the themes was considered; how IoT and servitization correspond, how IoT and SMEs relate and how SMEs and servitization come together in the literature.

Literature on IoT and Servitization is beginning to converge on an idea of "digitization", which considers the impact and evolution that IoT and servitization have on one another (Turber, Brocke, Gassmann, & Fleisch, 2014). It seems mostly focused on how the technology can enable servitization, but a consideration of other aspects of enabling may be seen in the near future in this space. Figure 21 presents some ideas as to how the IoT can enhance servitization enablers.

Servitization Enabler	How can IoT Further Enable?
Technology	Technology created for the IoT allows for capabilities that can provide data and information in a cost effective way
Development tools	The IoT can provide information about customer need and product usage that can be useful in the application of servitization development tools and potentially allow these tools to be more effective
Service-oriented viewpoint	The IoT allows for a much better understanding of a product in use, which can contribute to the business' changing perspective of what value they provide their customer

Figure 21: How the IoT can improve servitization enablers

Literature on IoT and SMEs seemed to focus on the fact that the cost of some of the aspects of IoT (for example, sensors) made the technology accessible for SMEs (Skipper, 2014). However, not having the resource to understand the complexity of the phenomenon and

how it may apply within the context of their business still remains a big challenge (Giuliano & Bengtsson, 2013).

Most research on servitization in industrial cases have been conducted at larger firms (T. S. Baines, Lightfoot, Benedettini, et al., 2009; Gebauer, Ren, Valtakoski, & Reynoso, 2012). However, the research being done at Aston University has produced some interesting case studies with manufacturing SMEs (T. Baines, 2013a; Musson & Forrest, 2015).

Large companies, such as Daimler Group and LG are initialing ways to engage with technologies and capabilities that are originating from the IoT, with particular consideration into servitizing their offerings. These large companies are understanding that this change will impact most of their business processes, but are confident in taking that risk (Ferber, 2013).

3.6 Developing a conceptual framework

Miles and Huberman (1994, p.18) define a conceptual framework as "a written or visual presentation that explains main factors, concepts or variables in a given context and the relationship among them. It has the advantage of being flexible and easily modified as new information is presented." Furthermore, it provides a better understanding of complex, multidisciplinary phenomena in a manner that cannot be conducted by purely quantitative methods (Jabareen, 2009).

A conceptual framework can serve many purposes. It can be used as a simple arrangement of ideas, particularly for research (Shields & Rangarjan, 2013). It can be considered a transitional concept between a model and theory (Meredith, 1993). It can link concepts, each defined by a set of components (Jabareen, 2009). It can be as simple and generalizable as Deming's "Plan Do Check Act" framework, or as specific as explaining ecosystem repair in alien-invaded riparian zones (Holmes, P, Esler, K., Richardson, D. & Witkowski, 2008).

Due to the definition and the wide variety of possible outcomes, it was decided early in the case study that a framework would be the best output of the research as it would allow for flexibility along the research journey. Additionally, a framework seemed to sit perfectly in the space between the academic concepts considered and the industrial applied space needed to be explored for the outcome of a successful Engineering Doctorate.

For this research, it became apparent early on in the relationship with Arcola Energy that there was a lack of usable tools at the SME level that allowed them to fully understand and utilize the concepts of IoT and servitization. The company was aware that there were opportunities and challenges with developing new services and utilizing new technologies,

but had no standardized way of approaching how to manage these. It was thought that the understanding learned about SMEs, servitization and the IoT could be combined into a framework that could aid in understanding of how these themes were relatable. Furthermore, a framework could serve as a tool that could be used to help the development of servitization, utilizing the benefits of the IoT, for SMEs.

As there is limited guidance on a systematic method to build a conceptual framework, key attributes for what would constitute a conceptual framework in the context of this research were first defined. Seven attributes, drawn from different sources, were considered as a way to test the framework as it was developed in the stages of the research. These attributes were:

	Attribute	**Source**	**Reasoning**
1	Easily modified with the introduction of new information	(Miles & Huberman, 1994).	A framework relating to fast changing technology, such as the IoT, must be able to reflect and adapt to those changes.
2	Facilitate understanding of underlying concepts	(Burnard & Bhamra, 2011).	The underlying concepts of the three themes are particular important to understand in order to have a successful application of a business model change.
3	Form foundation for future activities	(Burnard & Bhamra, 2011).	The success of the innovation of this framework is partially depending on its ability to be utilized effectively.
4	Improve and optimize an operation	(Jairo R. Montoya-Torresa, 2015).	This framework should be able to help an SME systematically improve and optimize how they are doing business.
5	Aid in decision making and provide guidelines	(Meredith, 1993).	The objective of creating the framework was to help SMEs systematically develop a service, utilizing the IoT and make decisions based on specific needs.
6	Flexible for use in different context and	(Jabareen,	This framework should be useful for SMEs in a variety of industries and with differing

	scenarios	2009).	business models; it should be more generalizable.
7	Captures something real and does it in a way that is easy to remember and apply	(Hunt, 2010)	The framework should take tangible factors (servitization and IoT) that are very real to SMEs today and be a simple, easy to use tool to improve the way they do business.

Figure 22: Attributes considered for the development of the conceptual framework

Chapter 3 in Submission 4 discusses the process considered to develop the first iteration of the conceptual framework. Essentially, the main concepts, SMEs, IoT and servitization, were considered along with their components (which have been visually outlined in Figure 12, Figure 17, and Figure 20). The relationship between these concepts and their components were then visually orientated in a logical fashion to show the relationships and how the concepts may be considered. The process considered the "Who", that is the SMEs, the "What", servitization, and the "How", utilization of the IoT. It connected these concepts with actions, such as 'understand' and 'establish' to help the viewer consider how these concepts should be processed. This version of the framework is shown in Figure 23.

3.6.1 Analysis of First Framework

The creation of the first framework was entirely based upon the literature review. It is a summary visualization of the three themes and attempts to show how the concepts relate. After it was created, it was assessed against the attributes the researcher defined to be important and necessary in the framework being developed from this research. In the context of the literature review and the other thematic framework visualizations, this first framework achieves attributes 2 and 3 from Figure 22; it facilitates understanding of the themes and could potentially form the foundation of future activities from this understanding for a business. However, it falls shorts of the other defined attributes as this

version of the framework is more closely related to the definition of a framework put forth by Shields and Rangarjan (2013); a simple arrangement of ideas for research. While it provides a good starting point for the conceptual framework, the analysis from the case study research was needed to try to achieve the other attributes.

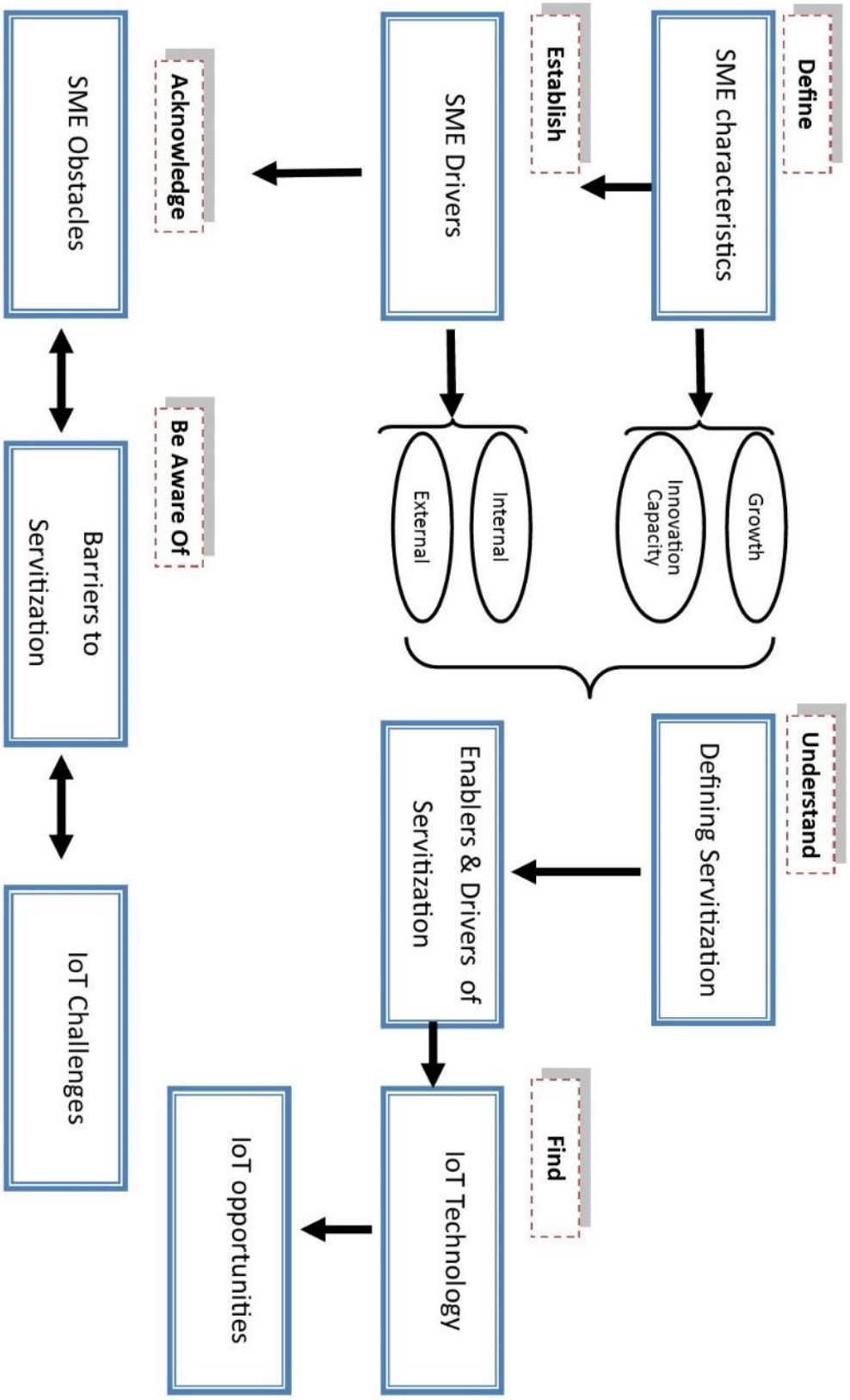


Figure 23: The first iteration of the conceptual framework from the literature review

3.7 Summary

This chapter served to provide a brief introduction to the main themes, SMEs, servitization, and the IoT, of the innovation and how they appear in the literature. First, SMEs were defined and common traits presented, then drivers and inhibitors of innovation and growth for these businesses was considered and analyzed. It was found that, while many businesses wanted to innovate and grow, SMEs lacked the resources, tools and capabilities to do this successfully. Next, a potentially value-adding business model concept, servitization, was discussed, and the motivators, enablers and challenges presented and compared. Servitization, when successful, can provide many benefits for a business, but often struggles to be developed properly, due to inappropriate or a lack of development tools and issues with company mindset. Finally, the IoT was defined, the capabilities of what it allows and the challenges it presents was discussed. The IoT offers the potential to improve how services can be developed, through a better understanding of the customer need and product usage, as well as improved communications between the business and the customer.

Further analysis of interactions between these themes were also presented and discussed. The consideration of three distinct themes and how they interrelate is one of the innovative aspects of this Engineering Doctorate. It is an attempt at interdisciplinary research at a new cross-section of topics. Interdisciplinary research can be difficult, but can help to lead to new insights and facilitates a more radical interaction between different styles of knowledge. In particular, there can be an improved link between technological advances with social innovations (Stirling, 2014) .

The idea that the IoT goes beyond just a technological enabler for servitization is an important realization moving into the case study research. Considering the main enablers of servitization in conjunction with the benefits of the IoT, there is scope for the IoT to help enable servitization, which could be especially beneficial to SMEs, because the IoT could reduce the time and cost needed. However, the complexity of adding services is still difficult and what is needed most is a tool that can help SMEs better understand and apply servitization to their business.

Developing a framework to clarify the main aspects of these themes was presented as a way to develop further innovation. This first iteration of a framework was based strongly in the academic theory and ideas of the themes and serves as the core of the innovation. Further iterations were developed from industrial applications and feedback, which simplified the framework to a more workable tool, but the basis is still strongly rooted in comprehensive theory and literature on the themes.

Chapter 4: SME Case Study

4.1 Introduction

This chapter introduces and explains the main empirical research conducted during the Engineering Doctorate. It will introduce the company studied and the specific project that was used to evolve the framework presented in Chapter 3. Then, the chapter will explain the methodology applied to conduct the research and discuss the results of the study. Finally, how the case study applies to the evolution of the created framework will be discussed and a final version of the framework will be presented.

4.2 The Case Study Company: Arcola Energy

Arcola Energy is based in Hackney, London and can be categorized in the professional, scientific and technical activities sector, the second largest sector in terms of SME employment in the UK. The SME currently employs about 15 people and is actively recruiting at the time of this writing for more engineers. The company was established in 2010 and shares facilities with a theatre (Tyler, 2010). The company has relied on government support and collaborative research and development in its early days, but has also seen solid growth in the sales of the their products and services over the past two years (InnovateUK, 2014). The company develops and sells fuel-cell based energy solutions and is in the process of expanding manufacturing capabilities of Polymer Electrolyte Membrane Fuel Cell (PEMFC) technology on the watt and kilowatt scale. Arcola has three main product lines that focus on small scale portable power (about 1-100W), medium scale portable power (100W- 1kW) and small scale automotive (1-10kW) (Arcola Energy, 2014). In recent months,

the company has also evolved to incorporate their technical expertise and in house development of remote monitoring systems to create new services for their customers.

While research was going on with the Formula Student project in the early days of the Engineering Doctorate (discussed in section 2.2 Understanding SMEs), parallel work with the HVM Catapult led to engagement with Arcola Energy. When it was decided that the Formula Student project would not be sufficient for the research, Arcola Energy was approached as a possibility for a case study, considering the company's interest with IoT technology, unique models they were exploring with their business and their status as an SME.

4.3 The Case Study Project

Approximately six months were spent with the company before the project was determined for the case study, which is explored in greater detail in Submission 4, Chapter 4. These six months were spent understanding the company's issues with data collection, management and the presentation of the IoT-enabled capability. The project selected considered both the company's development and use of IoT tools and opportunities and their evolving capability to provide services in many aspects of their business model.

Arcola Energy was one of three partners in an Innovate UK-funded feasibility study around the development of a hydrogen market in the UK. This project started in June 2014 and ran for 18 months (6 quarters), concluding in November 2015. The funding call was opened in September 2014 and was titled, "Unlocking the Hydrogen Energy Market." It was a joint funding effort between Innovate UK and the Engineering and Physical Sciences Research Council (EPSRC) of "up to £6m in collaborative R&D to stimulate innovation in technologies that will enable a wider market for hydrogen energy systems." (TSB, 2013).

Arcola Energy's role was to develop monitoring systems for the fuel cell systems so that important data about energy usage can be collected. This data will then feed into a development of customer understanding and optimization of the service. The two other stakeholders in the bid have expertise in business services and industrial hydrogen gas supply and PEM fuel cells, respectively. While the collaboration aspect of the project is a main theme, the focus of this case study was on how Arcola Energy would be applying their IoT expertise in the development of a service business.

The project considered the feasibility and business case of providing "Energy-as-a-Service" in off-grid situations, specifically for industries in construction, utilities and transport. These industries can experience situations where energy is needed but can be otherwise costly and inconvenient to source. A key technological innovation being developed at Arcola Energy through a system configuration tool that, when given certain data, allows for service providers and account managers to specify customized solutions to customers. This tool will learn from the data being collected to evolve an increasingly accurate model for the business. At its conclusion in November 2015, the project met the end goal of having a viable business model ready for implementation.

An active role was played during this project, contributing to the end result of the overall project. This contribution included process maps for the overarching as well as underlying business process, a costing analysis and advisement on servitization concepts. This was categorized as a type of qualitative data, specifically participant observation data, as it allowed for insight into the case study from a unique perspective. Some of this work was presented to Innovate UK representatives at the concluding meeting of the feasibility study.

These representatives indicated in this meeting that they were impressed with the aspects delivered. They further acknowledged that, while the technological developments were innovative for the project, the main innovation was around the business model and how that was developed ("Final Innovation in Services for Off-Grid Hydrogen Energy Innovate UK Meeting.," 2015).

4.4 Research Philosophy

In the establishment of the research philosophy, the orientation of the research ontology and epistemology was first considered. Ontology is defined as "assumptions we make about the nature of reality" and epistemology is defined as the "general set of assumptions about the best ways of inquiring into the nature of the world" (Easterby-Smith, Thorpe, & Low, 2004, p.31). In more simple terms, ontology is concerned with the nature of reality and the role of the observer in the research (Easterby-Smith et al., 2004; Saunders, Lewis, & Thornhill, 2012). It can be roughly divided between a perspective of realism and relativism. The epistemological approach is influenced by the ontological orientation of the research, as it establishes what knowledge is imperative to the work (Saunders et al., 2012).

For this research, the ontological orientation leans towards Relativism, as it is dependent on the viewpoint of the observer and due to the wide variety of themes of the work, requires finding a consensus between different viewpoints (Easterby-Smith et al., 2004). This is parallel to what is defined as Subjectivism or Social Constructionism, which takes the perspective that social phenomena originate from perceptions and subsequent actions of humans (Saunders et al., 2012).

More specifically to this Engineering Doctorate, the ontology relates to the fact that the researcher played a central, active role in the case study which was shown through the types of data collected and produced (for example, the work done by the researcher for the feasibility study, as explained in section 4.5.1, particularly with regards to the participant observational data). This influenced the researcher's viewpoint, as was seen from the results of the second coding (section 4.5.4), particularly around the fact that the second coders expressed a shortcoming around a lack of context of the case study. Additionally, the researcher had to interpret subjective qualitative data as well as correlate the themes (presented in Chapter 3) of the research that in some contexts may not seem relatable in some interpretations. The core effort of the Engineering Doctorate was to relate three themes in a way that they had not been considered previously, which was the result of considering the various viewpoints, issues and research and combining them in a new way.

From the starting point of relativism for the ontological orientation, the epistemological orientation would then be considered to follow Interpretivism, as it is defined in Saunders et al (2012) or Social Constructionism, as defined by Easterby-Smith et al (2004). Interpretivism is counter to a Positivist or even a Realist approach, which are usually more appropriate to natural sciences. Because of the role of human decision and action, it is the obvious choice as a research philosophy. Saunders, et al, (2012) present the perspective that research philosophy may not follow specific rigorous defined positions, but may lie on a continua. This was seen in the research journey by the researcher, as the codes defined during the case study evolved throughout to the final interpretation and analysis, which is further expanded upon in Section 4.5.2 and in Appendix A. Therefore, while these main perspectives give some

structure to this research work, there may be aspects of other philosophical approaches that may prove worthwhile for future consideration.

4.5 Research Method

This research takes an iterative combination of an inductive and a deductive approach, using literature to create a framework, and through the field work to test that framework. First, a conceptual framework was derived from literature in a deductive fashion. Next, case study data was applied inductively to empirically test the findings from the literature and improve the framework. The final outcomes of the doctorate are predominantly inductive, though there is deductive influence in the early stages of development. This aligns with the idea that these two approaches are blurred, put forth by Partington (2002) about empirical research conducted to test theories or frameworks.

Careful consideration of the strengths and weaknesses of the various possible research methods was given. A purely quantitative approach was ruled out, as it is associated with highly structured data collection techniques with a positivist philosophy (Saunders et al., 2012) and is suited for other types of research questions, i.e. ones that emphasize breadth as opposed to depth of findings. Since the aim of this research was to explore in-depth how a small firm utilizes the Internet of Things to servitize their business, rather than conduct a large-scale study of all firms, a qualitative methodology is most suited for the purpose. The interpretive philosophy adopted in this study is more conducive to a qualitative methodology. However, a mono-method qualitative approach, where only one form of data, such as semi-structured interviews is collected, was considered to not be robust enough for strong conclusions.

A multiple-method qualitative study was decided to be the most appropriate approach, because various types of qualitative data were collected in the form of observations, semi-structured interviews and documentation. A major advantage of a multiple method is that it allows for triangulation of different sources of evidence to strengthen conclusions (Saunders et al., 2012). Silverman (2010) also highlights the benefits of a multiple methods approach[1], but cautions that time, resources and experience can constrain and make determining the true nature of the study difficult.

Case Study

The core strategy of this research was a case-based approach. Using Yin's (2014) definition of a single case study, the rationale used for this strategy is that it is a common case. It is an insight into a small business that shares many common traits with other small businesses, to see how they utilize the Internet of Things to servitize their business offerings. A case study includes a wide range of data, including interviews, observations, documentary analysis and questionnaires that usually need to be triangulated (Saunders et al., 2012). While this can be a controversial approach, strong arguments have been made for the theory, reliability and validity of a well-conducted single case study as a solid method for generating theory and generalizing findings (Flyvbjerg, 2006).

[1] While Saunders (2012) differentiates multiple methods from mixed methods, other literature, such as Silverman (2010) does not and classifies multiple methods and mixed methods as the same approach.

Time Horizon

The aspect of time must be considered with this study and there are two approaches to consider in this regard. The first is a cross-sectional approach, which gives the outcomes of a phenomenon or occurrence at a specific time. The second is a longitudinal approach, which explores a change over a time (Saunders et al., 2012). This research follows a fifteen-month feasibility study started in September 2014. More specifically, the work will show the process the SME will go through to use its existing and potentially new IoT technologies to develop the beginning stages of an Energy-as-a-Service offering. Therefore, it is best to define it as a longitudinal study.

4.5.1 Data Collection

Yin (2014) outlines six major sources of evidence for case study research: documentation, archival records, interviews, direct observations, participant-observation and physical artifacts. Four of these six types were collected over the course of 25 months, from October 2013 to November 2015; namely direct observations, participant-observation, semi-structured interviews and documentation. These data were tracked in a separate spreadsheet that dated each interaction with Arcola, categorized the type of evidence it was, and gave a short description. The strengths and weaknesses of the evidence collected is shown in Figure 24. Multiple sources of evidence, particularly in case study research, allows for triangulation to occur in analysis. This is a major strength overall of conducting a case study (Yin, 2014).

Source of Evidence	Strengths	Weaknesses
Direct observations	• Immediacy: covers action in real time • Contextual: can cover the case's context	• Time-consuming • Selectivity: broad coverage difficult without a team of observers • Reflexivity: actions may proceed differently because they are being observed • Cost: hours needed by human observers
Participant-observation	• (Same as above for direct observations) • Insightful into interpersonal behavior and motives	• (same as above for direct observations) • Bias due to participant-observer's manipulation of events
Interviews	• Targeted: focuses directly on case study topics • Insightful: provides explanations as well as personal views (e.g. perceptions, attitudes and meanings)	• Bias due to poorly articulated questions • Response bias • Inaccuracies due to poor recall • Reflexivity: interviewee gives what interviewer wants to hear
Documentation	• Stable: can be reviewed repeatedly • Unobtrusive: not created as a result of the case study • Specific: can contain the exact names, references and details of an event • Broad: can cover a long span of time, many events and many settings	• Retrievability: can be difficult to find • Biased selectivity, if collection is incomplete • Reporting bias: reflects (unknown) bias of any given document's author • Access: may be deliberately withheld

Figure 24: The strengths and weaknesses of the sources of evidence collected from the case study, adapted from Yin (2014), p. 106.

Direct Observations

Direct observations in a case study can range from formal to casual data collection and is useful in providing additional information about the topic being studied in the case study (Yin, 2014). Over the course of the two years, at least two days per month were spent at the Arcola Energy offices in Hackney, London. Furthermore, other time was spent at meetings off site, at places like Cheltenham at the Commercial Group offices and a company away

overnight event in South Downs. During this time, observational data was collected and recorded in a series of three notebooks. These notebooks were periodically typed up, to maintain a digital copy of the data should anything happen to the hand-written version. These notes cover the period from the first meeting with Arcola Energy on 30 October, 2013 to the final Off Grid Project meeting on 24 November, 2015.

These observations include ideas from discussions with the employees at Arcola, notes from any meetings attended, and the researcher's thoughts.

Participant Observation

According to Yin (2014), participant observation data is a special mode of observation in which the researcher becomes an active observer, assuming a variety of roles within the fieldwork situation. Other sources also consider this sort of data important to the interpretation of an event, according to J.J. Hader & E.C. Lindeman (1933), this interpretation can

> "only be approximately correct when dealing with a set of two points of view, the external and the internal. Thus, the vision of the person who has been a participant in the event, whose desires and interests have been, somehow, monitored, and the vision of the person who was not a participant but an observer or analyst, merge into a complete synthesis."

An active role was a part of the case study; resulting in contributions to project deliverables used by Arcola and their partners on the project, namely the development of process and capability maps, costing models, creating use cases and business modeling for providing a service. Overall, 15 pieces of work were conducted for the Off-Grid Project and eight pieces of work were conducted for the SME. This work is in a variety of formats, Visio process maps,

spreadsheets of data parameters collected from IoT sensors and Power Point presentations for the Off-Grid project meetings. These data sources supported some of the notes collected from observational data (such as meeting notes) and also showed the themes explored in the case study when coded.

Semi-Structured Interviews

Eight interviews from six different individuals were conducted for this case study. The participants interviewed were all employees of Arcola Energy, and three of them were also working on the Off-Grid Project specifically. Each interview lasted between 20-30 minutes. The first set of interviews were conducted in October 2014 with five individuals and the second set was conducted in July 2015, with three individuals. These interviews were then transcribed by the researcher.

The first set of interviews in October 2014 was to get feedback about the company from a varied list of perspectives. The second set in July 2015 focused on the Off-Grid project and how it relates to the future overall direction of the company. All of the formal semi-structured interviews conducted were recorded and transcribed, to be coded.

Documentation

Documentation data is relevant to most case studies and can take a variety of forms (Yin, 2014). The researcher had access to most company documents throughout the course of the case study. From these, 26 documents were used in the analysis. The documentation from this case study stems from email correspondence, company records, and project documentation, mostly stored in the cloud (Google Docs). Project and company

documentation consists of any relevant documents or diagrams about the projects worked on or generally about the company. These include project reports, visual outlines, and emails.

4.5.2 Data Analysis

The data was coded in two cycle process, in procedures outlined in Saldana, (2013). The first cycle coding method was descriptive coding, or topic coding, where the data was categorized into twenty-four different nodes using descriptive coding. Descriptive coding is a way to summarize passages of qualitative data by words or short phrases. Then, in the second pass of coding, pattern coding was used to group these nodes together; by the themes seen in the literature review. According to Miles & Huberman (1994), pattern coding is the second cycle of coding that develops the major themes from the data, and helps with the formation of theoretical constructs and processes. For this research, the pattern coding created a meta-data of six nodes:

1. Arcola Energy SME
2. Arcola Energy IoT
3. Arcola Energy Servitization
4. Off-Grid Project Business Case
5. Off-Grid Project IoT Technology
6. Off-Grid Project Servitization Development

The first node was dedicated to the characteristics of the SME being studied. The second and third nodes considered the topics of both IoT and Servitization as it was seen generally in the business. The final three nodes considered these first three aspects as they applied specifically within the Off-Grid project.

For this part of the analysis, NVivo was used to help organize and code the data. The text was imported into Nvivo, and nodes were made to categorize the data. Some data (such as an Access database created by the researcher in the category of participant observation data) was not able to be imported, however, there was other data referencing this work (such as notes and emails). An example is shown in the appendix A. Further analysis was done after the coding to rank the importance of the themes considered in the context of the case study. For example, the literature review showed a list of drivers for an SME, and data from the case study was used to show how strongly or weakly these specific drivers applied to this SME. This ranking is shown in Submission 4.

Limitations

Qualitative research and case study research have many well-known limitations. Qualitative research generally provides a rich picture of understanding of a situation, but it can be difficult and time consuming to interpret and disseminate (Maxwell, 2013). Additionally, the rigor of a case study can be questioned if the research is not conducted in an organized and systematic manner (Yin, 2014). Modern methodology literature has contributed a great deal over the past few years to prove that case based research can be generalizable, generate valuable knowledge and overcome researcher bias (Flyvbjerg, 2006; Maxwell, 2013). For this research, these limitations were considered and the risks were minimized through the amount of time invested in the case study, the systematic way a range of data sources were collected and analyzed and a review of a sample of the data by two second coders, discussed in the next section.

4.5 Results of the Case Study

The data from the case study was analyzed with respect to the three themes of SMEs, servitization and IoT in a systematic way. The full analysis appears in Submission 4, Chapter 5. The main outcome achieved from this case study was an understanding of the process an SME would undertake to develop a Servitization business model utilizing the IoT in a real world setting. This understanding was coupled with the literature review to develop the comprehensive framework, which is presented in its final version in Section 5.5.

4.5.1 SME Theme

Both the overall company and the specific project, when relevant, were considered for this part of the analysis. It was found that the company had many common drivers and obstacles for businesses and for SMEs in particular. The data sources used for this analysis were observational data, participant observation data, semi-structure interviews and company documentation. A more specific reference of these sources and which sub-themes they relate to is given in section 5.2 of Submission 4.

First the characteristics and traits of Arcola Energy were compared with the various traits found from the literature. The company met the definition of an SME by both the number of employees and annual turnover. According to the descriptions found, Arcola Energy best fit into the professional, scientific and technical sector. The business meets the requirement for a company interested and actively engaging in growth activity; seen through statements by the managing director and by the increase in employees and turnover in the past five years. Arcola had capability for innovation as well, showing strengths in their technical skills, quality of their research and development and their ability to collaborate effectively.

Next, the drivers for the company were considered, both for the company in general and for the specific case study project. One of the strong external drivers for both was the relationship that existed with customers. Internally, there were also several strong drivers, including the drive to seek out new opportunities, the desire to adapt, reduce costs and increase turnover.

Finally, the internal and external obstacles were contemplated. Externally, the biggest threats to the company are the current economy and any favorable or unfavorable legislation that may be passed with regards to energy technologies. Internally, obstacles existed for the company around capital resource and lack of tacit knowledge and for the project around managerial capacity.

4.5.2 Servitization Theme

For the servitization theme, the analysis was focused mainly on the Energy-as-a-Service project. A detailed description of the nodes and the supporting data sources is given in Section 5.2, Submission 4. For the aspect of defining servitization, it was a very fluid task for the partners involved as there are many different methods through which service can be delivered. The original project charter, written in January 2014, states that the project;

> *"..will enable a service approach to energy supply for customers in construction, utilities and transport sectors. The key technical innovation is the development of a sophisticated, data-driven system configuration tool that will enable service providers and account management teams to specify a hydrogen energy solution to customers without detailed knowledge. This project will enable the service providers to gain returns from the TCO benefit of a H2 & FC (and sometimes battery) combination. In addition, the service model will further drive energy efficiency by encouraging the installation of energy efficient equipment, such as LED lighting and PIR sensors to enable better matching of power use and supply from a Hymera-based system."*

Much of the definition of servitization for the project was based upon the technology, specifically the IoT capabilities of monitoring to accurately predict both the customer need to install a system and the usage rates to optimize the hydrogen fuel deliveries.

One particularly interesting aspect that was considered during the analysis of the project's servitization definition was how aligned much of the thinking was to the Service Dominant Logic (SDL) presented in the literature review. Specifically, the partners recognized the importance of a quality relationship with the customer and how the value of what they were offering was dependent upon the customer's need. Furthermore, they wanted to engage with the customer to allow them to understand and take control of their usage, which could have a potential effect on the costs. This aligns with SDL thinking in that the customer is a co-producer and that the value is determined by the beneficiary.

The enablers for the servitization for this project were seen mainly from the technology, particularly the IoT technology. However, this also allowed for a more servitized mindset from the partners as well, as the IoT tools presented unique use cases that could be considered more readily. The project lacked many specific servitization development tools, but as one of the partners had expertise in customer service, they were able to provide some expertise on this. However, the innovation manager at Arcola Energy did reflect that it would be good to have better development tools and knowledge, as reflected in his comment below:

> *"So I think one of the key learnings is that there is a service role required. So it's not just about product and technology, customers need the service. It's a proof of market, if you like of a servitized business. Um, I think there's quite a bit of learning in there about the specifics of the project, the business model, what the price points are for competitor technologies and where it fits, that's just been useful, useful in any new*

> *technology course, not specific to Servitization. Um, but I think in relation to that is an element of complexity of what a service model looks like as opposed to "make, sell, ship, support," the conventional product model. Ok, there are complexities in that, but when you're trying to do a service model in a way that is profitable there's a lot of things to take into consideration and the complexity of the flow chart, means that there's a lot to take into account and work out where all the costs are. I think a lot of that we've done from the ground up and maybe there is common lessons that are learned around doing this in other sectors that could be re-applied to this one so we know we were not missing a trick. And we've had very good support in all of that, of course"*

The drivers to servitize were seen to be the traditional drivers found in the literature; financial, strategic and marketing. The strategic driver was particularly strong as it was an opportunity to succeed in a niche market but also show viability of the technology in a business sense.

Overall, the feasibility of the business idea was decided to be a success at the end of the project and the partners are actively moving forward with it. This success was partially helped by the fact that the project did not face as many difficulties with servitizing the model as was reported by other companies in the literature. The biggest challenges faced around servitization on this project was the lack of both creative techniques and a methodical design to innovate the service; however, this was balanced by the flexibility and adaptability of Arcola Energy and by some expertise that one of the partners provided.

4.5.3 IoT Theme

While the specific term, "Internet of Things" was not readily used in company documentation, it was a central development seen in the case study project, particularly in regards to the remote monitoring system that the main engineer was creating. Additionally, the semi-structured interviews reflected that it was a term that was comprehensively understood by most of the individuals involved at Arcola Energy on the project. The focus was on practical development of the monitoring technology. There was an awareness, especially from the project engineer, that this ability to monitor only was part of the overall opportunity from the IoT; he was very focused on developing a user interface that would intelligently communicate the data to the various stakeholders in the business concept. It was this deep understanding of the IoT and the potential capabilities that was paramount in the successful development of the business idea.

The opportunities available from utilizing the IoT were also fairly well understood by key members of the project. Arcola Energy's Innovation Manager was keen to see the concepts of service and IoT merge within the company;

> *"I think fundamentally it's only possible to do the sort of services we want to do with the range of technologies if we're using IoT technologies. It's not possible otherwise…… So there's two things. One is, IoT technologies are essential to where we want to go in services and Two: there are developments in IoT that we can make the most of, cheaper hardware, other companies doing things that we don't have to re-invent that's going to help us get there more quickly and scale more quickly than trying to do it ourselves. So it's a really useful area to be a part of so we can focus on what we're good at."*

This ability coupled with the holistic understanding of what the IoT is, from both key members of the SME and on the project was critical in the success of developing the service business model. There was a holistic consideration of what the IoT may provide for the

company; how it may affect their supply chain and relationships, how it may help the company develop and offer services, and how they can possibly learn from other use cases around IoT. In particular, it was observed that remote monitoring would have two main roles in the project; first to understand a particular site so as to appropriately fit an energy system to it, and second to monitor the site after system installation to know when hydrogen needed to be delivered and to assure there was no disruption in the energy service.

The challenges for the IoT were presented in three main categories, social and government, technical and business. For this project, the biggest challenge was how to incorporate the IoT and the opportunities it afforded the project into the business idea. Social and government challenges seemed to be addressed by writing in ownership of any data associated with the energy system to the company as opposed to the end user, which aligns with any current legislation considered by Arcola. Technical challenges were less around the devices themselves and more around the development of a user interface to process and understand data that was collected from sites in a quick and easy way.

The project engineer in charge of the design and development of the data monitoring system said that the main challenges were around how to incorporate that data into developing a successful business;

> *"How we present the data, it's a huge obstacle. Because regardless of the technical difficulties, which there will always be, it's not really an obstacle because it's just a difficulty that you solve and move on. But having that platform and getting data from all of the products that are up and running. How to use it efficiently to A- Improve services and B- get the customer or the person that's using it more involved. Yeah, it's pretty much what you do with the data that you are sending across from the product you are using. So I think, that will always be the biggest obstacle. Because at the moment all we're doing is thinking that, because our customers, well, we have a small clientele, most of them are*

> *knowledgeable of fuel cell systems or knowledgeable of the systems we are developing, so, how the data is presented is just targeted to techies and engineers and we're not thinking right now of the bigger picture of when we're going to present it to hundreds of customers and so on. So I think that's a big challenge."*

Overall, the biggest obstacle for IoT utilization within the context of this case study project will be around the data analytics and how quickly, efficiently and clearly that can happen for the stakeholders, customers and end users.

4.5.4 Second Coding to Mitigate Researcher Bias

Samples of five of the semi-structured interview transcripts were given to two other researchers to second code to help mitigate bias in the data analysis. In addition to the transcripts, a copy of the literature review was included for the researchers, to help them understand the main themes of the research and a brief coding instruction with a short example of how to apply the themes to the data.

First Coder

The first researcher has a background in qualitative coding and coded similar themes to what was coded from these interviews. He coded manually in the word documents that the interviews were typed up in. A main difference in what was seen from the first coder is that he did not capture as many codes, but this was because of his lack of familiarity with the technical aspect of the interviews. Over the five interview samples, the researcher returned 49 total individual codes, 17 under Servitization and related themes, 18 under IoT and related themes and 14 under SMEs and related themes. He used much of the same language that was used in the literature review, since this was his main reference to the context of the material being discussed in the interviews.

All the codes were relevant to what were used in the first pass coding by the researcher; he did not do a second pass of coding fully, but many of the codes contained language that would make this obvious. For example, "Servitization (enabled by technology)" One main difference between this coding and how the original coding was done was that the second coder did not differentiate the specific SME of the case study from the general main themes. It highlights a slightly different approach to analyzing the data, but after a discussion with the second coder; he arrived at similar conclusions to the researcher. One issue he highlighted was the difficulty to fully understand the larger picture of the case study, having not participated in any of the research as it was ongoing or to have the available time to consider all the data produced from the case study.

Second Coder

The second coder has an extensive research background in Servitization and familiarity with using NVivo for coding. The coding of the interviews she was given was done in Nvivo. While it could be seen that the first coder drew his knowledge from the subjects discussed in the interviews from the literature review, the second coder applied a broader expertise of one of the core areas of this research, Servitization. This led to more detailed nodes around the barriers and enablers and drivers of Servitization than was done in the researcher's coding. Quantitatively, the second coder had three main nodes; barriers, definition and enablers and drivers, that each had sub-nodes. Barriers had seven sub-nodes coded, with 40 codes; definitions had four sub-nodes coded, with 29 codes; and enablers and drivers had seven sub-nodes with 46 codes. This is over double the number of codes returned by the first second coder for the same data set.

The nodes created by this coder were focused around her background in Servitization, which gave a unique perspective to the data. Of interest was how the second coder approached the IoT aspects of the data. From the researcher's perspective, the aspects of the IoT (such as monitoring) were coded in a more defined way and from this set of coding, these aspects were folded into the main areas of Servtization. For example, a comment on presenting the data was categorized by the second coder as a general barrier, but in the researcher's analysis, it was more specifically categorized as an IoT challenge.

Differences

Some of the differences are discussed above in the individual discussions about the second coders. Table 3 below shows quantitatively the differences in the sample of five interviews that were included in this exercise. The most interesting difference is the different approach taken in the three different assessments of the data. Discussions with the second coders teased out reasoning for this; namely that these coders were not involved in the case study itself; did not have access (or time available to access and assess) all the data produced from the case study and therefore each brought a different perspective to the data they did analyze. Additionally, the quantity of codes varied massively from each coder. The first coder had the least codes/nodes produced; upon further discussion, this was due to his lack of confidence of full understanding of the topics considered. Conversely, the second coder produced over double the number of codes identified by the researcher. This has a couple of explanations; 1) the researcher had access to the rest of the data and was coding in a wider context and 2) the second coder's main expertise was in Servitization and thus had a more in depth perspective on seeing this from the data.

Table 3: A comparison of nodes and codes output from the second coding exercise

	Coder 1	Coder 2	EngD Researcher
Total Nodes	3	18	6
Total Codes	49	184	87
Servitization Theme Nodes/Codes	1/17	11/138	2/23
IoT Theme Nodes/Codes	1/18	7/46	2/34
SME Theme Nodes/Codes	1/14	N/A	2/30

Similarities

However, due to the quantitative differences and slight variation in the wording of the codes used seen in the second coding exercise, looking at what was coded and how showed strong similarities in the coding. For example, comments about company resource and skill barriers were under one code for the researcher, but more granular for the second coder. There was general consistency in considering the definitions of the subjects covered in the interviews, the barriers discussed and the enablers and drivers identified in the data set.

Overall, the perspective gained from both the coders led the researcher to the conclusion that the same general themes were seen from the data set of interviews and, coupled with the other data sources, built confidence in the overall analysis of the entirety of the case study data.

4.5.5 Summary of Case Study Results

Similarities to literature

For much of the case study, there was strong alignment with what was found in literature on previous studies or theories around the themes investigated.

SMEs

Each business would have a slightly different configuration of characteristics, determined by the industry it was in and the people that were involved in the business. However, literature reflected common traits of SMEs. Arcola Energy was found to have many of the traits and characteristics that were expected of a company interested in growth and innovation, though some were more prominent that others, such as the company's ability to collaborate. The drivers and obstacles the company faced were also reflected in literature.

Servitization

Arcola Energy's attributes, namely their flexibility and mindset, positively affected their approach to servitization. The literature showed that having these attributes led to better success when attempting to apply a servitization model in a company.

IoT

Arcola Energy's competency with the IoT aligned with the evolution presented in the literature and a path could be seen through the case study research of how the company would continue to evolve this expertise. Also, the SME's technical competency gave them a strong advantage in understanding and applying the IoT within the development of the

service business model, which was a valuable observation for the evolution of the framework in the context of this research.

Differences from the literature

Some difference to what the literature reflected were also seen from the research.

SMEs

SMEs cover a very wide range of industries and business models. For this research, Arcola Energy could best be classified as an SME in professional and scientific sector, however, they also had some motivations and efforts being put into developing their manufacturing capabilities. Therefore, while this single case study can be generalized to an extent, it must be done with the caveat of SMEs with similar traits and perhaps in the same industries.

Servitization

Perhaps the most interesting difference observed was the way that Arcola Energy considered the aspect of Servitization. In the early days of the relationship with the company, they were focused on developing their IoT capability and understanding the data produced. Much of the literature focused on a company deciding to servitize, then looking for technology to enable this transition. In this case study, the IoT led the company to consider a servitized business model. While this was not initially realized in the case study analysis, feedback on the research led to this change being directly reflected in the final model of the framework.

IoT

The main difference between the case study and what was found in the literature around the theme of the IoT was mostly around the company's realization of the functionality of the phenomenon. There was a line of sight within the goals of the company to improve this functionality, though the method as to how they would achieve that functionality was not always obvious. In other words, while the literature reflected many potential opportunities with the IoT, the case study reflected only a small aspect of those opportunities had been realized in the company.

4.6 Evolving the Framework

The second iteration of the framework was based upon the observations of the case study project and is shown in Figure 25. The framework starts with *defining* the key core competencies, traits and desire for innovation and growth of the company. The next step is to *consider* company drivers and obstacles honestly. The third step in the process is to *establish* the customer and stakeholder requirements and wants. Next is to dedicate time to fully *understand* the concept of servitization and how it applies within the business context. The fifth step is to *utilize* any existing IoT competencies or develop these competencies to complete the final step to *create* the service offering.

It is noticeably different from the first iteration. This difference is due to the application of the criteria that is shown in Figure 22, feedback from the sponsor company, PTC, and the understanding from the case study research. The first iteration of the framework could help facilitate understanding of the themes and may provide a foundation for future activities, but it was overly complicated and was not easily modified, which were two attributes considered

important for the result of this Engineering Doctorate. This second iteration now meets the first four criteria put forth in Figure 22.

The major changes made were to reduce the number of boxes from nine to six and create one line to follow, rather than the two represented in the first framework. Additionally, three of the action words and phrases used in the first iteration were removed and replaced (Find, Acknowledge and Be Aware Of). However, six total action words remain consistent in the evolution of this framework, to show the actions that the company needs to take along its journey of change.

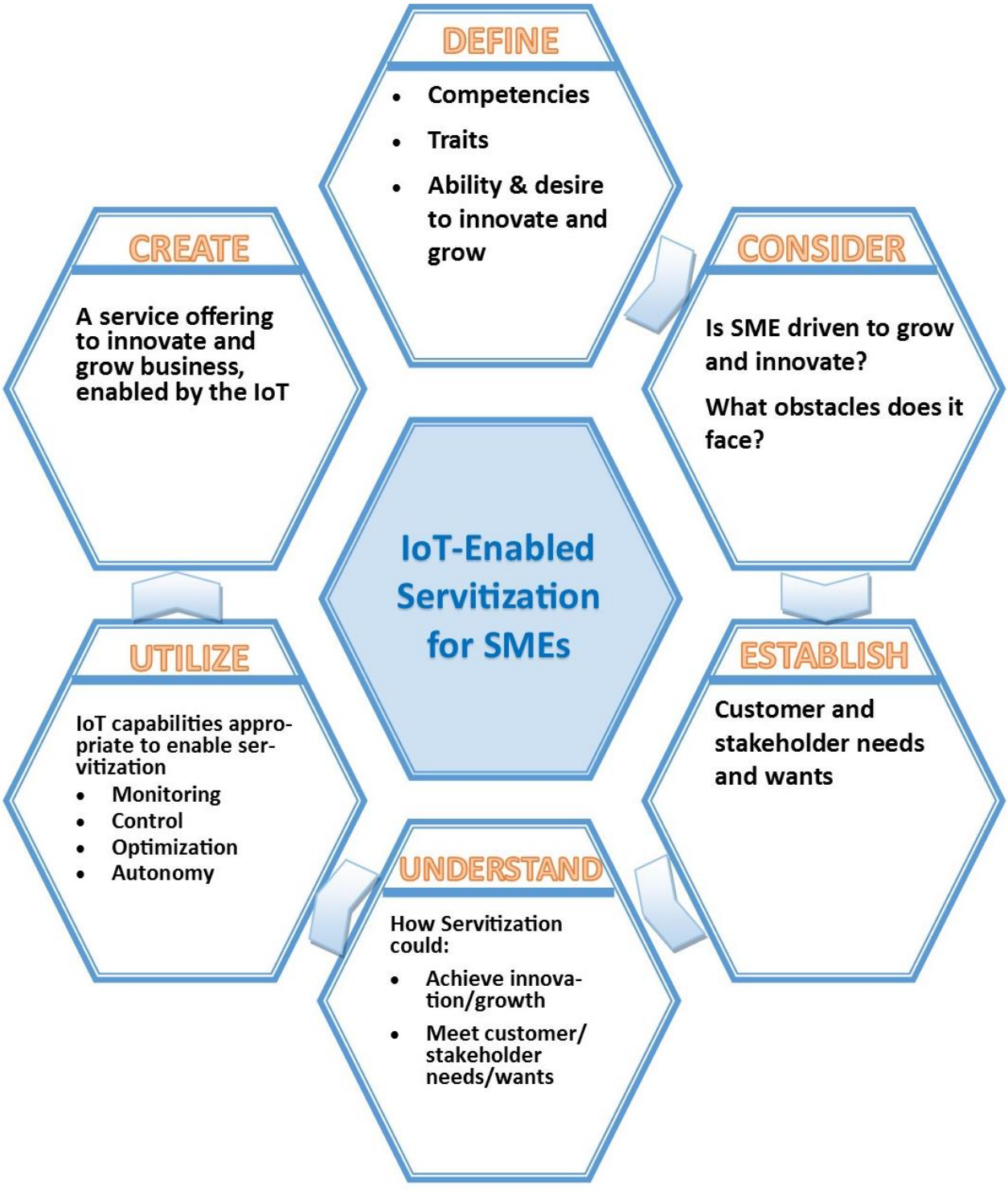


Figure 25: The second iteration of the framework

4.7 Summary

In summary, this chapter has introduced the case study that was undertaken to further develop and test the innovative concept of the framework. The company studied and the project central to the research was presented and explained. The research methodology, the types of data collected and the analysis method was discussed. The results of the case study, as it was analyzed in relation to the original themes, were summarized from Submission 4, and the main outcomes highlighted. Finally, a second iteration of the framework, which was a dramatic change from the first framework developed from the literature, was presented and explained.

The next chapter presents the dissemination of the framework and correlated concepts. It will also present the feedback and results of this dissemination. A final version of the framework will be presented based on this dissemination, which will solidify the innovation created for this Engineering Doctorate.

Chapter 5: Creating an Innovative Framework for Industry

5.1 Introduction

This chapter presents the innovation developed in the research as it applies to industry. It will consider the perspectives of the Engineering Doctorate sponsoring company, PTC, and of SMEs in general. This will be completed through the presentation of evidence from both entities. Feedback from PTC will be presented and discussed. Additionally, the results of a session with West Midlands SMEs where the framework was presented and feedback given from SME representatives will also be shown and analyzed.

5.2 A New Potential Market for PTC – SMEs

A comprehensive history of the sponsor company, PTC, as it relates to the research of this Engineering Doctorate, can be found in Appendix B.

5.2.1 The original Engineering Doctorate Project

The original project outlined for the Engineering Doctorate in autumn 2011 was to explore how open source hardware design could aid in creating PLM tools for SMEs. This was started through the research that was conducted with the Formula Student team, as discussed earlier in section 2.2 Understanding SMEs. The justification for this project at the time was the fact that while PTC was good at acquiring and maintaining larger customers, such as Caterpillar and John Deere ("PTC History and Acquisitions," 2015), with their software products and services, they were not providers in the SME space.

5.2.2 Justification for SME focus

As the relationship with PTC grew in the first 18 months of the program, it became more apparent that the original focus of the project was less relevant to the changing direction of the company. However, the time and effort spent on the original project helped to facilitate the development of the final project. The understanding of an SME, through the literature and the observations of the Formula Student teams, gave excellent insight. When a better understanding of PTC's direction was reached, it made sense to continue the core SME focus of the project, while exploring different aspects of that focus more in line with PTC's evolving business.

PTC's new subscription based model presents a perfect opportunity for the company to better explore a new market, equipped with services and products that are better suited for this space. A subscription model allows for a lower monthly cost for the software from PTC, as opposed to a large upfront payment. This is an important aspect that could benefit cash-strapped SMEs. Additionally, the capabilities and accessibility of the IoT means that many SMEs are exploring how to engage with this new phenomenon (Giuliano & Bengtsson, 2013; Wilson, 2014). Finally, servitization offers a new way for SMEs to be competitive (T. Baines, 2013a; Musson & Forrest, 2015), especially if they are enhanced with tools, technology and opportunities afforded from the IoT.

5.3 Dissemination and Feedback

Different activities were undertaken in autumn 2015 to gain valuable insight and feedback from key stakeholders and subject matter experts.

After the first iteration of the framework was developed from the literature, a visit to PTC's headquarters in Needham, Massachusetts, USA was conducted to get some feedback on the framework and the direction of the research. The literature review and the first iteration of the framework were published in a conference proceeding for the fourth annual International Conference on Business Servitization, which was held in Madrid, Spain in November 2015. The second iteration of the framework and some results of the case study analysis were included in the presentation at this conference.

Additionally, after the case study was fully analyzed, the second iteration of the framework and the process undertaken to create it was developed into course material on the professional program stream for the Service Design and Delivery MSc course at WMG. Finally, there was engagement with WMG's SME team to organize an event where SMEs were invited to hear about the framework and the process and give feedback. This section will highlight the main findings from each of these encounters and show the value that each activity had in the further development of the final innovation.

5.3.1 PTC visit in September 2015

In early September, 2015, a week-long visit was made to PTC headquarters in Needham, Massachusetts, USA. There, time was spent with the industrial mentor of this project; Senior Vice President of Global Education, John Stuart and his team. During this week, the researcher attended four company meetings about PTC's work in this area, an employee briefing, and four one-to-one meetings with key PTC employees about the research. Additionally, training on the PTC IoT software platform, ThingWorx was attended with other PTC employees. A key part of these interactions was the presentation of the research

concept, along with the research completed up to that point to both John Stuart and Andy Barlow, VP ThingWorx Academic Program Manager. This was the research completed with the literature and the first iteration of the framework, shown earlier in section 3.6 Developing a conceptual framework.

The feedback was captured through the researcher's notes. Andy Barlow suggested that the framework was complex and academic, but was a good start to align with the direction of the company. He noted that a bottom up approach, which considers PTC's customers, and their customers, be considered. He introduced a newly developed internal tool used at PTC with their customers called the IoT Value Roadmap, which visually outlines and categorizes several common use cases and matches them with both operational and strategic value drivers. This tool, and the corresponding video, were useful in the further development of the framework.

5.3.2 Teaching on professional MSc Course; Service Design and Delivery

In October 2015, material was prepared to teach on the Service Design and Delivery module, which is a component of the part-time, professional Master's course by the same name at WMG. In the course were professionals from a few different larger corporations, such as the oil company, Schlumberger and the airplane manufacturer Airbus. The material presented was divided into three sections; SMEs, Servitization and IoT. Alongside the lecture material, additional material was also developed that created different theoretical case study SMEs, in different industries. These theoretical case study SMEs were explored in small groups to allow for engagement with the subject material on an applied level.

The case study examples took the students through the process of the framework, which was then presented at the end of the session. The engagement levels of the participants required the module leader to adjust the session to allow it to continue for two hours longer than originally planned.

Feedback and engagement of the participants was collected by the researcher through observational notes. These notes reflect that the participants were actively engaged throughout the entire session, pulling for more information throughout. One aspect that was documented was that, though the students were representatives from larger firms, they were extremely interested in learning more about SMEs and the issues they faced. The explanation was given by the participants that many of them engaged with SMEs in their company supply chains, so understanding these types of companies was particularly relevant.

Two main challenges in applying the framework were observed during the module and documented by the researcher. The initial challenge was the first step of the framework, identifying the competencies of the company. This may have been due to the theoretical nature of the exercise. However, this also correlated with some observations of the case study, during which the SME also faced challenges in correctly identifying what their competencies were.

The second challenge observed was deliberately built into the exercise. This challenge was to explore the idea of company culture with regards to business change and risk. Each theoretical company in the exercise had a descriptor that conveyed some level of culture and level of risk aversion to the students. It affected the final business models that the students

produced in the exercise and was a discussion point in the feedback. This challenge is the most prevalent with any business change and is not to be underestimated.

Upon conclusion of the module, verbal feedback was documented by the researcher from the participants, including:

- Framework was generic enough to be applied in different industries
- The ideas and concepts presented would help one student engage with her management about an idea to servitize within her company

In addition, some constructive criticisms were:

- *Emphasizing involvement of the customers*: it was indicated that this was not realized as apparently as intended in the presentation of the framework.
- *Engaging stakeholders*: this was not included in the framework. Given the perspective of the participants from larger companies, this is an important aspect to consider in regards to how these companies work in broader supply chains.
- *Consider incorporating other system engineering tools, such as Pugh Matrix*: the suggestion was given that some sort of quantitative assessment element of the framework would be useful.
- *Clarify that the IoT goes beyond just a technology enabler for servitization*: while technology in general is considered an enabler of servitization from the literature, the IoT goes beyond just being a technology, but brings an entirely new paradigm shift for business; as discussed in the literature review.

Overall, teaching the research material on the module was both a useful exercise in communicating the research, as well as an opportunity to gain insight into the innovativeness of the idea from an industrial perspective. Even representatives from larger corporations could learn about the possibilities from engaging with IoT in developing services.

5.3.3 Servitization Conference

Over the summer of 2015, an abstract was submitted and accepted at the fourth annual International Business Servitization Conference, which took place in Madrid in November 2015. In September, the literature review and the first iteration of the framework were submitted to the conference proceedings. Leading academics in the field of servitization and service science were in attendance and some feedback was received on the research presented.

The most valuable feedback received in the discussion after the researcher's presentation was the suggestion to consider the IoT competencies prior to considering servitization in the sequence of steps in the framework. This led to further reflection on the case study data. It was realized that Arcola Energy viewed their servitization in this context as well; they first developed their competencies in IoT and then considered ways to servitize their offerings. This difference from what was originally understood from the literature is further discussed earlier in this Innovation Report, in Section 4.5.4.

5.3.4 SME Event

Finally, at the end of November, 2015, a morning event was hosted and organized with help from the WMG SME team to present the research and gain feedback from interested SMEs. The itinerary of this event was to present the research and the framework and facilitate a

discussion with the participants. Representatives from six different West Midlands SMEs were in attendance. These individuals participated in informal discussions during and after the presentation.

The researcher has also prepared a short survey to collect feedback from willing attendees. The intent of the survey was to understand the position of the SMEs at the event and to gauge interest from SME representatives in utilizing a framework in their businesses. Five individuals agreed to give feedback. The survey was comprised of eight questions and the responses were given anonymously.

The first two questions were demographic questions, shown in Figure 26.

Question	**Responses**		
Q1: Is your company considered to be (circle one)	*Micro*	*Small*	*Medium*
Number of responses:	1	2	2
Q2 Is your company considered to be (circle one)	*Product focused*	*Service focused*	*Combination of both*
Number of responses:	0	4	1

Figure 26: First two demographic questions of SME survey

The next questions are shown in Figure 27. Question 3 (and subsequently 3A) was asked to find out about the company's current position in regards to its IoT capabilities. Question four was to determine if the person filling out the questionnaire made strategic decisions for their company, and thus would be more aware of the processes in place to drive change within the business currently. Question five asks about plans to develop a new service within the company. Question six asks about the utilizing a framework like the one shown to help them

develop strategy and innovation within the company. Question seven was asked to see if the framework would be useful as a software solution to the SME.

Question	**Yes**	**No**
Q3: Does your company have any existing IoT capabilities?	1	4
Q3A: If yes, in what? (circle relevant competency) *Monitoring Control Optimization Autonomy*	*Monitoring* *Control* *Optimization*	
Q4: Do you make decisions about strategy or innovation at your company?	3	2
Q5: Is your company considering developing a new service in the near future? **One response was N/A*	4	0*
Q6: Would you use a framework like this to develop strategy and innovation at your company? **One response was "Maybe"*	4	0*
Q7: If the structure of this framework had a simple, affordable, easy to use software component to it, would you be more likely to use the structure to develop a service within your company? **2 responses were "don't know", one was "maybe" and one did not answer*	1	0*

Figure 27: Second part of SME survey

The final question was open ended and was written in a way so as not to prompt any particular responses:

Q8: Do you have any further comments about this session or the framework?

The responses are given below. It is promising to note that, even though this is a small sample, the responses show positive interest in this area and show an underlying industry pull to understand and utilize servitization enabled by the IoT.

Out of the five surveys, four wrote in responses to question 8, which were:

- Can we have a copy of the framework to review and see if it's going to work for us? <email address>
- Other industry examples would be interesting/ IoT applications and opportunities for adding commercial value to customer. Thank you very much!
- Very informative session. As a software company, we've come from the servitization → IoT, but very interesting to see the IoT → servitization model, particularly for physical devices.
- I think we would prefer an expert to consult for us to demonstrate how this could be applied for us and our customers

While the number of individuals who participated in the survey was not enough to draw any strong statistical conclusions, it does show that there is SME interest and engagement in this topic, and a potential opportunity to develop a truly unique solution in this space. This final activity of engagement was to get feedback from the target market and to validate the potential opportunity and innovation, in the context of the time and resource available to do so.

Most of the respondents were considering developing a service soon and could make strategic decisions at their company. This indicates a pull in the SME market for a tool or framework to enable this strategic change. The comment about utilizing an expert was also particularly interesting and aligned with some of the ideas that were considered during the visit to PTC in September 2015. One of the areas of PTC business is a consultant service, that engages with customers to find the best solution for that specific company's need. Another

potential use of the framework would be as a tool to help train these consultants to better understand SME requirements or as a tool for these consultants to improve the service they are delivering. In this way, the framework provides a unique starting point for combining current PTC tools into a workable solution for SMEs.

5.3.5 Summary of Dissemination of Research

In summary, four different groups of people and scenarios were engaged with to get holistic feedback on the research as well as test the innovativeness of the idea. Figure 28 shows the activities, in chronological order, of these events. Each group is highlighted on the left, while the specific activity and outcomes are summarized on the right.

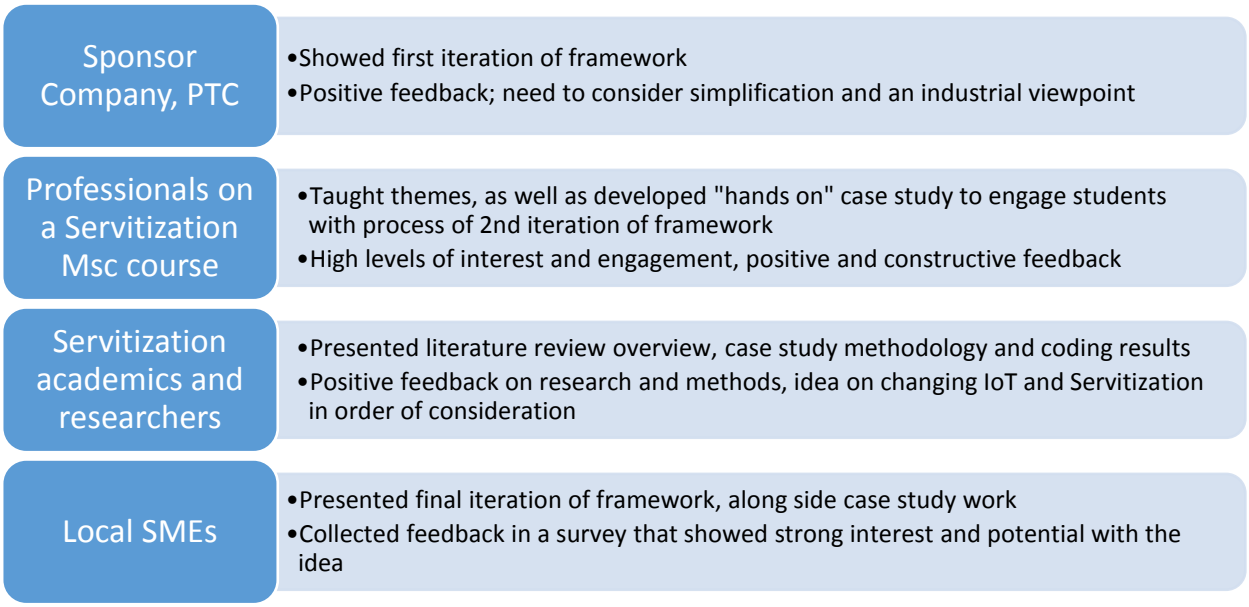


Figure 28: Summary of dissemination and feedback activities for research

5.5 Final version of the framework

After the Servitization conference in November 2015, and just before the SME event, also held in November, the framework was further edited (from what is shown earlier in this report in Figure 25) to incorporate the feedback from other academics and researchers, namely changing the consideration order of IoT and Servitization in the framework. This has resulted in the final version of the framework, which is shown in Figure 29. The same basic shape of the framework was kept; the main changes were with regards to the order of consideration for IoT and servitization and the reorganization of the steps to allow for an evaluation step.

5.5.1 The steps of the framework

The framework created is partly inspired by other, more generic decision frameworks, such as Plan Do Check Act framework outlined by William Edwards Deming in Lean Thinking (Bicheno & Holweg, 2009). It is also inspired by a derivative of the DMAIC (Define, Measure, Analyze, Improve, Control) framework in Six Sigma methodology (George, Rowlands, Price, & Maxey, 2005). This derivative framework is used in Design for Six Sigma (DFSS), or in the development of new products and is known as DMADV (Define, Measure, Analyze, Design, Validate) (Cronemyr, 2007).

However, the framework created in the context of this research was not designed to be generically applicable as the frameworks that influenced its structure. The framework created was focused on the themes; SMEs, IoT and servitization. It will, however, be applicable to a variety of SMEs interested in IoT and Servtization and is not dependent on them being in a specific industry. The framework can be considered this way because of the

attributes of the SME of the case study and how these attributes are more broadly applicable to other SME businesses, as discussed in section 3.2 Defining the SME and establishing drivers and obstacles.

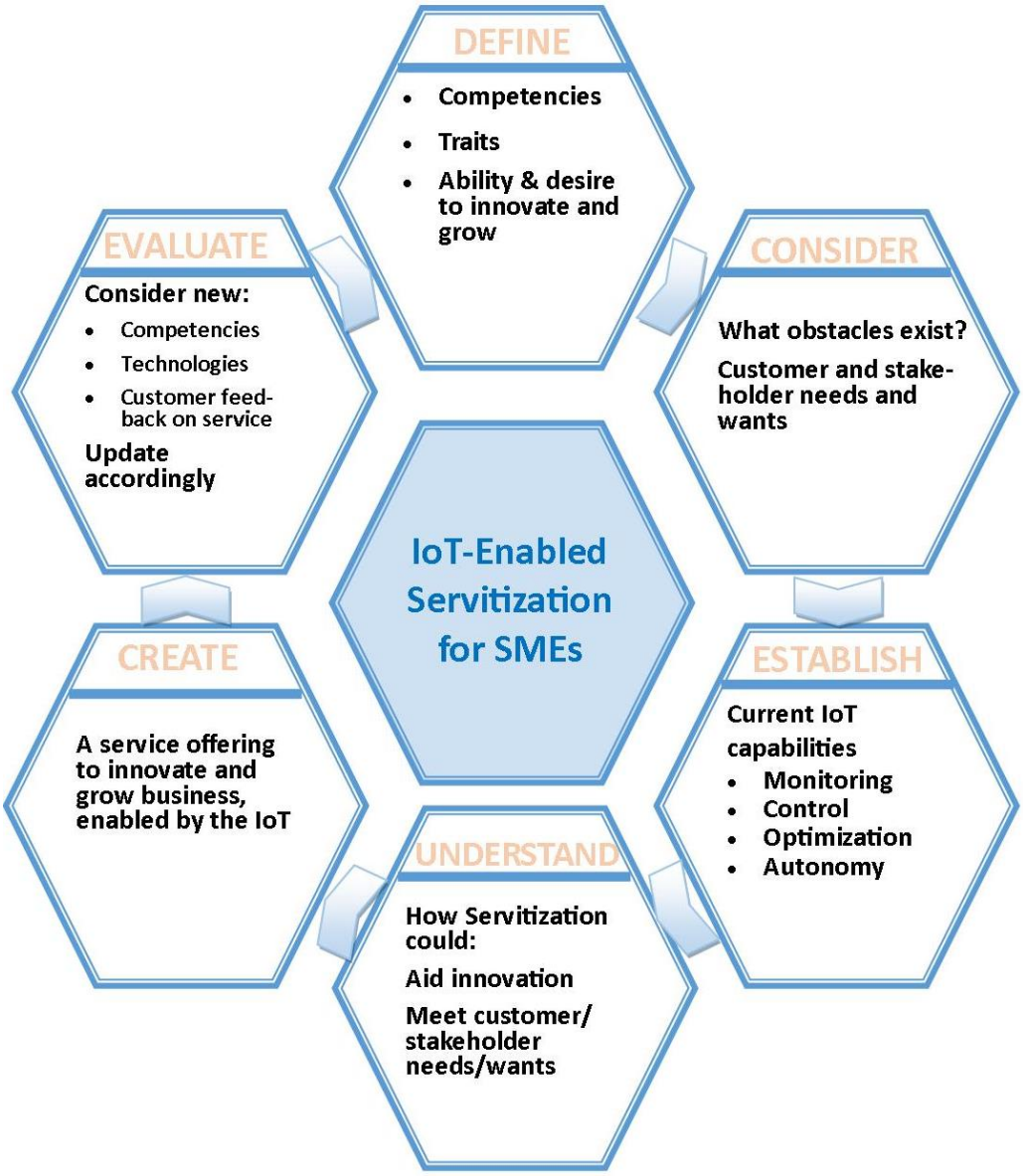


Figure 29: The third and final version of the framework

The framework consists of six actions, in order:

1. **Define:** For this step, the company should first define their main core competencies and highlight main traits. Every company is slightly different, and SMEs are no exception. The traits that need to be defined are both quantitative and qualitative; as outlined in Chapter 3 and more extensively in Submission 4. These include company size, turnover, employees, industry as well as the culture of the company with innovation and growth.

   This step has three main areas. First, it is about defining the company in its current state. This is first done through identifying the basic descriptors of the company, its size, turnover and industry, which is shown in 3.2.1 Defining competencies and traits of the SME. Additionally, the type of industry the SME is in should be defined. BIS, (2014) identified sixteen industries to classify SMEs.

   After defining the traits of the SME, this step of the framework is to define the competencies and drivers of the company; particularly around growth and innovation. First, the company must decide if they want to grow, and what way they want to achieve this growth. The top four actions to achieve grow are

   1. To increase skill of workforce
   2. To increase turnover through exploitation of new markets
   3. Develop and launch new products and services
   4. Reduce costs by increasing productivity of workers (BMG Research, 2013)

   Growth is often fueled by innovation (OECD, 2007). Figure 7: Innovation Capabilities for SMEs shows the innovation capabilities from the literature defined for SMEs. During this stage of applying the framework, an SME considers these capabilities and how well they are achieving them.

Finally, this step requires the company to consider their drivers, both externally and internally. These drivers have been defined from the literature and are shown in Figure 8: External and Internal Drivers for SMEs.

When testing this framework on a professional module, a table was presented for the participants to fill out about theoretical SMEs. This table included the quantitative definitions, the innovation capacities of the SMEs, and the identification of drivers. A recreation of the table is shown in Table 4.

Table 4: Application of Step 1 of Framework

Trait/Characteristics	Definition for SME	Reference
Size & Turnover	*i.e. 9 employees, £600K turnover*	(European Commission, 2005)
Industry	*i.e. Scientific/technology*	(BIS, 2014)
Innovation Capabilities	*i.e. Ability to enter new markets*	(BMG Research, 2013; Love & Roper, 2015; Parrilli & Elola, 2011)
Internal Drivers	*i.e. desire to adapt*	(Laforet, 2011; O'Regan & Ghobadian, 2005; Salavou, H., Baltas, G. and Lioukas, 2004)
External Drivers	*i.e. competition*	

2. **Consider:** The next step, after defining the company, is broken down into two parts. The first is to consider the SME's obstacles and the second part is to consider the challenges faced by their customers. This second part was added to this step as a direct result of the feedback highlighted in this chapter.

   Considering the obstacles an SME faces is best done after identify the company's drivers, as explained in 3.2.4 Comparing Drivers and Obstacles. This is because what could be a driver for a company could also be an obstacle, such as competition

(Garengo et al., 2005; Love & Roper, 2015). It is important for a company to be able to accurately identify what obstacles it faces and how it relates to what drives it. A complete list of obstacles is shown in Figure 10: Obstacles for SMEs. These are recapped below in Table 5.

Table 5: Obstacles for SMEs

Obstacle	Definition for SME	Reference
Internal Obstacle	*i.e.lack of human resource, limited capital resource*	(Garengo et al., 2005; Lane et al., 2010; Love & Roper, 2015; Morabito et al., 2005; Parrilli & Elola, 2011; Rahman & Ramos, 2010)
External Obstacle	*i.e. competition, legislation*	

In understanding its own obstacles, this allows the SME to be in the mindset of then understanding the obstacles of their customers and is one of the key aspects to developing a successful service later on (T. S. Baines, Lightfoot, Benedettini, et al., 2009; Neely, 2013). The obstacles may be similar, if, for example the SME's customer is another SME. However, they also may be quite different and it is important for the SME to truly understand the needs and wants of their customer. The better the relationship with the customer is, the better the SME will understand the need they are fulfilling with their service.

3. **Establish:** The next step is also a change from the second iteration, as a direct result of feedback. While general capabilities were considered by the company in step 1, in this step, the company should consider specifically any competencies that relate to the main capabilities of IoT: monitoring, control, optimization and autonomy.

These four capabilities were put forth by Porter & Heppelmann, (2014) and are seen as an increasing level of skill and competency, starting with monitoring and ending with autonomy. An SME can identify where they are at with their IoT capabilities through understanding these levels of maturity and plan for development of new capabilities. Table 6 can be used as a tool to help consider the IoT capabilities for the SME.

Table 6: Applying an Understanding of IoT Capabilities for SMEs (Step 3)

IoT Level	Description	Capability Developed?
Monitoring	Data flows one way, sent through sensors and IT infrastructure	
Control	Data flows two ways, basic commands can be coded in algorithms to remotely control activities of product	
Optimization	The application of data analytics to understand aspects like user behavior to optimize the system	
Autonomy	Products can work independently and coordinate with other products and systems	

4. **Understand:** This step now brings in an understanding of servitization. This is categorized into the three areas outlined in the literature review: definitions, opportunities and challenges. After a more general understanding; ideally coupled with solid use case examples; the SME can have a clear idea of how servitizing an aspect of their business can help create value for themselves and their customers.

   The three aspects of this step were broken down into three tasks on the professional module that tested the application of this framework. The first task asked the participants to consider Servitization in the context of the theoretical SME they were given. This means finding aspects of the business model that align with the SME's

culture. Section 3.3.1 Definitions of Servitization shows many of these general definitions that would be a good starting point for discussion about how Servitization may apply in context for the SME. For example, the SME may consider the eight types of product service systems outlined by (Tukker, 2004) which maintains that the value is determined by the producer or may decide that it prefers a service dominant logic lens (Vargo & Lusch, 2008) which sees value as being determined by the consumer and that the core of exchange is the application of specialized skills and knowledge.

There is also a parallel way to consider the evolution of Servitization to the evolution of IoT competencies described in the previous step. Rustema, (2015) presented the evolution of a service as shown in Figure 30. The SME could use ideas like this to help understand servitization and contextualize it for their own needs.

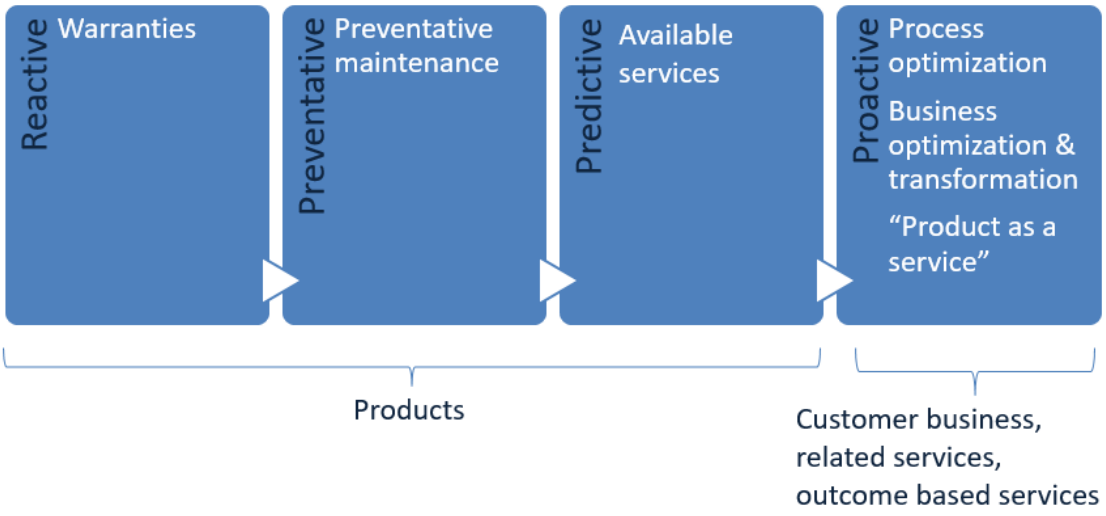


Figure 30: Evolution of a Service (Rustema, 2015)

The second task was to consider the enablers and drivers of servitization that would be applicable in context for the SME. Literature presents some general ones, as

discussed in section 3.3.2 Motivators and Enablers of Servitization. There are three main enablers for servitization; technology (T. S. Baines, Lightfoot, Kay, et al., 2009), service development tools (Shostack, 1984) and culture (T. S. Baines, Lightfoot, Kay, et al., 2009; Vargo & Lusch, 2011) and there are three main drivers for a company to servitize it's offerings; financial, strategic and marketing (T. Baines, 2013a). These enablers and drivers were also seen in the context of the case study.

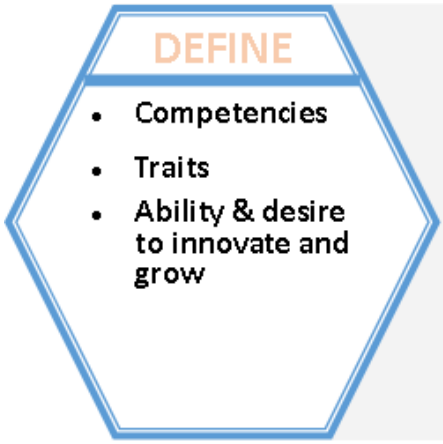
The final task is to consider the potential barriers and the risks they might pose to the development of the service for the company. There are five main barriers, highlighted in Section 3.3.3 Barriers to Servitization. These barriers include a lack of internal resources to innovate the service offering, a lack of knowledge about the customer need, a lack of a methodology to create the service, a lack of a good relationship with the customer and having an inflexible service process (T. S. Baines, Lightfoot, Kay, et al., 2009; Fischer et al., 2009; Mathieu & Valérie, 2001) In addition to these five, the case study showed an additional risk of collaborating with other companies to provide the service.

5. **Create:** After four steps of what is essentially planning for a company, now is the step that utilizes this newly found and organized knowledge into a workable business model for the company.

   This business model incorporates the traits and characteristics of the SME, a comprehensive understanding of their customer need, an understanding of the opportunities available through the IoT, and a contextual understanding of servitization and how this will help them satisfy the customer need.

6. **Evaluate:** Finally, the last step is to reflect on the model created. Is it delivering value as expected? Are there new aspects to consider, such as newly developed technologies or customer feedback? Can the company now evolve their competencies further to provide new value-add services to their customer?

These steps are also visualized in the following guide:

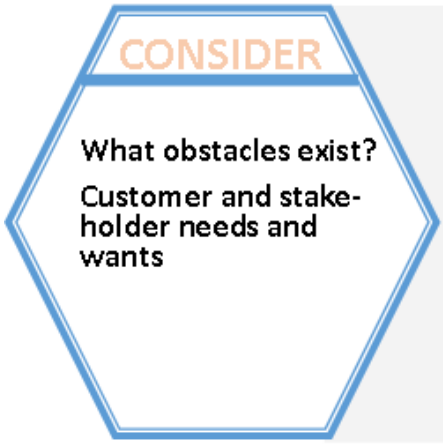


Define the SME in it's current state—what industry is it in, what is the annual turnover, what are the core competencies.

Then define the SME's desire and ability to innovate and grow.

Example:

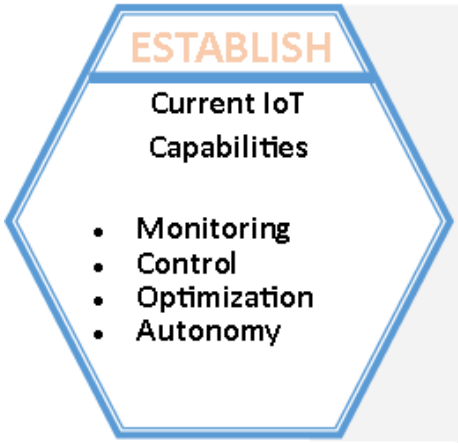
A micro SME with 10 employees has a £1 million annual turnover and is in the technology industry. They have particular strengths around data analytics and have shown the ability to innovate through their flexibility, ability to collaborate within their supply chain and the technical skills of the employees. They are driven to grow though customer demand and the internal company culture of creativity.



Consider the internal and external obstacles faced by the SME and how these may relate to the drivers defined in the previous step. Next, consider the needs and wants of the customers and stakeholders to the SME.

Example:

The micro SME faces both internal and external obstacles; the main internal obstacles are limited human and capital resource. They also face external obstacles from uncertainty in legislation around data and potential competition. Their current main customers also face issues with limited capital resource, so it's an issue that they understand and can look at addressing.



Establish the current specific capabilities the SME has relative to the IoT. Some of these may have been partially defined under general competencies in step 1; this step serves to further understand and define the company's IoT competencies in the current market definitions.

Example:

The SME has developed the capability to capture data in real time from their technology products in the market. They are working on developing the capability to control and send commands back; but current capability only allows for one way flow of information.

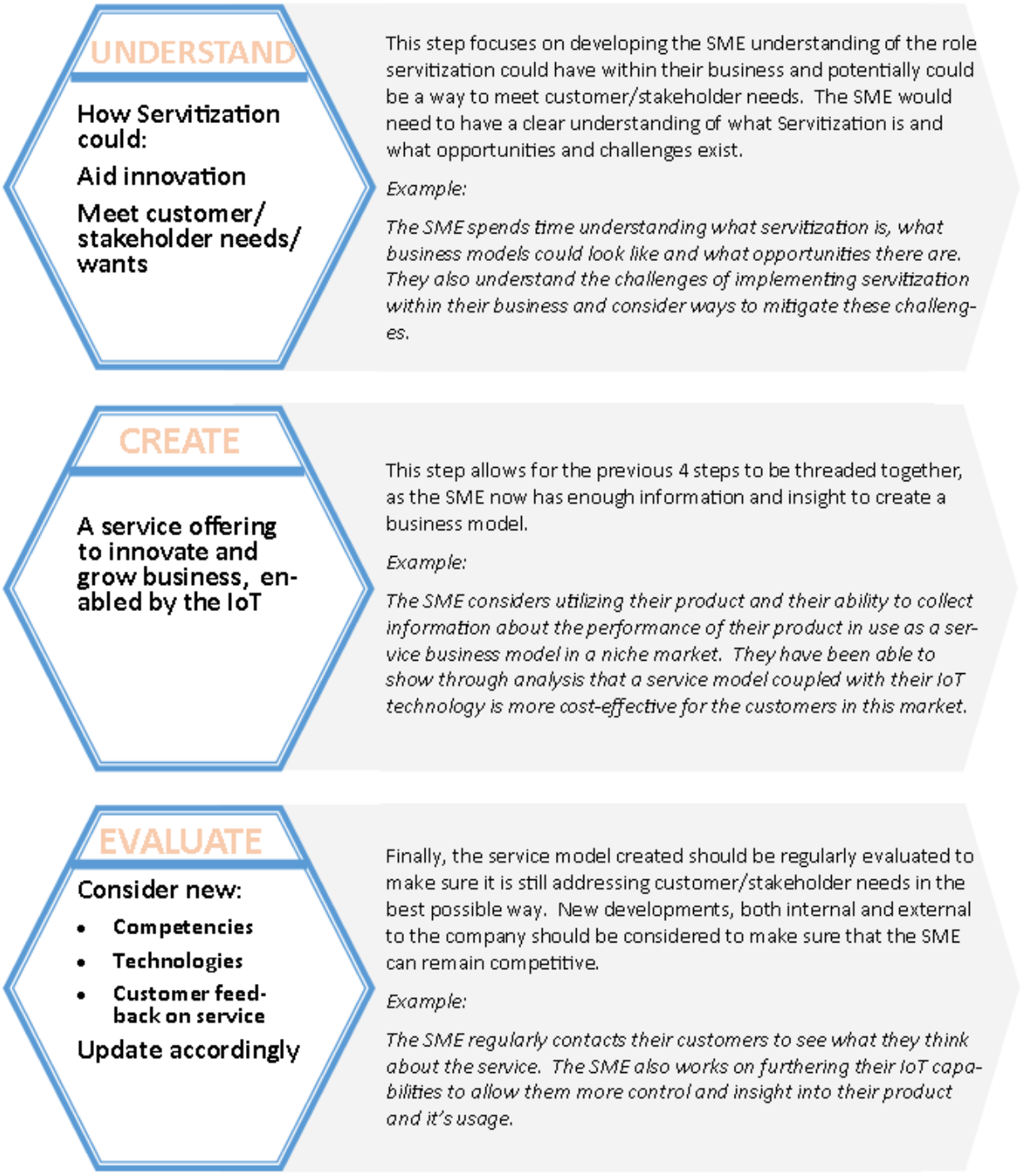


Figure 31: A visual guide to using the framework

It is important to realize that this framework is iterative. In many respects, it draws from the ideas of the minimum viable product in lean start up thinking (Blank, 2013; Nobel, 2013; Ries, 2011). The development of a minimum viable product requires getting a sellable product to

market quickly while keeping a strong engagement with the customer to make continuous improvements. In a way, it is slightly outsourcing the testing phase of a product to the consumer (Blank, 2013). While the framework is influenced by this thinking, it is also a bit more pragmatic in the early steps to also engage customer and stakeholder feedback. One of the downfalls of lean start up thinking can come from harm to reputation of the business, a failure which is best avoided when possible. Other failures, however, can be learned from and, if handled well with the customer, can strengthen relationships with a good customer experience.

5.5.2 Evolution and Analysis of the Final Framework

The framework started from ideas from literature pieced together in nine main sections, as illustrated in Figure 23: The first iteration of the conceptual framework from the literature review Figure 23. After conducting the longitudinal case study with the SME, Arcola Energy, a second, much more simplified version of the framework was developed. This version was reduced to six sections and showed more of a process flow from the first iteration, this is shown in Figure 25. After receiving feedback from the sponsor company, PTC, professionals on a servitization MSc and other SMEs, the final version of the framework was constructed, as is seen in Figure 29. This final version incorporated several areas of feedback that were highlighted earlier in Section 5.4, namely the stronger conveyance of the customer perspective in the framework journey, the consideration of IoT beyond just it's technological attributes, the inclusion of stakeholder consideration and the change in order of consideration of IoT and Servitization.

Finally, the framework was considered against the seven attributes defined in Figure 22:

1. *Easily modified with the introduction of new information*

   The ability to modify the second version to this final version showed that the framework was in a state where it could be modified readily.

2. *Facilitate understanding of underlying concepts*

   The addition of reference materials enhances this final version to achieve a better understanding of the underlying concepts of the framework.

3. *Form foundation for future activities*

   One of the main goals for the framework was to help SMEs plan future activities in a methodic way. The level of interest from SMEs, the sponsor company, professionals and academics indicates that this framework would be a useful tool in forming foundations for future activities.

4. *Improve and optimize an operation*

   The framework should help SMEs improve the way they achieve changes in their business and allow them to improve any current methods they have,

5. *Aid in decision making and provide guidelines*

   The framework provides a structure that can be followed to help make decisions about applying relevant competencies with the right technology to develop a successful model.

6. *Flexible for use in different context and scenarios*

   While the framework may not work for every type of SME, it can be useful to those in some sectors; as shown by the input from the validation phase of the research.

7. *Captures something real and does it in a way that is easy to remember and apply*

The framework is six main steps and has been developed from an understanding of the literature on the themes as well as participation in a longitudinal case study to understand how this process may happen in a real scenario.

5.6 Summary

In summary, this chapter served to present the final steps in developing the framework. The chapter first discussed the sponsor company, PTC and their current direction in the space of both IoT and servitzation.

A justification was given to show the importance of creating innovation in a context that could benefit SMEs, due to the opportunities that are available in this sector. Then, the variety of actions that were taken to ensure the innovation of the research were presented. The actions taken involved a wide variety of stakeholders; including the sponsor company, potential industrial clients and other relevant academics. They included attending a conference, presenting to local SMEs and disseminating the material and the framework to professionals in a Master's Degree level setting. In closing, a detailed description of the final framework was presented. The following chapter will serve to critically analyze the research completed and show evidence of the innovation.

Chapter 6: Analysis and Discussion

"Innovation requires knowledge, ingenuity, and, above all else, focus." – Peter Drucker

6.1 Introduction

This chapter serves to bring the main strands of the Engineering Doctorate research together to confirm the innovation of the research. It will critically consider the research and discuss strengths, weaknesses, and consider the potential value. Finally, the chapter will present potential future directions.

6.2 Defining Innovation

The core driver of this Engineering Doctorate was innovation; to take the themes and results of the research and create an outcome which was definable as innovation. For this to be achieved, the researcher first had to define innovation within the context of her work.

Joseph Schumpeter (1934) argued that anyone seeking profit must innovate; and indeed, many firms profit from a variety of activities, other than apply new technologies. Schumpeter states that an innovation can occur when:

1. A new product is introduced
2. A new method of production is introduced
3. A new market is established
4. A new source of raw materials is found
5. Any new organization in an industry, such as the creation of a monopoly (Schumpeter, 1934)

Management theorist, Peter Drucker maintained that, "most innovative business ideas come from methodically analyzing seven areas of opportunity, some of which lie within particular companies or industries and some of which lie in broader social or demographic trends (Drucker, 2002)." Drucker contends that innovation can be achieved through:

1. Unexpected occurrences
2. Incongruities
3. Process needs
4. Industry and market changes
5. Demographic changes
6. Changes in perception
7. New knowledge

Other perspectives on innovation range on various levels of restrictiveness. Business author, Scott Berkun, defines innovation as a significant positive change and argues that it is to be differentiated from invention. He argues that the bar for defining an outcome as "innovative" is very high and the word is overused in business (Berkun, 2013). Others would argue that innovation has a much broader concept and can include refinement of existing ideas, processes, services and products (Lesonsky, 2011).

However, the definition of innovation that resonated most in the context of this research is the idea that innovation is connecting dots. This concept of innovation is embodied by the Steve Jobs quote;

> *"You can't connect the dots looking forward; you can only connect them looking backwards. So you have to trust that the dots will somehow connect in your future. You have to trust in something—your gut, destiny, life, karma, whatever. This approach has never let me down, and it has made all the difference in my life (Jobs, 2005)."*

Steve Jobs, however, is not unique is making this assertion about innovation. Seth Godin (2012) discusses the concept of dot-connecting in the context of modern-day education systems, arguing that students are too often taught the dots (subject materials) but not how to connect them. Richard Branson runs his Virgin companies with a formula of A-B-C-D (Always Be Connecting the Dots) (Brier, 2013).

This Doctorate connected the dots between three concepts – SMEs, Servitization and the IoT and explored ways these concepts could work together to create something new.

6.3 The Innovation Statement

The overall purpose of this research was to demonstrate innovation in the development of a tool that considered these unique themes. The scope of this research was confined to the context of these themes; SMEs, the IoT and servitization; more specifically, how the IoT could be utilized to better optimize the process of servitization for SMEs. The conclusion of innovation has two main layers; academic and industrial. The research has already attracted strong interest from a range of representatives; academics, SMEs and industrialists alike.

6.3.1 Academic Innovation

The literature review found that, while sometimes two of the three themes had been studied together, no prior literature could be found that combined all three themes. This allowed a gap to be explored. In other words, this is comparative to Schumpeter's idea of creating a new market to innovate, where the "market" is new knowledge in an academic context. More colloquially, the different themes could all be considered different dots, each with their own areas of existing research and literature. This doctorate combined these dots and explored what that looked like. Additionally, the application of a longitudinal case study to study the phenomenon, while not innovative as a method, allowed for the first instance of the utilization of IoT by an SME to develop a servitization model within their business.

6.3.2 Industrial Innovation

From an industrial perspective, no framework exists for SMEs to reference for utilization of the IoT for Servitization. The framework created describes a new method of producing a service in the context of an emerging technology and phenomenon (the IoT).

In addition, understanding of SMEs is limited, which creates difficulty for engagement from larger corporations, academic institutions and governments. From the perspective of the sponsoring company in the context of this Engineering Doctorate, both the results of the case study and the developed framework are useful. The case study can add perspective for PTC in their costing model for their newly developed subscription business and the framework is potentially a useful tool in engaging with SMEs or training partners to PTC to help facilitate providing services to new clients in the SME sector.

6.4 Potential Market Opportunity

Discussions with PTC stakeholders, representatives from their partners and local SME representatives have helped to facilitate some ideas as to how to capitalize on the ideas formulated from this research. This section serves to present the ideas for market implementation of the innovation based upon the discussions with these stakeholders and from market data about UK SMEs. It identifies a potentially interesting market opportunity for the framework to be used in.

6.4.1 Internal Tool for PTC

The realization that the framework could be a valuable internal tool for PTC was made during the visit to PTC headquarters in Needham, Massachusetts in September 2015. It came about from discussions with individuals in the Global Education department. This department of

PTC is responsible for PTC's outreach and coordination with academic institutions and training for employees and partner organizations.

During this visit, contact was made with a representative from one of PTC's partner firms. This firm provided services and PTC software products to local clients in their business's area in the Midwest area of the United States. This representative discussed that her company was actively working on both developing better relationships with SMEs around the development of their IoT capabilities and indicated that any tools to help them engage with SMEs more would be beneficial. While this was only one representative from one firm, further discussions in September 2015 with PTC sponsors helped to establish that PTC partners, like this specific firm, would find value in the use of the framework being created.

6.4.2 Tool for Consultants

During the presentation of the case study at both the academic conference and the SME event in November, another use for the research and framework is a tool for consultants that work with SMEs in the relevant industries. A West Midlands consultancy suggested that it would be a valuable tool in the context of his business, as they worked with a number of SMEs interested in adding value to their core business.

6.4.3 Potential Market

In the UK, SMEs account for £1.6 trillion in annual revenue, which is approximately 47% of private sector turnover. SMEs have had a sustained growth in the UK since 2000, as shown in Figure 32. At the start of 2014, UK SMEs exceeded 5 million private sector businesses for the first time ever (BIS, 2014).

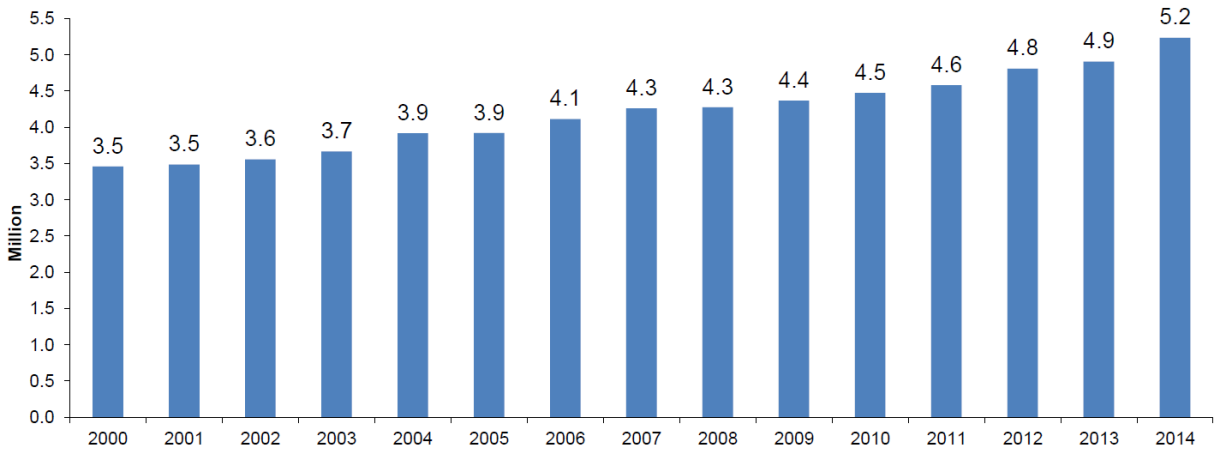


Figure 32: The growth in the number of private sector UK SMEs since 2000 (BIS, 2014)

A comprehensive analysis, shown in Appendix C, concludes that the market opportunity for PTC, if they can successfully break into the SME market, even at 0.01%, could result in over 10,000 new customers in the UK alone.

6.5 How to use the Framework

There are two main methods by which this framework can be utilized. The first is by a SME, as an internal development tool. The second idea is to add the framework to the collection of tools and expertise used by a consultant (such as PTC) and use it to help provide a service to a SME.

An exercise to apply the framework in a SME setting was part of the material developed for the Service Design and Delivery module that was taught in October 2015 and discussed in section 5.3.2 Teaching on professional MSc Course; Service Design and Delivery. In this exercise, the professional students were organized into small groups and given a hypothetical small business, in different industries such as construction, manufacturing and professional and scientific. They were led through the steps of the framework and created a potential

service that could be applied in the business. This exercise is similar to how the framework might be used in a real-world setting. The students on the module went through the steps that are highlighted in section 5.5.1 The steps of the framework.

The other way to use the framework is from the perspective of a consultant, coupled with industry knowledge and expertise to help a SME. This may be feasible for some SMEs to afford, but may not be an option for all. The way to use the framework would be similar to above, following the steps highlighted in section 5.5.1 and creating a service.

6.6 Critical reflections of the research

This research has strengths and weaknesses; this section serves to critically reflect upon these aspects.

6.6.1 Strengths of the research

From the beginning, the motivation of this doctorate was to accurately consider a true industrial perspective and to produce a meaningful outcome. While the time spent with the Formula Student team was valuable; it was thought necessary to couple this experience and knowledge with a real industrial example. This was completed through the longitudinal case study.

One of the benefits of doing in-depth doctoral level research is the time allotted to seriously consider the issues and discover a useful and applicable research area. The time and effort invested in this research to establish a firm research direction is a strength. Two months were spent with the sponsor company at the beginning of the second year of program, and further engagement with key individuals from PTC was maintained to understand their

expertise and competencies in both servitization and the IoT. Several months were also spent with the case study company to understand their main challenges with servitizing their offerings and their competencies with remote monitoring. Additionally, time was invested in modules to understand servitization as a concept.

The research undertaken for the case study utilized careful research methods that were suitable for the context. Several types of qualitative data were collected over the course of two years with the company and was coded in two iterations. These methods were presented in detail in Submission 4 and in section 4.4 Research .

Finally, the most important factor of this research is that it connects three themes in a new way. It is relevant to most companies in most industries currently and fulfills a need to better understand and engage with the new technologies, mindsets and tools being developed from the concept of IoT as it relates to servitization.

6.6.2 Limitations of the Research

No research is above criticism and limitations must also be recognized from this research, namely with regards to the method of study used (single case study), no quantitative aspect to the research, and a lack of full application of the framework in industry.

A single case study can have many weaknesses as a research approach. A main weakness, as described by Yin (2014) is that a case may change over time; that the case may later develop in an alternative direction. This was specifically experienced during the time spent with the SME. After a few months of exploring various topics at the company, it was decided to develop a case around a project (the off-grid energy project) with a set completion date.

Focusing on a specifically defined project within the SME minimized distractions and directions changes, as there were set deliverables along the course of the project.

There are other potential weaknesses from case study research. A case study has to be conducted at a very abstract level, which can be challenging and the rigor of a case study can be questioned if the research is not completed in an organized and systematic manner (Yin, 2014). For this research, this risk was addressed through the collection of data in a systematic way in four categories (described in detail in Section 4.5) from the beginning of the study. Another potential weakness is misunderstandings on the theory, reliability and validity of the method (Flyvbjerg, 2006). Current methodology literature has developed over the past few years to prove that case based research can be generalized, generate valuable knowledge and overcome researcher bias (Flyvbjerg, 2006; Maxwell, 2013). This research was conducted with the intent to find generalizations that could be applied to other SMEs. Additionally, a sample of data was checked by other researchers and coded separately to minimize bias.

Qualitative research also has many well-known limitations. While it generally provides a rich picture of understanding of a situation, it can be difficult and time consuming to interpret and disseminate (Maxwell, 2013). Analyzing and understanding the outcomes of the case study data was indeed difficult and time consuming, however was ultimately rewarding, leading to an overall successful study with interesting outcomes.

Finally, a difficulty of this Engineering Doctorate was the fact that there was a lack of a full application of the framework in an industrial setting. However, to be accurately able to measure the effect such a tool might have on an SME would require months, possibly years.

The 18-month project that was studied with the SME was, at its core, a feasibility study to simply understand and consider the potential market opportunity. The fact that a full industrial application was not able to be conducted was mitigated by approaching SMEs for feedback, as discussed in Chapter 5, section 5.4.4.

Additionally, it must be considered that developments like frameworks can take several years for their impact to be fully gauged. A prime example here is Porter's five forces. This framework was first published in 1979, which Michael Porter was just getting started in his career, but it was more fully recognized by the business and academic community over a decade later, in the 1990s (Porter, 2008). A framework can be innovative but industry may not take immediate advantage of that, making an objective measure of success difficult in the short term. The most important aspect to keep in mind about this Engineering Doctorate research is that there is a strong market interest in the topics considered and the framework created, as demonstrated by feedback from SMEs and PTC.

6.7 Opportunities for future research

There is growth in both areas of IoT and servitization, in the technologies being developed and the markets being created. There is potential to apply the findings of this research into further research and innovation into developing solutions that can best take advantage of this growth. Main opportunities for further research include:

1. Further application of the framework in multiple case studies with SMEs
2. Development of a consultant/educational tool for PTC and partners
3. Further academic analysis of the framework and its strengths and weaknesses as a strategic tool

6.7.1 Further application of the framework in multiple case studies with SMEs

The next step would be the application of the framework into a small number of diverse SMEs. The main industries that would most benefit from this type of innovation, such as manufacturing and professional and scientific. Part of this application would be the development of a software tool that readily aides this application of the framework and allows the innovation to become a more tangible product development for the sponsor company.

6.7.2 Development of a consultant/educational tool for PTC and partners

Further research would be to use the framework as a tool to help PTC employees and partners to develop stronger relationships with new customers in the SME sector. PTC conducts training and development of solutions for individual businesses. The framework can be a visual aide that allows for more concrete solutions to be found more quickly. This research could initially be conducted with a few key stakeholders, then feedback collected to improve the design of the framework for further commercial use.

Further academic analysis of the framework and its strengths and weaknesses as a strategic tool

A potentially valuable academic exercise would be as a generic strategic tool that compliments existing tools for businesses. Though the original design of the framework was to focus narrowly on the business model of servitization and how this can be enabled by the IoT, there were generic ideas that influenced the development of the final framework. This

was discussed previously in section 5.5.1 The steps of the framework. This exercise would promote a better understanding of the framework and how it benefits SMEs rather than the limited success of many other analysis tools.

6.8 Summary

This chapter has presented and explained the innovative research and outputs of the Engineering Doctorate. It has considered this innovation through both an academic and an industrial lens. The use of the framework in two settings; by a consultant working with an SME and by the SME, was discussed and challenges of these applications presented, based upon initial work with industry-based Masters students. Strengths and weakness of the research and the innovation have been reflected upon. Finally, future opportunities for both academic research and industrial applications have been outlined and discussed. The next chapter will serve to summarize this report.

Chapter 7: Summary and Conclusions

7.1 Introduction

This chapter will summarize this report, discuss the outcomes and present conclusions.

7.2 The Research Aim and Objectives

The research journey started by considering the facts that there were opportunities and challenges with both the IoT and Servitization that are not fully considered, understood or utilized for competitive advantage by many SMEs. From this starting point, opportunities were explored, challenges identified, and a strategy was developed that could aid these SMEs, particularly organizations wishing to innovate and grow. This was achieved through the development of a conceptual framework. Furthermore, how the IoT can enable servitization for SMEs is not a topic that has been fully considered by previous research, meaning that this work also resulted in a contribution to knowledge in a new area. The objectives necessary to complete this aim were outlined in Chapter 1.

7.3 The Research

While a variety of areas were explored, the core research focused on the themes of SMEs, the IoT and servitization. A comprehensive literature review was conducted that addressed these themes. Additionally, an industrial-based, longitudinal case study was completed with a London-based fuel cell company, Arcola Energy. This research had several interesting results, namely that there was a desire by a large proportion of SMEs to innovate and grow, that there was an opportunity for this growth through servitization and that a tool was needed to realize this opportunity. This requirement is addressed with the development of a conceptual framework.

7.4 The Framework

The framework was created following a review of the current literature which considered the three themes, SMEs, the IoT and servitization. These themes were first considered separately and then cross-theme analyzed to understand how they related to one another. The results of the two-year case study with Arcola Energy drove further modification to the framework so that it could be a generic tool for SMEs to consider if they wanted to also employ the IoT to develop services within their own businesses. This tool could be used by the sponsor company, PTC, to engage with customers in a new area.

The framework can be used as a strategic tool to help an SME consider their competencies, drivers and challenges and then identify opportunities for growth and innovation in developing value-adding service through the increasing capabilities offered by the IoT. Alternatively, it can be used by consultants or the sponsor company as a tool to help them engage with a new market of SMEs to simplify both the process of engaging with new technologies and tools and business strategies. The simplicity of the framework is key, as SMEs are limited in many resources and it allows for these complex concepts to become more readily accessible to the business. Most importantly, this framework can help to establish the beginnings of a mindset shift in terms of being able to develop new services and engage with innovative technologies and tools.

7.5 The Innovation and Impact

Two main outcomes resulted from this research. The first is the academic outcome; which considers the three themes of SMEs, Servitization and the IoT in context. The second outcome is the framework that was created. This framework was based upon the review of

literature, the results of an industrial case study and the feedback received from experts and stakeholders.

The framework created has the capability to benefit both the sponsor company PTC and SMEs alike. It simplifies complex concepts and processes to allow for SMEs to better manage the strategic decisions necessary to allow for innovation and growth in a company. Additionally, there is a potential benefit for broader economies and supply chains. Generally, economies do well with a strong base of small to medium sized businesses generating revenue, providing employment and innovating. Therefore, any tool that can aid SMEs to innovate, grow, and contribute to the general economy has long term benefits.

Impact has already been seen from the material created for the MSc module in Service Design and Delivery for professionals from industry, discussed in detail in Section 5.4.2. There was interest and engagement from the professionals on the course. Furthermore, the application of the framework as a potential training tool resulted from this module exercise. Impact has also been seen through engagement with industry, through dissemination of the framework to West Midlands SMEs; the feedback from the SME representatives who participated in that event helped to establish a need for the framework created and is presented in greater detail in Section 5.4.4. Finally, the expertise developed has been recognized by leading academics in the field of servitization, as the researcher has recently accepted a reviewer's role in the International Journal of Production Economics that considers IoT and servitization.

7.6 Conclusions

In exploring the relevant issues to the main stakeholders of this Engineering Doctorate, it was found that SMEs need new ways to innovate their business models in an ever-changing landscape. While there are myriad ways to innovate, one way that may be valuable to SMEs is through the utilization of the IoT phenomenon to develop a Servitization model. This can be a potentially good opportunity for SMEs, however, many do not have the tools or understanding that would help them start on this transformation within their business. Exploring this space; SMEs, the IoT and Servitization, was a key outcome of this doctorate. From this exploration, a framework was developed that has the potential to aid in this sort of transformation for an SMEs, either through the application of the framework directly or through the themes of the framework being used through an external agent (such as a consultant). This framework was developed through three main stages, which considered academic, industrial and stakeholder input. The result is a framework in a completely new area that in itself is innovative and can also help be a catalyst for innovation through its use.

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Appendix A

Data from Case Study

There were four types of data collected during the case study. This appendix will quantify the sources of each type, and include an example of the coding done on each type. Most of this data was uploaded into NVivo software, where nodes were defined and labeled throughout the sources. These nodes have been pulled out into tables below for coding examples. The only data that was unable to be uploaded for analysis in Nvivo was the participant observational data, due to most of this data was comprised of visual diagrams and process maps. These were coded manually.

Semi-Structured Interviews

A total of eight interviews were conducted and recorded over of the course of the case study, with six separate individuals in Arcola Energy. Each interview lasted between 20-30 minutes. The first set of interviews were conducted in October 2014 with five individuals and the second set was conducted in July 2015, with three individuals. These interviews were then transcribed by the researcher. Example of coding, from interview quote with Engineer on Case Study Project from July 2015:

> *"I don't know if you've noticed, but in the last year or so, the objectives and direction of the company has been changing because we've needed to adapt to whatever the money is or whatever the projects take us(1). Keeping the structure we currently have of low power and education services,(2) ~100W scale with Hymera, and kW scale for cars, it's pretty dependent on how the fuel cell market develops, because that's going to help us to sell more services.(3) If we rely only on monitoring products, for example. I don't think it's going to be enough on its own to help us grow.(4) I see that only as a tool to enhance customer services or to enhance the customer experience of the service, not really the tool to help us grow. I like to see, in 5-10 years, Arcola growing both as the expert and go to company in fuel cell electric vehicle systems as well as the company developing off-grid solutions.(5)"*

Ref.	Quote from Example	1st Pass Coding Node	2nd Pass Coding Node
1	"*in the last year or so, the objectives and direction of the company has been changing because we've needed to adapt to whatever the money is or whatever the projects take us.*	Arcola Energy business structure	Arcola Energy SME
2	*"Keeping the structure we currently have of low power and education services"*	Arcola Energy competencies	Arcola Energy SME
3	*"it's pretty dependent on how the fuel cell market develops, because that's going to help us to sell more services"*	Customer understanding; potential barriers	Arcola Energy Servitization
4	*"If we rely only on monitoring products, for example. I don't think it's going to be enough on its own to help us grow"*	Monitoring IoT Capability, limitation	Arcola Energy IoT
5	*I like to see, in 5-10 years, Arcola growing both as the expert and go to company in fuel cell electric vehicle systems as well as the company developing off-grid solutions*	Arcola Energy Long Term Objectives	Arcola Energy SME

Company Documentation

The researcher had access to most company documents throughout the course of the case study. From these, 26 documents were used in the analysis. Most of these are sensitive. The example shown below is from the project plan of the Off-Grid project that was central to the case study.

> *"To achieve the principal project objective, we will develop a **system configuration tool** (Design-Build-Operate-Maintain) to allow non-technical staff to scope out requirements for hydrogen in an **"energy-as-a-service" model** (1) (Design-Build-Operate-Maintain). This will facilitate the use of H2&FC in a range of relevant off-grid settings.(2)*
>
> *The development of the system configuration tool and associated technology implementation entails a number of deliverables and outputs, including:*
>
> - *Power consumption and H2&FC monitoring systems for off-grid energy use(3)*
> - *Case studies on a range of off-grid power scenarios detailing power use profiles. (4)*

- *Two real-life assessments of hydrogen in an "energy-as-a-service" model (5)*
- *Development of a supply chain for hydrogen in an "energy-as-a-service" model*

The acceptance procedure and criteria for the 'energy-as-a-service' model will be contained in some key project deliverables:

- *Safety case for use of hydrogen in an "energy-as-a-service" model – including assessment of legal requirements, Failure Mode Effect Analysis (FMEA), and clear instructional documentation (6)*
- *Business case for use of hydrogen in an "energy-as-a-service" model – this will include extensive modelling of different scenarios (7)*
- *A commercial stage-gate review will be carried out at the end of Q4 when project partners will review project findings and make a decision on the commercial viability of the proposed service provision"*

Ref.	Quote from Example	1st Pass Coding Node	2nd Pass Coding Node
1	*"scope out requirements for hydrogen in an **"energy-as-a-service" model"***	Off Grid Project Service Definitions	Off-Grid Project Servitization Development
2	*"This will facilitate the use of H2&FC in a range of relevant off-grid settings"*	Arcola Energy short term objective	Arcola Energy SME
3	*"Power consumption and H2&FC monitoring systems for off-grid energy use"*	Off Grid Project IoT technology	Off-Grid Project IoT Technology
4 & 5	*"Case studies on a range of off-grid power scenarios detailing power use profiles"* *"Two real-life assessments of hydrogen in an "energy-as-a-service" model"*	Off Grid Project IoT technology and service definitions	Off-Grid Project Servitization Development
6	*"Safety case for use of hydrogen in an "energy-as-a-service" model – including assessment of legal requirements, Failure Mode Effect Analysis (FMEA), and clear instructional documentation"*	Off Grid Project details & obstacles	Off-Grid Project Servitization Development
7	*"Business case for use of hydrogen in an "energy-as-a-service" model – this will include extensive modelling of different scenarios"*	Off Grid project service example	Off-Grid Project Servitization Development

Observational Data

The researcher kept hand-written notes throughout the case study, in a series of three notebooks. These notebooks were periodically typed up, to maintain a digital copy of the data should anything happen to the hand-written version. These notes cover the period from the first meeting with Arcola Energy on 30 October, 2013 to the final Off Grid Project meeting on 24 November, 2015. The following example is from an Off-Grid Project meeting in June 2015. (Names have been changed to the roles in the project).

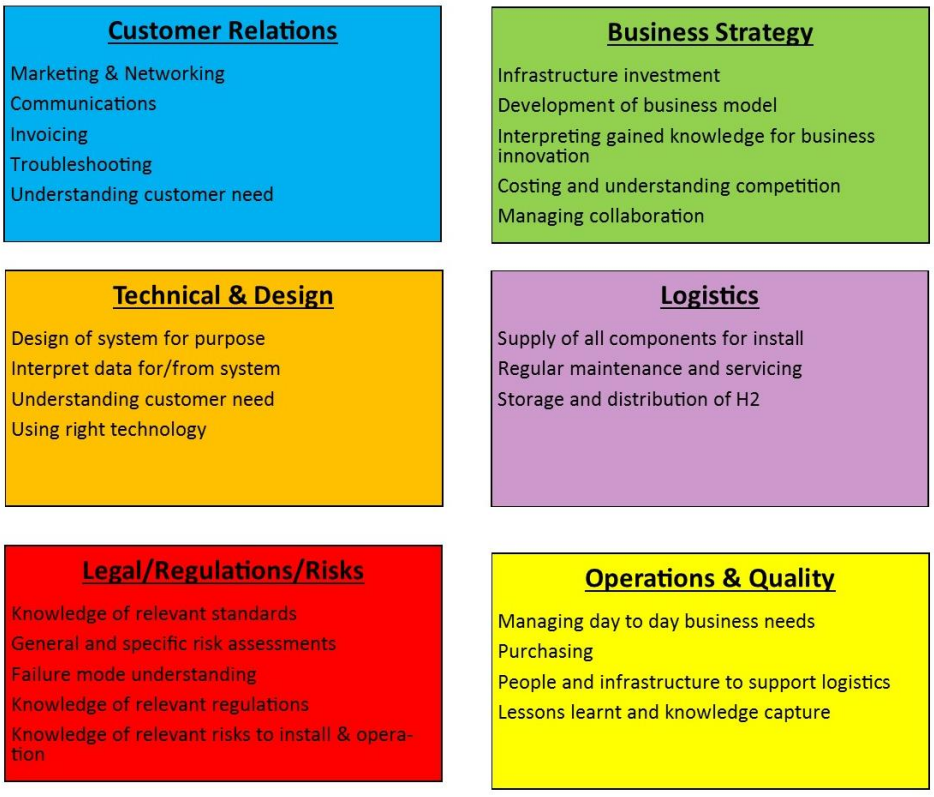
> *[Project Engineer] is processing monitoring data from 2 sites. ("simple" and "complex") Monitoring for the next 3 months, different scenarios.(1)*
> *[Innovation Manager]: market research to see how FCs are (or aren't) integrating with other renewables. Talked with a PV manufacturer, interested in integration.*
> *Road sign: integrated → also interested. People recognize the problem/need → enabling and creating a new market.(2)*
> *[Project partner]: Service needs to be good. [Partner] deliverables → none for this quarter. Customers can take 6-9 months to submit (budgets, need, etc) improve communication and presentation of service.*
> *Barriers of misconceptions to a service.(3)*
> *Additional advantage → provide the data about usage (for companies) for meeting standards/laws, knowing about energy needs.(4)*

Ref.	Quote from Example	1st Pass Coding Node	2nd Pass Coding Node
1	*processing monitoring data from 2 sites. ("simple" and "complex") Monitoring for the next 3 months, different scenarios.*	Off Grid Project IoT Monitoring Technology	Off-Grid Project Servitization Development
2	*People recognize the problem/need → enabling and creating a new market*	Off Grid Project; Servitization understanding; IoT capabilities	Off-Grid Project Servitization Development
3	*Service needs to be good. Customers can take 6-9 months to submit (budgets, need, etc) improve communication and presentation of service.*	Off Grid Project service development challenges	Off-Grid Project Servitization Development
4	*Additional advantage → provide the data about usage (for companies) for meeting*	Off Grid Project IoT technology,	Off-Grid Project Servitization

standards/laws, knowing about energy needs.	Customer understanding	Development; Off-Grid Project IoT Tech

Participant Observation Data

As part of the case study, the researcher helped to conduct work relevant to the Off-Grid Project and for Arcola Energy. Overall, 15 pieces of work were conducted for the Off-Grid Project and eight pieces of work were conducted for the SME. This work included helping to create process maps and organize visually some of the concepts being considered for the project. One of the pieces of work done, which is shown below, was a diagram outlining and categorizing the competencies needed for the project. This piece was initially coded (1st pass) as "Off Grid Project competencies" and then second-pass coded as "Off-Grid Project Business Case."



Appendix B

PTC's Current Objectives and Strategy in the IoT and Servitization

A Short History of PTC

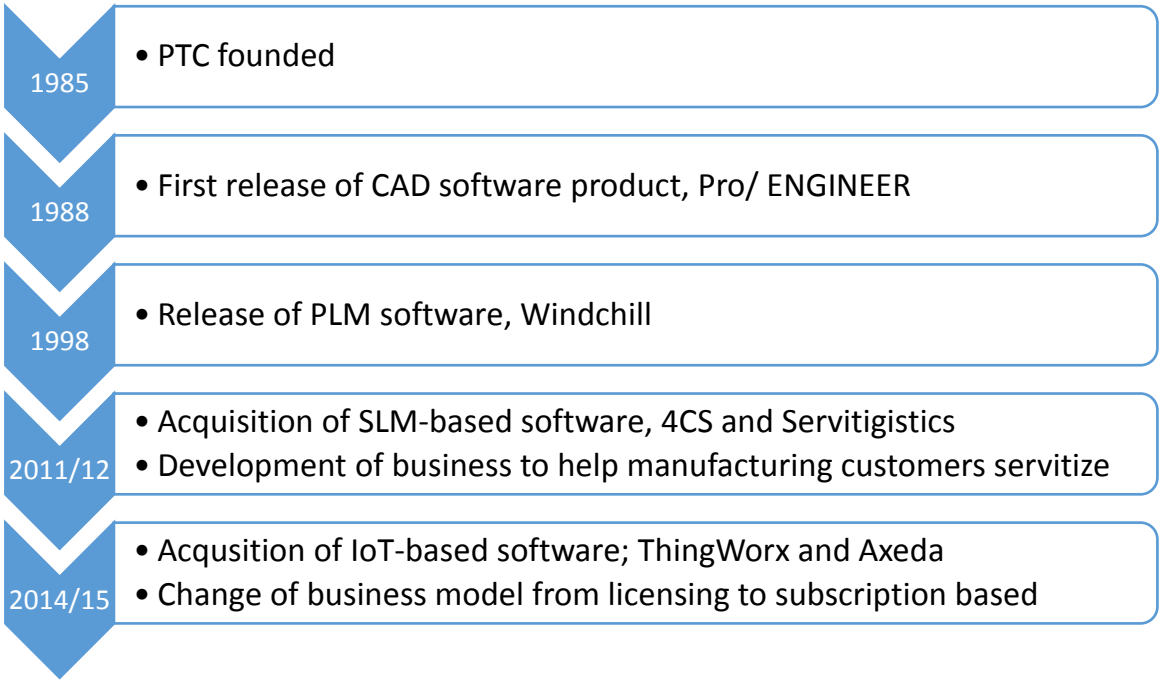


Figure 33: PTC's relevant history ("PTC History and Acquisitions," 2015)

PTC was founded in 1985, originally with the name Parametric Technology Corporation. In 1988, it was the first company to release three dimensional (3D) parametric modeling Computer Aided Design (CAD) software ("PTC History and Acquisitions," 2015). This first product was the CAD software package known as Pro Engineer, or Pro/E. Parametric modeling differs from the alternative, which is direct modeling, in that it allows for dimensions and relationships of parts in an engineering drawing to be made scalable. While both types have advantages and disadvantages (PTC, 2011), the robustness of Pro/E launched the company through the late 1980s and early 1990s, landing them as a Fortune

500 company in 1995 and added to the S&P 500 in 1997 ("PTC History and Acquisitions," 2015). In 1998, the company released its Product Lifecycle Management (PLM) software package known as Windchill. The company has then spent the next two decades growing its portfolio of software products though several acquisitions. Important events in the history of the company as it relates to this Engineering Doctorate are shown in Figure 33.

PTC's Entry into Servitization

In 2011, PTC acquired 4CS, a software suite that helped to improve service revenue and profitability through the integration of warranty, service, support and service parts processes for manufacturers. In 2012, they acquired Servigistics, which is software aimed at helping manufacturers develop services ("PTC History and Acquisitions," 2015). The capabilities of these two software packages were integrated with PTC's existing software to comprise a multi-faceted solution for the development of service. Overall, there were nine areas that PTC categorized for services with the software the company acquired, and they integrated these capabilities with their other products, such as Arbortext, Creo, PTC's evolution of their original CAD software Pro/E, and Windchill (PTC, 2015c):

1. Technical information
2. Service parts information
3. Warranty and contract management
4. Service knowledge management
5. Service parts management
6. Field service management
7. Service depot management
8. Service network management
9. Service parts pricing

The focus of PTC's servitization software is mainly product and manufacturing based and the company takes the perspective that their software helps customers develop existing or new services to compliment or enhance existing products (PTC, 2015c).

PTC's Entry into IoT

In 2014, PTC began its involvement with the Internet of Things through the acquisition of ThingWorx and Axeda; which the company hopes will make them a major player as the IoT develops in the future. ThingWorx is a platform that creates applications that can facilitate Machine to Machine (M2M) communication over the internet. Axeda is a cloud-based solution that allows for the management and connection of products ("PTC History and Acquisitions," 2015). In 2015, two more relevant acquisitions were made in the IoT space for PTC; ColdLight and Vuforia. ColdLight is a predictive analytics software package that will enhance PTC's existing portfolio and Vuforia is an augmented reality software package that will help further PTC's "digital twin" concept. The concept of the digital twin for PTC means connecting the design of a product to the specific usage and requirements of a specific product. The digital twin utilizes the core competencies of PTC in CAD with their growing competencies in the IoT to provide an entirely new software package and service to their customers. For example, a customer could have a design in CAD of their product. This product is then fitted with sensors that feedback information about the use and requirements of that specific product, creating new opportunities in failure prevention and understanding of usage.

In addition to acquisitions, PTC furthered their influence in this space through publications in journals such as the Harvard Business Review and dissemination of business ideas about

applying IoT capabilities. In November 2014, PTC's CEO, Jim Heppelmann partnered with Dr. Michael Porter from the Harvard Business School to write how "smart, connected products" are changing competition. These products, and how they interact with the forces of the market, could be the next paradigm shift in business, they argue (Porter & Heppelmann, 2014). A follow up publication in October 2015 discusses this shift for companies in greater detail, putting forth the ideas that "smart, connected products" force companies to redefine both their industries and strategies and will require new relationships, processes and structures (Porter & Heppelmann, 2015).

PTC's Business Model Change

In their latest fiscal report for 2015, PTC announced a drastic change in their business model. The plan is to move the company into a subscription model from a perpetual license model (PTC, 2015a). This shift is a type of servitization, but it will allow for customers to improve the way they pay for software that they need and use. A large proportion of it will also be cloud-based. This is particularly relevant to this Engineering Doctorate research because submission 2 was the result of time spent at the PTC in early 2013. At this time, the company was considering different options for the future of the company, and the focus was in understanding the potential opportunities in cloud-based software and the Software-as-a-Service business model. The research submitted to the company highlighted the main direction of competitors and technology with regards to CAD in a cloud-based environment and field service software in a cloud-based environment.

As of 2015, PTC has a total of 28,000 active customers, in industries like automotive, electronics and high technology and medical devices (PTC, 2015b). The company employees

6000 globally, alongside nearly 1400 dedicated service professionals and over 750 partners, which are resellers, hardware and system integration partners and service and training partners. Figure 34 is a representative of where revenue originates for PTC.

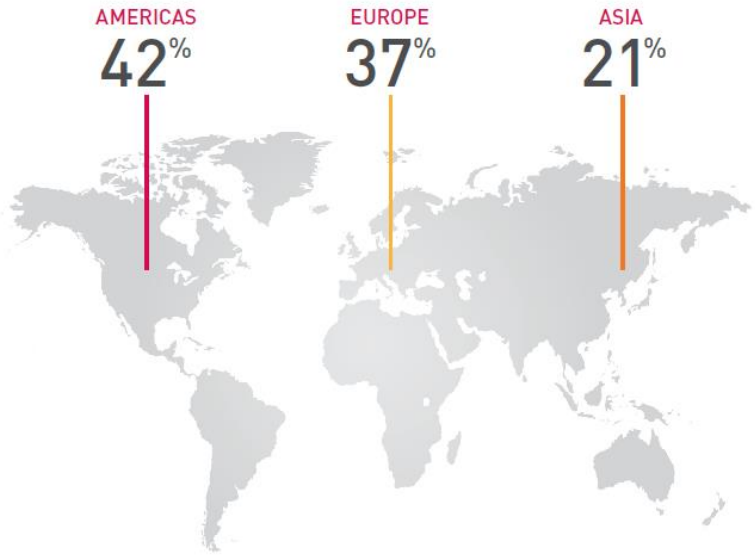


Figure 34: Map of percentage of revenue from different parts of the world for PTC (PTC, 2015b).

Appendix C

Potential Market Opportunity Analysis

To analyze the potential market, first start with the consideration that 13% of all SMEs were classified as "growers", based on previous survey data from the Department for Business Innovation and Skills conducted in 2012. Growers were specifically defined as companies that increased the number of people employed by at least 5% or had increased turnover by at least 5%, which a minimum increase of £50,000 (BMG Research, 2013).

The more recent Department for Business Innovation and Skills survey (2015) of UK SMEs did not do a similar segmentation on growth, but it noted that 38% of SMEs claimed to have innovated products or services and 32% had innovated processes; both figures were slightly down since 2012 (Figure 35). Additionally, the 2014 survey addressed growth, but more from the perspective of businesses that were aiming to grow within the next year and what their plans were to achieve that growth.

	2014	2012
All SME employers (n=)	4355	4768
	%	%
Innovate products or services	**38**	43
Innovated processes	32	33
Exporting	19	19
Trained staff	**57**	60
Have internet access	**98**	91

Figure 35: Key trends in UK SME capabilities(The Department for Business Innovation & Skills, 2015)

Since growth and innovation are linked concepts; as discussed in detail in the literature review section of Submission 4 and briefly in this Innovation Report in Chapter 3, it is assumed that the growth achieved by the UK SMEs can be attributed to some form of

innovation. However, a comparison of the surveys suggests that not all innovation necessarily leads to growth. The discrepancy between the two figures is approximately 25% of all UK SMEs.

If nearly 1/3 of SMEs are actively engaged in some sort of innovation within their company in the UK, some of these businesses may further benefit from a tool or framework to improve their innovation. This could even turn this innovation into tangible growth, for the 25% innovating but not necessarily seeing corresponding growth.

Further analysis requires the consideration of both the size (micro, small or medium) of the SME as well as the industry. Table 7 compiles some of the survey results from the most recent BIS study of UK SMEs and categorizes the industries and the size, along with aim to grow percentages of each size of SME. The table lists the biggest six SME industry sectors; Retail and wholesale, professional and scientific, construction, food and accommodation, administration service and manufacturing and also shows these industries corresponding intentions for growth.

Table 7: UK SME size, industry and growth data from most recent BIS survey (The Department for Business Innovation & Skills, 2015)

Size	***Micro*** *(1-9 employees)*	***Small*** *(10-49 employees)*	***Medium*** *(50-249 employees)*	***All SMEs***	***Aim to Grow in next 2-3 years?***
Number of businesses	1653	1714	988	4355	
% of survey sample	38%	39%	23%	____	
Aim to grow in next 2-3 years?	71%	80%	87%	73%	
Industry Breakdown					
Retail & wholesale	19%	18%	15%	19%	69%
Professional & scientific	14%	10%	9%	14%	78%
Construction	13%	8%	6%	12%	63%
Food & accommodation	9%	13%	8%	10%	69%
Admin services	8%	7%	12%	8%	83%
Manufacturing	6%	11%	19%	7%	81%

Of the top SME sectors aiming to grow in the next 2-3 years, Table 8 shows the main ways each sector plans to achieve this growth. These are relevant to the research conducted for this Engineering Doctorate and the framework developed. The development of a new service at an SME could lead to the exploitation of a new market; as was discovered in the case study. Additionally, the skills needed to both understand and exploit the IoT to develop new services are unique. These skills within a company's workforce would need to be developed.

Table 8: How top SME industry sectors plan to achieve growth (The Department for Business Innovation & Skills, 2015)

Industry	*Plan to achieve growth by:*		
	Exploiting new markets	***Develop and launch new products and services***	***Increase skills of workforce***
Retail & wholesale	68%	62%	74%
Professional & scientific	66%	54%	87%
Construction	56%	38%	82%
Food & accommodation	68%	62%	74%
Admin services	74%	54%	84%
Manufacturing	84%	65%	79%

The previous considerations of the SME's size, sector, desire for growth and innovation is conducted to allow for a market analysis to quantify the potential opportunity from the research of this Engineering Doctorate. The most recent figure on annual SME revenue published by BIS is £1.6 Trillion. The breakdown of how this is distributed by sector is shown in Figure 36. By far, the biggest sector that contributes to turnover is wholesale and retail, accounting for 35% of all SME turnover.

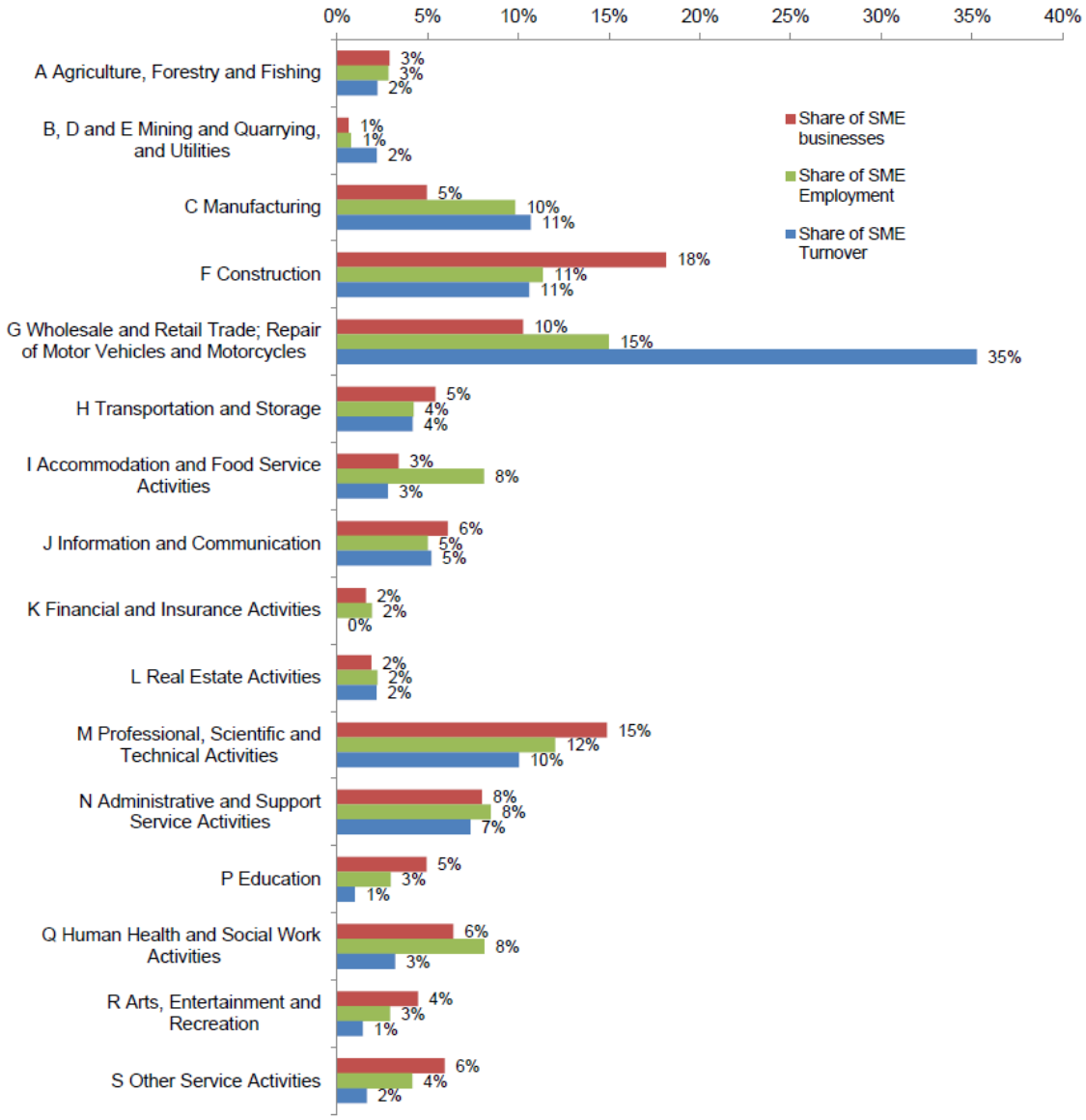


Figure 36: Breakdown of SME businesses, employment and turnover by sector (BIS, 2014).

For this analysis, two main relevant industries will be considered; manufacturing and professional and scientific. These two industries are considered the most relevant due to the case study research and the sponsor company. The case study SME was classified in the professional and scientific sector and was a small company, with 15 employees. Additionally, the main industry in which PTC has customers is in the manufacturing industry.

Considering each industries percentage of the total annual SME turnover of £1.6 Trillion, each industry would have:

Table 9: Annual Turnover of Manufacturing and Professional & Scientific SME sectors

Industry	***Turnover Percentage***	***Turnover***
Manufacturing	11%	£176 Billion
Professional & Scientific	10%	£160 Billion

The combined annual revenue in these two sectors alone is approximately £336 Billion. If PTC or a consultant could enter the market to aid these companies develop a service, they could potentially earn a portion of this revenue. If the assumption of 0.1% of the revenue generated in these two sectors is made, that could equate to £336 Million. The reported annual revenue for PTC in the 2015 fiscal year was $1.259 Billion (approximately £826 Million) (PTC, 2015b).

Table 10: The number of SMEs in manufacturing and professional and scientific sectors (BIS, 2014; The Department for Business Innovation & Skills, 2015)

Industry	***Number of Businesses Percentage (BIS, 2014)***	***Number of Businesses***	***Number of Businesses Percentage (BIS, 2015)***	***Number of Businesses***
Manufacturing	5%	260,000	7%	364,000
Professional & Scientific	15%	780,000	14%	728,000
TOTAL	20%	1,040,000	21%	1,092,000

The two BIS sources on SMEs, the first published in November 2014 and the second published in March 2015 have slightly different numbers for the percentage of total

businesses in this two sectors. The first publication gives manufacturing and professional and scientific sectors 5% and 15% respectively, while the second says that they comprise 7% and 14% of all SME businesses. The ranges of what these two slightly different numbers mean in terms of the number of businesses in these two sectors is shown in Table 10.

This means that 0.01% of these two sectors would range from approximately 10,400 to 10,920 businesses. PTC currently has about 28,000 global customers, so being able to manage that many new customers would require restructure to the business – but some of this restructure is already occurring, through the change to the subscription business model, as well as restructuring of the departments.

These numbers only account for UK SMEs, the potential in the rest of Europe and the US would increase the potential opportunity here for PTC.

Appendix D

Formula Student Ethics Paperwork

THE UNIVERSITY OF WARWICK

Biomedical and Scientific Research Ethics Committee (BSREC):

Application Form for Research Ethical Approval

SECTION 1. APPLICANT DETAILS

1.1 RESEARCHER

Researcher's Title: Ms
Researcher's Forename: Courtney
Researcher's Surname: Thornberry

Researcher's Faculty/School and Department: WMG

Researcher's Status:

Undergraduate Student	☐
Taught Postgraduate Student	☐
Research Postgraduate Student	☒
Staff	☐
Other	☐

Please specify:

If Student:
Name of course/qualification: International Engineering Doctorate

If Staff:
Researcher's Post:

1.2 RESEARCHER'S CONTACT DETAILS

Warwick e-mail address: c.thornberry@warwick.ac.uk
Daytime telephone number: 22264
Postal address: IIPSI

1.3 SUPERVISOR (COMPLETE FOR ALL STUDENT PROJECTS)

Supervisor's Title: Dr
Supervisor's Forename: Alex
Supervisor's Surname: Attridge

Supervisor's Post: Project Manager

Supervisor's Faculty/School and Department: WMG
Supervisor's Warwick e-mail address: a.attridge@warwick.ac.uk
Supervisor's daytime telephone number: 75420

SECTION 2. PROJECT DETAILS	
2.1 Project Title:	Warwick Racing Formula Student Team: Improving Team Performance and Innovation
2.2 Estimated Start Date of Project:	1 June 2014
2.3 Estimated Completion Date of Project:	1 October 2014
2.4 Sponsoring Organisation: (for University of Warwick staff and students, undertaking non-commercial projects, this will be the University of Warwick)	University of Warwick
2.5 Funder: (e.g. unfunded student project, unfunded Departmental project, Medical Research Council (MRC), Economic & Social Research Council (ESRC), EU)	EPSRC

2.6 TYPE OF PROJECT

Is the project:

Primary Research	☒
Research limited to the use of previously collected *identifiable* data	☒
Research limited to the use of previously collected *anonymised* data	☐
Other	☐

Please specify:

2.7 LINKS WITH OTHER BSREC APPLICATIONS

Is the project linked to any other BSREC application? No

If yes, detail:

Project title:

Chief Investigator:

BSREC Reference (if known):

Nature of linkage:

2.8 LOCATION

Will any part of the project be undertaken overseas? No

State all of the locations at which the project will be undertaken, whether in the UK or overseas e.g. public place, school (a), school (b) etc., in researcher's office:

2.9 PARTICIPANTS

State the total number of planned participants: 200

BREAKDOWN OF PARTICIPANTS

Where applicable, state the breakdown of participants by type and number of each type of participant, e.g. children, parents, teachers, etc.:

Type of Participant:	**Number:**
Engineering University Student	200

SECTION 3. RISK AND ETHICAL CONSIDERATIONS CHECKLIST

Complete the checklist ticking '**Yes**' or '**No**' to all questions.
Note that, where you have ticked '**Yes**' to a question below, you will need to specifically address the ethical issues raised by that point in the study protocol.

		Yes	No
A	Does the study involve **participants who are particularly vulnerable** or **unable to give informed consent** or **in a dependent position** (e.g. children, your own students, over-researched groups, people with learning difficulties, people with mental health problems, young offenders, people in care facilities, prisoners)?	☐	☒
B	Will participants be taking part in the study without their consent or knowledge at the time, or will **deception** of any sort be involved (e.g. covert observation of people in non-public places)?	☐	☒
C	Is there a risk that the highly sensitive nature of the subject might lead to **disclosures** from the participant concerning their involvement in illegal activities or other activities that represent a threat to themselves or others (e.g. sexual activity, drug use, or professional misconduct)?	☐	☒
D	Could the study induce **psychological distress or anxiety**, or produce **humiliation**, or **cause harm**, or lead to **negative consequences** beyond the risks encountered in normal life?	☐	☒
E	Does the study involve **substantial physical exertion**?	☐	☒
F	Does the study involve the **administration** of any substance?	☐	☒
G	Does the study involve **physically intrusive procedures**, use of **bodily materials** or **human tissue**, or **DNA/RNA analysis**?	☐	☒
H	Is any **reward**, apart from travelling and other expenses, to be given to participants?	☐	☒
I	Does the study involve **collaboration with any company** or **organisation** external to the University of Warwick?	☐	☒

J	Could the proposal give rise to researchers having any **conflicts of interest**?	☐	☒
K	Will the researchers go to any areas where their **safety may be compromised**?	☐	☒
L	Will **pregnant women** be participants in the study?	☐	☒

SECTION 4. SIGNATURES AND DECLARATIONS

4.1 RESEARCHER/APPLICANT

I undertake to abide by the University of Warwick's Research Code of Practice in undertaking this study.

I understand that BSREC grants ethical approval for projects, and that the seeking and obtaining of all other necessary approvals and permissions prior to starting the project is my responsibility.

I understand that I must not begin research and related projects with human participants until I have received full approval from the relevant Research Ethics Committee of the University of Warwick.

I understand that any changes that I would like to make to this study after receiving approval from BSREC must follow BSREC procedures as detailed on the BSREC web pages.

Name of Researcher: Courtney Thornberry

Signature: Courtney Thornberry

Date: 16/06/14

NB: The applicant must post a wet ink signature copy of this form to: BSREC Administrator, B032, Medical School Building, Warwick Medical School, University of Warwick, Coventry, CV4 7AL.

4.2 SUPERVISOR AUTHORISATION FOR STUDENT PROJECTS

I confirm that I have read this application and will be acting as the student researcher's supervisor for this project.

The proposal is viable and the student has the appropriate skills to undertake the research. Participant recruitment procedures, including the Information Leaflet(s) to be provided and the process for obtaining informed consent, are appropriate, and the ethical issues arising from the project have been addressed in the protocol.

I understand that BSREC grants ethical approval for projects, and that the seeking and obtaining of all other necessary approvals and permissions prior to starting the project is the responsibility of the student.

I understand that research and related projects with human participants must not commence without full approval from the relevant research ethics committee of the University of Warwick.

Name of Supervisor: Alex Attridge

Signature: .....

Date: 16/06/14

NB: An e-mail from the Academic Supervisor that states the above, in lieu of a wet ink signature on this form, may be sent to: bsrec@warwick.ac.uk

Warwick Racing Formula Student Team: Improving Team Performance and Innovation

Summary

Formula Student, or Formula SAE as it is known in other parts of the world, is a comprehensive university-level engineering project where students design, build, test and race a single-seat race car. There are several limitations on the design, most notably the restriction on engine size to less than 600 cc. Graduates with experience in Formula Student are highly sought after in industry as the project is one of the best in universities today to reflect real industrial experience.

The Warwick Formula Student team is a 4th year undergraduate engineering academic project that is supported by WMG. In recent years, there have been opportunities explored around collaboration to improve team performance. These collaborative efforts have happened on three levels:

1. Within the university by engaging lower year engineering students in the extra-curricular aspects of the project
2. Nationally, through a collaborative network between UK teams
3. Internationally, through a collaboration with Monash University and the Monash Formula SAE team

These efforts have led to increased knowledge transfer between team years, improved relationships with suppliers for the project and a better understanding of competition deliverables. This work studies these newly formed relationships through semi-structured interviews and observations of team activities and interactions. It is conducted at WMG as part of the researcher's Engineering Doctorate project.

Background

Collaboration as a tool for innovation in product and service design has become an area of study in many industries (Knudsen, 2008; Meyer, 2003; Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002). Companies can achieve many benefits from collaboration, namely increased market share (McCarthy & Golicic, 2002), increased income (McLaren, Head, & Yuan, 2002), and increased flexibility and capabilities (Holton, 2001). There are various aspects of collaboration for industries, that range from shared funds, technology acquisition, R&D partnerships, joint ventures and networking (Suh & Kim, 2012).

Of particular interest is how Small to Medium Enterprises (SMEs) innovate through collaboration, as many lack much of the resources available to larger firms (Suh & Kim, 2012). Alternative models to innovation, such as open innovation or open source hardware or software design allow SMEs to complement insufficient resources (Lee, Park, Yoon, & Park, 2010). The differences between open innovation and open source are shown through project structure and focus. In most Open Innovation projects, the companies are central and there is a defined benefit to all involved (Chesbrough, 2006). A recent definition of Open Innovation classifies it as "systematically performing knowledge exploration, retention and exploitation inside and outside an organization's boundaries throughout the innovation

process" (Lichtenthaler, 2011). In an Open Source context, the focus is more on the contributors and the relationships that come together to solve a particular problem. There is much less structure in an Open Source project and there are often very few limitations on contributors (Grams, 2010).

While Open Innovation is not a new concept for businesses, it has become a recent growing trend as many businesses cannot do everything internally. This need to open innovation presents several challenges to businesses, particularly in organisational and management capabilities to be able to fully realise the value from collaboration (Lichtenthaler, 2011). A real challenge is present for SMEs, as many may not have the capability, resources or experience to adequately manage any Open Innovation projects.

Formula Student is an opportunity to study the effects of collaboration at many levels in a structured environment. The project has many similarities to SME behaviour, such as size, management structure and resources. It is entirely run by a group of engineering 4th year undergraduates, who have minimal, if any, industrial experience. This is parallel to many young SMEs in business today. While many teams, including Warwick, use some level of advanced Computer Aided Design (CAD), Project Data Management (PDM), Project Lifecycle Management (PLM), and other project collaboration software, the structure to innovation within the project evolves each year with each new team. Also, each team is structured differently, depending mostly on how the project is integrated into academic deliverables for the students' course.

Developing an understanding of collaborations between groups is critical in knowing how to organise and plan these collaborations, particularly at an SME level. Very little practical research has been done in this area and case studies could provide valuable lessons.

Aims/Objectives

In accordance with the research outline defined above, there are a few research questions generated for this study:

"How does the Formula Student team collaborate with previous and potential team members and other teams?"

"How is this process of collaboration evolving?"

"What are the benefits and potential broader applications of this type of collaboration?"

The objectives are as follows:

1. Initiate relationships between UK-based Formula Student teams and provide a communication infrastructure via an online platform.
2. Develop a semi-structure interview question set to obtain feedback from users of this collaborative network
3. Analyse and coordinate user communication of the network with user feedback.

Method

Three main qualitative approaches will be undertaken for this research. For objective 1, listed above, the researcher will take an action research approach. Some initial work has already been completed, namely the problem has been addressed through the researcher's relationship with the past three Warwick Formula Student teams. This problem was identified as the fact that there was not any accessible or easy infrastructure in place to communicate with other UK Formula Student teams. This was initially resolved through an online resource through a Warwick-based collaborative network, the West Midlands Collaborative Commerce Marketplace (WMCCM). However, upon evaluation, initial members said they would rather access a more widely used platform, so the network was relocated to Facebook. To set up a network that will be successfully used by team members, the researcher needed to find a platform that would readily be used and easily accessible to individuals wanting access. Therefore, as shown in Figure 1, the problem of finding a usable platform was cycled through. An initial platform was tried and used, then evaluated to find a better platform for use.

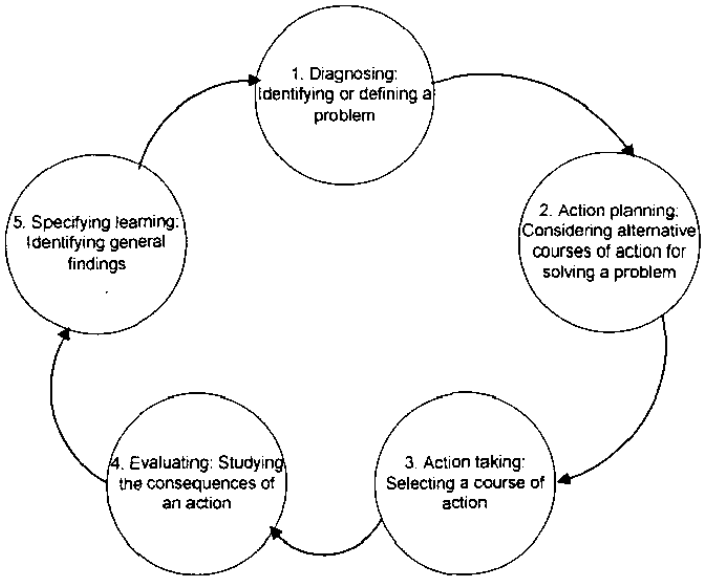


Figure 1: A cyclical approach to action research that will be applied to meet objective 1 (Avison, 2002).

Through most of the work carried out so far and for work to be continued, the researcher has engaged in a participant-observer research method (DeWalt, 2010). Since January 2012, the researcher has interacted on a regular basis with Warwick Formula Student team members. This experience ranged from attending most team management meetings, to machining parts for the car, to helping to organise and present various component of the final competition. This observation research is also applied in the online forum for the collaborative network, as the research sometimes engages in the information shared and discussed by team members. In the analysis of the research, some quantitative measures, such as number of members on the network, will be included in the results. Additionally, much of the information shared and discussed will be coded to categorise the data. Then, it will be analysed for

content. As the data will be generated continuously while members communication, it will be collected on a periodic basis to be able to see trends.

Finally, semi-structured interviews will be conducted with key members, usually project managers, of each participating team in the network to understand the perception of the collaborative space to the members. The interviews will be recorded and then transcribed at the annual competition in July at Silverstone, ideally. If the key members are not available for an interview at this time, other arrangements will be made. The main objective of the interviews will be to assess the perception of the impact of the network over the year of preparation for the competition. These interviews will only be given by team members who are willing and interested to give feedback about the network.

Analysis

For the observation research, the data first will need to be coded to analyse more effectively. This will be done through categorising the types of communication. For example, discussions about suppliers will first all be categorised under supplier discussion. Then, a deeper content analysis will be done to determine the quality of the discussion. In this example, it may be further categorised to differentiate discussions asking for a particular supplier from advice about a particular supplier and so on. This will be done to the point where all the data is mutually exclusive, that is, no communication can be categorised in more than one area.

From there, the researcher will quantify the interactions in the various categories and connecting communication between various teams involved. For example, if a member from Warwick asked a question about a brake part, the number of people to respond to the question, as well as the number of different teams to respond would be quantified.

Finally, based on the quantified results of the online collaborative network, the semi-structured interviews will be analysed to connect, in a qualitative manner, to the actions that have been seen on the network. While the interviews will be conducted and recorded one-on-one, the results will not be presented in a way that any specific person or team is highlighted in their feedback on the network, so as to protect the individuals, get honest feedback and anonymise the data. For both content from the network communications and semi-structured interviews, the software package Nvivo will be used to aid in the content analysis.

Ethical Considerations

The following section describes the ethical considerations needed for this study.

Recruitment

The initial six teams that were part of the collaboration network when it was started in December 2012 on the current platform were invited through a relationship that existed with a common industrial sponsor. The researcher met with and discussed the network with key team members, obtained email contact, and invited them to the platform. From this starting point, membership grew from the current members, as more teams were invited through social contact and word-of-mouth from current

members spread about the online network. As of June 2014, there are thirteen UK teams participating in the network.

For the semi-structured interviews, the researcher has the email and Facebook contact details of key team leaders from each team and is able to contact them to arrange face-to-face or over the phone interviews with the research questions.

Informed Consent

For the data collected from the network, there is no formal informed consent, though most members are aware of the researcher's efforts and motives. The information posted on this space is in the public domain and accessible to anyone with permission into the group. However, the researcher will post both an information sheet and the study results on the network, to make members aware of the study and of the results of their use of the network. Once ethical approval has been given, the researcher will also post information about the study to the online group, to make all members aware, just as an extra courtesy and precaution.

For data from the interviews, the participants will be given a consent form, explaining the purpose of the research, their role, and the use of the information they provide. At the time of this writing, there are 13 active teams in the UK collaborative network, so the researcher will be looking to interview one member from each team, in most cases, the project manager of the team. In the case that an interview will not be able to be conducted face to face, the consent sheet will be sent beforehand via email, signatures collected and then emailed back.

Participant Confidentiality & Data Security

All of the data collected from the Facebook group will be collected and analysed via software called Nvivo. This software has a setting that allows for specific data, such as personal identity, to be excluded from the initial collection. This setting will be used to analyse the content of the Facebook data, as the researcher is only interested in coding the discussion topics, not individual identity of the comments.

All of the interviews will be transcribed by the researcher. The subsequent information will be coded and presented anonymously in any dissemination of the work. The recorded interviews and transcriptions will then be placed on a password-protected university networked computer and transferred to a password-protected USB flash drive upon project completion to be stored by the researcher or the researcher's supervisor in university facilities for a period of 10 years.

Financing

This project is 100% funded through the WMG International Engineering Doctorate Centre, no additional funding is required.

Dissemination and Implementation

The results of this work are hoped to be presented at a Warwick conference and may also lead to a publication. In particular, the organiser of the UK Formula Student competition, the IMechE, may be interesting in any finding of the work.

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Appendices

Semi-structured Interview Questions

What were your personal and your team's motivation for using the collaborative platform?

How did you and your team use the platform?

Did the platform or collaboration affect your performance at all?

What can you think of that would have improved your performance?

What communication types seem to work best for your team?

Anything else to add about the collaborative network or working with other teams you can think of?

Invitation Email to Participants

Dear _____,

I am writing to ask for your participating in a 20 minute interview about your involvement in the UK Collaborative Network for Formula Student. This interview will ask you some basic questions about your and your team's use of the network and give you an opportunity to feedback any comments you may have about the network. Your participation in this study is completely voluntary, your responses will remain in the confidence of me and will be securing stored at the University. This is being used to better understand how the teams collaborate effectively, and some of the data collected may be used in publications or presented at conferences. Please contact me with a time that would be appropriate to either call or meet in person. Additionally, feel free to contact me with any questions or concerns you may have. You may reach me at this email address or via my office number at 02476522264.

Thank you very much for your time and I look forward to hearing from you!

Sincerely,

Courtney Thornberry

Facebook Page Statement

This group, the UK Collaborative Network, is part of a university research study to understand group collaboration. Any data collected from this group is done so completely anonymously. Your contribution to this group indicates your willingness to participate in this study. If there are any issues, comments or questions, please contact the researcher, Courtney Thornberry, either via Facebook, or email c.thornberry@warwick.ac.uk or by phone at 024765-22264. Thank you very much for your time and I hope that is group is useful for your teams!

Sincerely- Courtney Thornberry

THE UNIVERSITY OF WARWICK

Study Title:	**Warwick Racing Formula Student Team: Improving Team Performance and Innovation**
Investigator(s):	**Courtney Thornberry**
Date:	**16 June 2014**

Introduction

You are invited to take part in a research study. Before you decide, you need to understand why the research is being done and what it would involve for you. Please take the time to read the following information carefully. Talk to others about the study if you wish.

(Part 1 tells you the purpose of the study and what will happen to you if you take part. Part 2 gives you more detailed information about the conduct of the study)

Please ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

PART 1

What is the study about?

This study is to understand the perception and impact of the UK Formula Student Collaborative Network, which was established as an online means of communication for UK FS teams. In particular, the researcher is interested to understand the levels of collaboration that are occurring within the group and how these may or may not relate to team performance at the Silverstone competition.

Do I have to take part?

It is entirely up to you to decide. We will describe the study and go through this information sheet, which we will give you to keep. If you choose to participate, we will ask you to sign a consent form to confirm that you have agreed to take part (if part of this study is an online or postal questionnaire/survey, by returning a completed questionnaire/survey, you are giving your consent for the information that you have supplied to be used in this study and formal signed consent will not be collected where postal or online questionnaires/surveys are concerned). You will be free to withdraw at any time, without giving a reason and this will not affect you or your circumstances in any way.

What will happen to me if I take part?

Participation in the study is limited to a 10-15 minute interview and discussion about the Collaborative Network, how you and your team used it and what you thought the benefits and/or disadvantages of it were.

What are the possible disadvantages, side effects, risks, and/or discomforts of taking

part in this study?

There are no physical side effects. You may not feel that you are qualified to answer some questions, but the point of the study is more to understand the perception of the usage of the study, so there are no wrong answers.

What are the possible benefits of taking part in this study?

Information given in this study will be fed back into the continued development of the network for the included teams to further utilise for future competitions.

Expenses and payments

Unfortunately, payments cannot be made for participation in the study. The researcher will do her best to minimise any inconvenience to the participants by contacting and meeting them at convenient times and locations.

What will happen when the study ends?

Each interview will be transcribed by the researcher from the audio recording of the interview. At the end of the study, the information from these transcribed interviews will be anonymised and analysed to contribute to any final dissemination of the overall study of the Collaborative Network. Any data that identifies specific individual will be kept on a password-protected University computer and not shared with the general public. This data will be destroyed after 10 years.

Will my taking part be kept confidential?

Yes. We will follow strict ethical and legal practice and all information about you will be handled in confidence. Further details are included in Part 2.

What if there is a problem?

Any complaint about the way you have been dealt with during the study or any possible harm that you might suffer will be addressed. Detailed information is given in Part 2.

This concludes Part 1.

If the information in Part 1 has interested you and you are considering participation, please read the additional information in Part 2 before making any decision.

PART 2

Who is organising and funding the study?

This study is a part of the researcher's Engineering Doctorate work at The University of Warwick. The researcher is supported through WMG and an industrial sponsor.

What will happen if I don't want to carry on being part of the study?

Participation in this study is entirely voluntary. Refusal to participate will not affect you in any way. If you decide to take part in the study, you will need to sign a consent form, which states that you have given your consent to participate.

If you agree to participate, you may nevertheless withdraw from the study at any time without affecting you in any way.

You have the right to withdraw from the study completely and decline any further contact by study staff after you withdraw.

What if there is a problem?

This study is covered by the University of Warwick's insurance and indemnity cover. If you have an issue, please contact Jo Horsburgh (details below).

Who should I contact if I wish to make a complaint?

Any complaint about the way you have been dealt with during the study or any possible harm you might have suffered will be addressed. Please address your complaint to the person below, who is a Senior University of Warwick official entirely independent of this study:

Jo Horsburgh
Deputy Registrar
Deputy Registrar's Office
University of Warwick
Coventry, UK, CV4 8UW.
T: +00 44 (0) 2476 522 713 E: J.Horsburgh@warwick.ac.uk

Will my taking part be kept confidential?

Your participation is confidential and any public data will not be specifically attributed to you or your Formula Student team. This study is to get feedback about the use and functionality of the Network and to understand how teams are experiencing it. All interview recordings and subsequent transcripts will be kept on secure, password-protected storage devices and computers, to which only the researcher and her supervisor will have access.

What will happen to the results of the study?

The results of this study will be utilised in two ways. The first way will be to reflect back on the Network and attempt to make any necessary changes or improvements. The second way will be to present the Network as a case study of team collaboration to organisations like the IMechE or academic journals.

Who has reviewed the study?

This study has been reviewed and given favourable opinion by the University of Warwick's Biomedical and Scientific Research Ethics Committee (BSREC): **Insert your BSREC number here (given to you when your study is approved) and include the date on your**

approval letter from BSREC.

What if I want more information about the study?

If you have any questions about any aspect of the study or your participation in it not answered by this participant information leaflet, please contact:

Courtney Thornberry
c.thornberry@warwick.ac.uk
Phone: 02476522264

Supervisor:
Alex Attridge
a.attridge@warwick.ac.uk
Phone: 02476575420

Thank you for taking the time to read this participant information leaflet.

THE UNIVERSITY OF WARWICK

BIOMEDICAL AND SCIENTIFIC RESEARCH ETHICS COMMITTEE

CONSENT FORM

Study Number:

Patient Identification Number for this study:

Title of Project: Warwick Racing Formula Student Team: Improving Team Performance and Innovation

Name of Researcher(s): Courtney Thornberry (Engineering Doctorate) & Alex Attridge (academic supervisor)

Please initial all boxes

1. I confirm that I have read and understand the information sheet dated 16 June 2014 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, education, or legal rights being affected. I understand that I will be taking part in an interview and this will be recorded. ☐
3. I agree to take part in the above study. ☐

Name of Participant	Date	Signature
Name of Person taking consent	Date	Signature