Capability Development Strategy in SME Manufacturing Firms: A Case Study

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I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the award of a degree by this or any other University has been acknowledged.

Abstract

The two research articles contained in this thesis, namely *"Capability Development Strategy in SME Manufacturing Firms: A Case Study"* ('Article 1') and *"New Knowledge Management framework for manufacturing SMEs working in strictly regulated sectors"* ('Article 2') are focused on different facets of the case study investigated at an engineering Small and Medium Enterprise (SME) over a period of 6 years. The two articles serve to better understand a successful process of *capability development* over a significant period of time and to understand the specific characteristics of knowledge management practices in SMEs with a specific focus on their life cycle, growth models and resources constraints. Existing literature regarding SMEs, their lifecycle and growth models, resource-based view of the firm, adaptability, and knowledge management (KM) were explored across the two articles to fully understand the context of the capability development process and its associated KM initiative. The study also involved the development of an innovative case study methodology using *process research* approach and aiming to create a comprehensive timeline for the *capability development* of the Company. In terms of findings, Article 1 indicates advanced management capabilities as an essential prerequisite for continued capability development in an SME, particularly over the long term. Article 2 creates a lightweight and highly usable KM framework for manufacturing SMEs dealing with complex regulatory environments for the first time or for those who are trying to streamline their compliance efforts from an ad hoc basis to a more systematic one. It is explicitly geared towards low cost, thus making it ideal for SMEs. Taken together, the two articles represent a comprehensive treatment of a long-term successful process to create new capabilities within the Company while extending existing ones.

Keywords: SME, capability, capability development, adaptability, process research, Knowledge Management, and KM Framework

Covid 19 Impact Statement

The study was impacted by the Covid-19 Pandemic and the ensuing lockdowns due to work from home (WFH) arrangements implemented at the Company under consideration. The activities delayed included:

1. Interviews planned for both Articles 1 & 2
2. Document Analysis, where documents were hard-copy only and could not be accessed online.

This resulted in an initial delay of five months from March 2020 to July 2020 when no empirical work could be carried out and the student was restricted to research activities that could be done under WFH as well as planning changes to the methodology to adapt to the new circumstances. All of the planned activities were eventually carried out in 2021 and early 2022. A major impact of Covid-19 is that Article 1 was expanded to include events of 2021 as well with data collection being expanded to include this year.

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Author’s Declaration

I, Sam John Abraham, do hereby declare that I am the sole author of this thesis.

I gratefully acknowledge the support of Mr. Dennis Hay of SMART Manufacturing Ltd. (Bideford, North Devon, UK) in providing certain data contained in Article 1.

To the best of my knowledge this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted as part of the requirements of any other academic degree or non-degree program, in English or in any other language.

This is a true copy of the thesis, including final revisions.

Date: 30.07.2023

Name: Sam John Abraham

Signature:

1. Introduction

The two research articles contained in this thesis, namely *"Capability Development Strategy in SME Manufacturing Firms: A Case Study"* (hereafter referred to as 'Article 1') and *"New Knowledge Management framework for manufacturing SMEs working in strictly regulated sectors"* (hereafter referred to as 'Article 2') are focused on different facets of the case study investigated at an engineering Small and Medium Enterprise (SME) over a period of 6 years.

SMEs account for a significant portion of the UK and European economies and is a major driver of employment. The UK Government defines an SME as any business with less than 250 employees and an annual turnover under €50 million (Department for International Trade, 2022). SMEs account for 99.2% of all UK businesses, contributing 61% of total employment as well as 51% of revenue as per ONS Business Population Estimates (2022). SME manufacturers contribute 9% of the total manufacturing output of the UK as per the same report while providing 57.9% of the total employment in manufacturing. In EU27 nations, they constitute 99.8% of all businesses while their share in employment is 52.4% (Eurostat, 2022).

The main contributions of this research are to:

1. better understand a successful process of capability development in an engineering SME over a significant period of time. (Article 1)
2. better understand the specific characteristics of Knowledge Management practices in SMEs with a specific focus on their life cycle, growth models and resources constraints. (Articles 1 & 2)
3. develop a novel methodology that combines process research within the case study method, suitable for SME research. (Article 1)

This research generated a template for other engineering SMEs in similar position in their life cycle to execute their growth vision through suitable management of their knowledge and capability development strategy.

In the next section, the overview of the Company is provided, followed by the research questions, aim and objectives of this research. The following section focuses on the Literature Review carried out followed by a section covering the methodology and data collection aspects of the research. This is followed by an overview of the data analysis of the research. The subsequent sections provide

overviews of the contributions of this research followed by the outputs of the case study and concludes this introductory chapter.

1.1 The Company

The SME under consideration is based at Bideford, North Devon and is typically involved in small or medium scale engineering projects. It occasionally works on large projects with order value greater than £100,000. The Company employs between 25 and 30 people and has 4 major product/service offerings, as illustrated in Figure 1: heating, ventilation and air conditioning (HVAC) (production and installation), laser cut sheet metal parts, bespoke engineering equipment and on-site servicing and maintenance of equipment (own or third party). Founded in 1986 with a focus on high end stainless steel fabricated equipment and HVAC work, it registered steady growth till 2005. However, it went through 2 rounds of restructuring between 2006 and 2009 before beginning a slow recovery. The Company's Management formulated a competitive strategy as well a long-term *capability development* initiative to support this recovery, and this is the context in which this study was carried out.

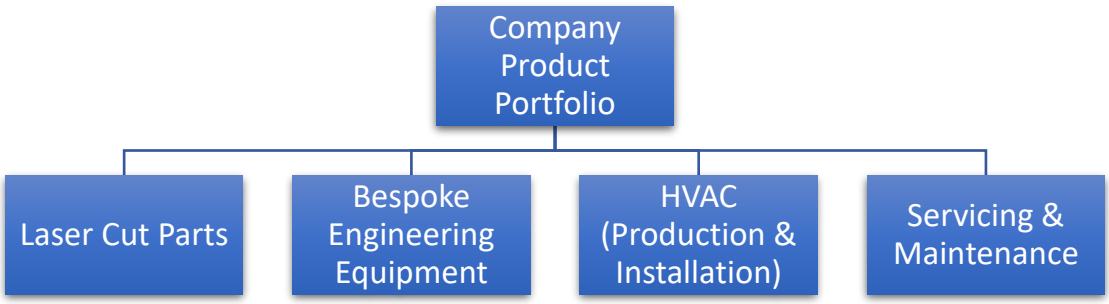

Fig. 1. Company Product Portfolio

The Company's competitive environment is characterised by stiff competition from local and regional competitors, with more than half a dozen competitors of varying sizes present within a 60-mile distance of the firm (Dun & Bradstreet, 2023a, 2023b, 2023c; Plymouth Manufacturers' Group, 2023). Some of these competitors are considerably larger than the Company and consequently have more resources in terms of number of employees and capital investment. While

not all of these firms compete along all of the product lines, the overall competitive environment is highly demanding. It is in this context that the Company's Competitive Strategy is created and executed.

1.1.1 Competitive Strategy

NOTE: This subsection is based on the data collected for the first article: Capability Development Strategy in SME Manufacturing Firms: A Case Study

As with most SMEs, the Company competitive strategy is very much informal and uncodified, with most information residing solely with the owner (Kraus et al., 2008). The focus of the Company's competitive strategy is to build on the existing strengths while developing new core competencies while maintaining minimal levels of long-term debts. Manageable and evolutionary change that boosts the long-term competitiveness of the Company is the ultimate goal of the strategy. Based on this, the main tenets of the Company's competitive strategy are: (1) increase sophistication (and thereby profitability) of goods and services, particularly with reference to bespoke engineering equipment product line; (2) increase volume production of laser cut sheet metal parts while offering competitive prices.

In order to execute this strategy, the Company embarked on a *capability development* initiative, starting in 2015. This involved development of capabilities along several aspects of the firm, some of which predated the actual launch of the initiative. This process has been detailed in the first article: *Capability Development Strategy in SME Manufacturing Firms: A Case Study.* This initiative also involved the acquiring, and extending of the knowledge required for the development of machines that are compliant with the ATEX Directives of the European Union [ATEX Directives deal with the safety requirements in *explosive* and *potentially explosive* environments], as the management had identified this as a potential growth area for bespoke manufacturing equipment. The second article, *"New Knowledge Management framework for manufacturing SMEs working in strictly regulated sectors",* details this process and the creation of a Knowledge Management framework based on this work.

To summarise, the first article gives an overarching view of the overall *capability development* Initiative while the second covers a niche aspect of it.

1.2. Research question, Aim and Objectives

The growth of SMEs, particularly in terms of creation of competitive advantage is often a hidden process with ambiguous outcomes (Storey, 2016). There is conflicting information in literature on this process and this is not surprising considering the long-term and haphazard nature of the process. On review of relevant literature, it was felt that there was a gap in the treatment of this process that adequately considers both practitioners' views and its theoretical background. This was particularly the case for engineering SMEs operating in highly competitive environments and required to perform to industrywide standards.

From extant literature on SMEs and related topics, it was clear that there was insufficient understanding of the processes through which an SME pursues long term growth (Gupta et al., 2013). In the present case, the SME sought to develop sustainable competitive advantage through capability development as per the two-pronged competitive strategy outlined above. From a research perspective, this represented a valuable opportunity to explore this process in detail while considering a practitioner's viewpoint as well.

Hence, the research aim was to understand how a manufacturing SME could generate, develop, and maintain a sustainable competitive advantage in a highly competitive market niche. Fabrizio et al. (2022) comment that an accurate understanding of own capabilities would enable firms to identify those that can be developed further and gain a competitive advantage over rivals. Therefore, an understanding of the competitive strategy employed by the Company under consideration should enable SME owners, managers, and entrepreneurs the ability to build and implement their own versions of the competitive strategy in their businesses at the appropriate juncture.

Building on the above aim, the research objectives were to:

i. define the gap in the existing knowledge regarding competitive advantage in manufacturing SMEs.
ii. identify suitable research methods and tools for the selected case study.
iii. create appropriate research instruments to identify and collect all relevant and available data.

iv. analyse and interpret the collected data and generate an understanding of the SME's efforts to develop and maintain a sustainable competitive advantage.

In the first step, a comprehensive literature review was conducted to understand the current state of understanding of competitive advantage and *capability development* process with reference to SMEs and its limitations. The general characteristics and growth models of SMEs were also explored to better understand the context of the process along with the resource-based view of the firm. Based on this, it was determined that the project required an innovative set of methods that would allow the author to describe and explain the process as observed. Hence, a longitudinal Process Research-based case study methodology was adopted for this purpose. Specific aspects of the *capability development* process would be explored separately which would allow more flexibility in exploring what amounts to a sub-project within a larger programme. On this basis, the exploration of the Knowledge Management (KM) effort and its outgrowth was spun off into a separate article also utilizing the case study method. Literature review of km in SMEs, engineering and manufacturing sectors as well as challenges associated with strict compliance environments were also conducted. Both articles used research instruments such as unstructured and semi-structured interviews and document analysis while the Capability development article used participant observation extensively. Based on the data collected through these methods, the Capability Development process and consequent boost in the competitive advantage of the firm has been described and explained. The KM article presents a KM Tool for other SMEs to use, and this is specifically geared towards those that operate in (or trying to enter) sectors requiring strict compliance.

1.3. Literature Review

A comprehensive literature review on the following topics was carried out as a part of this study, across the two articles, as follows:

1. Small and Medium Enterprises and their characteristics
2. Lifecycle and Growth Models of SMEs
3. Resource-based View of the Firm

4. Adaptability
5. Knowledge Management
6. Knowledge Management in practice

A key objective of the literature review was to explore how SMEs handled strategic change in business models as the new competitive strategy called for a gradual but consistent change to the preexisting business model of the Company. Over the course of the review, it was found that there is limited literature that deals with strategic change in business models with reference to SMEs. The exact modalities of change in business models are not sufficiently explained in extant works.

1.3.1. Small and Medium Enterprises (SME) and their Characteristics

As the firm under consideration was an SME, it was vital that the essential nature of such firms was well understood before embarking on the study. This allowed the research objectives to be defined appropriately and suitable research methods to be chosen to enable the exploration of these objectives.

In Article 1, the characteristics of SMEs were explored primarily from the point of view of qualities that have an impact on the growth (or lack thereof) of the firm in terms of capabilities. From literature, it was clear that SMEs typically demonstrate high levels of flexibility, innovation and personalised service to its customers while operating under very tight resource constraints (Durst and Bruns, 2018; Durst and Runar Edvardsson, 2012; Henschel and Heinze, 2018; Wong and Aspinwall, 2004a; Zieba et al., 2016). They tend to be defined by the personal qualities and experiences of the owner (Terziovski, 2010) and are willing to take carefully calculated risks in pursuit of growth (Fiegenbaum and Karnani, 1991). Formal planning is overlooked frequently (Kraus et al., 2008).

In Article 2, the characteristics of SMEs were explored from the point of view of Knowledge Management and the challenges associated with it. While the relatively flat hierarchy and close working relationships between personnel enable certain aspects of Knowledge Management, the resource constraints faced by the firm poses a challenge. It was also seen that KM guidelines intended for SMEs consider them as similar organisations to large firms and do not consider inherent characteristics that underpin their competitive advantage.

1.3.2. Lifecycle and Growth Models of SMEs

Article 1 explores the lifecycle and growth models of an SME as found in literature. This was done to understand the stage of growth of the Company and the context and appropriateness of its chosen competitive strategy. The limitations of such models are also explored and reviewed. A major factor in the inclusion of this topic in literature review was to find gaps in the understanding of SME growth and to provide a yardstick against which the findings of Article 1 could be assessed.

Authors commonly treat SME growth as a series of stages with transition points in-between with changes in organisational explored management style before the firm enters the next stage. The SME growth model presented by Scott and Bruce (1987) was studied to understand the different stages of SME growth and the common strategies employed by them in each given stage.

The major criticisms of these growth models are that they do not account for firms that fail early or those that decide to stay in a particular growth stage as they have reached their growth aims (Storey, 2016). Nor do they account for firms that have a more advanced management style than the nominal stage of development of that they are in.

1.3.3. Resource-based View of the Firm

Article 1 uses resource-based view (RBV) of the firm as the basis for understanding the competitive advantage (or lack thereof) of the Company. RBV sees the firm as a bundle of resources and the approach stems from the work of Penrose and Barney (1995, 1991). Barney posits that resources enable sustainable competitive advantages in a firm when they are (1) Valuable, (2) Rare, (3) Inimitable, and (4) Non-substitutable.

The choice of RBV as compared to other competing theories was based on two major reasons: Firstly, RBV is highly coherent intellectually and as such represents a good starting point for a longitudinal analysis of a firm's growth. Secondly, as a small firm, the Company has very limited ability to influence its external environment. Hence, in practical terms, internal changes to adapt to environmental changes are the locus of the firm's effort to create and sustain competitive advantage. As such, RBV represents a fine balance between intellectual coherence and practical reality. Its ability to adapt itself and remain

relevant more than 30 years after its inception has also been a major factor in choosing it in this work.

1.3.4. Adaptability

Article 1 considers *adaptability* as an umbrella concept, bringing together similar but distinct concepts such as *dynamic capability*, *organisational resilience* and *flexibility*. While several definitions of *adaptability* were considered, the article used Hodgson's definition of *adaptability* as "the inbuilt capacity of an organization to change its strategies, structures, procedures or other core attributes, in anticipation or response to a change in its environment, including changes in relations with other organizations" (2017, p. 6). *Dynamic capabilities* refer to the ability to change internal and external competences to rapid changes in environment (Teece et al., 1997) while *organisational resilience* emphasises successful recovery from environmental shocks (Vogus and Sutcliffe, 2007).

Article 1 considers the possibility of *adaptability* being the basis of competitive advantage in a firm and thus a distinct resource from an RBV perspective. The importance of *dynamic capabilities* to competitive advantage is well established in literature (Teece et al., 1997; Fabrizio et al., 2022). However, there is insufficient understanding regarding how access to company-based resources affect the development of these, nor guidance for SMEs on how to exploit their limited resources (Fabrizio et al., 2022).

In Article 1, capability is defined as ability of the firm to exhibit the different facets of adaptability to support and execute its competitive strategy and is treated as a logical outgrowth of the umbrella concept of *adaptability*. While competing concepts exists, *capability* is broadly defined as the objective of Article 1 is to develop the process of capability development in rich detail rather than a deep conceptual exploration of the definition of capability.

1.3.5. Knowledge Management

Article 2 explores the theoretical aspects of Knowledge Management (KM) as a discipline, with particular emphasis on the multiplicity of definitions on its nature as well as Nonaka's theory on KM (2007). Nonaka's "*Spiral of Knowledge*" or "*SECI cycle*" concept is explored in detail with the conversion between *tacit* and *explicit* forms of Knowledge. SECI cycle concept considers four primary modes of knowledge conversion: *(1) socialisation; (2) externalisation; (3) combination;*

and *(4) internalisatio*n. It heavily emphasises the need to convert *tacit knowledge* to *explicit knowledge*. Different approaches to this concept are explored along with their appropriateness to various situations. This treatment forms the basis for the operationalisation of *SECI cycle* in an SME environment in the later parts of the Article.

The review of KM concepts also looks at the criticisms on Nonaka's theory and gives justification for the author's use of it, especially as most extant literature explores their use in larger firms.

1.3.6. Knowledge Management in Practice

Article 2 considers KM in practice with three major aspects being covered, as follows:

i. KM in SMEs
ii. KM in Engineering and Manufacturing Industries
iii. Challenges for KM in Strict Compliance Environments

This has been done to understand the differences (if any) between KM in larger firms as compared to SMEs (with particular emphasis on small manufacturers) as well as its relevance to such firms.

From Literature, it was found that KM in practice tends to pose different challenges to SMEs as compared to larger companies. Knowledge Management in SMEs are supported by high levels of informal interaction between personnel as well as an emphasis on apprenticeship-based training. On the other hand, the extreme emphasis most SMEs place on day-to-day operations coupled with resource constraints hamper strategic efforts such as systematic Knowledge Management (Wong and Aspinwall, 2004; Durst and Runar Edvardsson, 2012; Zieba et al., 2016). Due to the high reliance on personal knowledge of its staff, SMEs have high exposure to the risk of Knowledge loss if and when a key member of staff leaves the firm (Desouza and Awazu, 2006; Coyte et al., 2012).

KM in the engineering and manufacturing sector is a wide-ranging and important process, with practitioners widely acknowledging its importance (Tan and Wong, 2015) and empirical evidence supporting this (Gunasekaran and Ngai, 2007; Shu et al., 2013). Despite this, knowledge assets are not given as much importance as physical assets. Key issues include knowledge islands forming within firms,

low efficiency of knowledge systems and knowledge lock effect, where employees are locked into certain positions and roles, and this results in the decline in communication between people in different roles.

KM in strict compliance environments is typically dealt with using automation by creating domain-specific Ontologies, which require significant investment and ongoing support to keep up with changes. While these are powerful tools, they are unsuitable for SMEs due to their initial and ongoing expense.

All these factors pointed to the need for an alternative approach in KM within SMEs.

1.4. Methodology and Data Collection

1.4.1. Process Research on Capability Development

In Article 1, one of the key challenges was to describe the growth of capabilities within the Company over a long period of time (6 years but with earlier events being considered for context) while understanding its underlying catalysing and inhibiting factors. A Process Research-based case study was found to be the most appropriate method considering these requirements. Process Research studies the evolution of the state of affairs and the reasons behind it. That is, it is concerned with "events, activities, and choices ordered over time" (Langley, 1999, p. 692). Process Research is particularly appropriate for complex data collected within an organisation that deals with a sequence of events that also has relevance on competitive strategy. Process Research also includes several strategies that can be used as needed to explain the events at hand. In this study, a combination of *narrative strategy* along with *visual mapping strategy* was followed with a view to create a timeline based on the data collected, covering the entire period under consideration. This would allow specific events to be recorded and described while keeping the overall picture in view.

In Article 2, the emphasis was on operationalising Nonaka's SECI Model within the Company in a way that was complimentary to its strengths while being cost effective. The legally sensitive nature of the subject matter was also taken into consideration. As a result, it was decided that a case study-based abductive-reasoning approach would be used to create a novel KM tool.

1.4.2 Comprehensive Data Collection

For both Articles, comprehensive data collection from various sources were carried out with several methods being used. This included:

1) Interviews

For Article 1, unstructured and semi-structured interviews were carried out with two directors of the Company with a view to understanding the history of the company, its current capabilities, and future plans. Data collected this way formed the primary basis for understanding the evolution in the Company's capabilities and its relationship with its competitive strategy.

For Article 2, the primary subject of interviews was the Chief Designer of the Company, and these were carried out at several stages of the case study. The initial interviews served to understand the Company's priorities in terms of compliance and in understanding its other requirements while later interviews involved detailed knowledge capture of relevant compliance procedures.

2) Participant Observation

In Article 1, the authors were directly involved in the *capability development* initiative with varying degrees of involvement. This allowed them to create a rich dataset on the sequence of events that unfolded with the initiative and its aftereffects.

3) Document Analysis

In Article 1, document analysis was used to complement the data obtained through other methods and in assessing specific facts and events regarding the Company. In Article 2, the use of document analysis was extensive as the subject matter related directly to regulatory compliance. Primary and secondary legislation, quality standards, compliance documents were all analysed over the course of the study.

1.5. Analysis of Data

Analysis of the collected data was done using the theories and concepts explored in the literature review.

For Article 1, resource-based view of the firm was primarily used with growth models of SMEs and the umbrella concept of *adaptability* being used to explain specific aspects. Based on this, Article 1 tracks the entire process of capability development in the chosen SME with a timeline to clearly enumerate the various steps within the process.

For Article 2, all available data was analysed based on Nonaka's Knowledge Management theory and in particular, the *SECI cycle*. As mentioned earlier, the emphasis was to create a useful Knowledge Base which could be used to operationalise the *SECI cycle*, and in particular the *externalisation* and *combination* stages. The Internalisation aspect of the cycle is covered in combination with *organisational learning* concepts.

1.6. Contributions

The major contributions of this thesis are:

1) Development of an innovative case study methodology using Process Research approach and aiming to create a comprehensive timeline for *capability development* of the Company. :

The innovation in methodology consists of the use of Process Research method in an SME environment, particularly in a longitudinal case study to describe the exact mechanism of capability development in an engineering SME. A literature review of over 70 research papers regarding dynamic capabilities in SMEs, carried out by Fabrizio et al. (2022) did not include any instance of the use of such a method in any similar study to track the progress of a particular aspect of an SME over a considerable period. Another systematic literature review into papers dealing with SME resilience also note that only 4% of 118 papers reviewed use a longitudinal research design and even then relies heavily on secondary data (Saad et al., 2021). This clearly indicates the novelty of the method adopted in the present study.

2) Effective synthesis of data collected from various sources primarily regarding the Company's current and projected capabilities, competitive strategy, and compliance strategy as well as supporting information on all these aspects.

In Article 1, the data collected from interviews (of Company directors), document analysis of design and performance data of representative projects and data

derived through participant observation were effectively synthesised using Process Research strategies (narrative and visual mapping) to understand the sequence of events and to determine relationships between them. While this is not novel in a general sense in an SME study, a review of literature suggests that this is novel for research exploring Capability Development in an SME (Breznik and Lahovnik, 2016; Fabrizio et al., 2022).

In Article 2, data has been collected from sources including primary legislation, interviews with subject experts, secondary legislation and synthesised to create a lightweight and user-friendly framework for compliance purposes. This is novel in a field that relies extensively on ontology-based solutions which would be unsuitable for an SME due to cost and complexity in its creation and upkeep.

1.7. Conclusions

Through the two articles, a better understanding of a successful process of *capability development* in an engineering SME over a period of time has been achieved. Specifically, within the context of the Company, Article 1 has highlighted the importance of the development of management capabilities as a prelude to the development of other capabilities. This also points to the limitations of the stage-growth models as put forward by various authors, such as Scott and Bruce (1987) and Churchill and Lewis (1983). For the period under consideration, the Company has consistently demonstrated a much higher degree of Management Capabilities than can be expected of a firm in its notional growth stage as per the models. Apart from the crafting of a realistic competitive strategy for the Company, the impact of this is keenly felt in 4 key aspects: (1) talent strategy; (2) capital expenditure; (3) relationship marketing and as an (4) enabler for the tight integration between departments and occasionally with external entities.

Article 1 examines the reactive nature of the firm and how it aids and hinders the long-term *capability development* process of the firm. While it impedes the process in the short term, the outgrowths from fixes applied to short-term problems moves the process forward. This is closely related to the umbrella concept of Adaptability and its related concepts (particularly “Dynamic Capability”) and has a high degree of influence on the *capability development* of the Company. While the present study has highlighted its importance to an SME, the exact nature of the influence bears further examination in future works.

Article 1 also examines the link between the slow pace of the *capability development* process and the reluctance of the Company to take on more financial risk in its pursuit for growth and looks at the possible effects of path dependency in this regard. The management is largely focused on leveraging existing resources to create new resources and effect *capability development* while also being open to leveraging external resources to overcome shortage of capital resources and expertise.

Article 1 clearly points toward advanced management capabilities as an essential prerequisite for continued *capability development* in an SME, particularly over the long term. This finding requires substantiation through further research, and this could be a fruitful avenue for further study.

Article 2 creates a lightweight and highly usable KM Framework for manufacturing SMEs dealing with complex regulatory environments for the first time or for those who are trying to streamline their compliance efforts from an ad hoc basis to a more systematic one. It is explicitly geared towards low cost, thus making it ideal for SMEs. It is the author's view that this KM framework, applied correctly, substantially reduces the barriers to entry for a manufacturing SME into market sectors that require high levels of compliance to regulation.

Taken together, the two articles represent a comprehensive treatment of a long-term successful process to create new capabilities within the Company while extending existing ones to effectively execute the chosen competitive strategy. It describes and analyses the process in detail while also pointing towards the requirements that the management and the wider firm must have to make the process a success over the medium and long terms. It also examines the potential retarding factors (self-imposed or otherwise) that can have an impact on the execution of strategies and the measures to overcome these. As such, it represents a template for other firms in a similar position in their growth to adapt and emulate to execute their growth strategies. For researchers dealing with SME growth, it presents a set of methods to describe various facets of the SME while being able to 'plug-in' theories for the effective analysis of each facet.

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Article 1: Capability Development Strategy in SME Manufacturing Firms: A Case Study

Abstract

This paper seeks to understand the process of *capability development* in an SME Manufacturing firm and strategies that underpin it. The research was carried out at an engineering Small and Medium Enterprise (SME) and literature regarding SMEs, their lifecycle, the resource-based view of the firm and the umbrella concept of "*Adaptability*" has been explored over the course of the study. It sought to understand the modalities of capability development through an innovative longitudinal Process Research-based case study methodology based on the Narrative and Visual Mapping Strategies based on interviews, document analysis and participant observation. This methodology was used to create a comprehensive timeline that explores the development of firm capabilities along five distinct but inter-related aspects, which are: (1) equipment, (2) technical, (3) organisational, (4) product/market innovation, (5) management. The findings indicate a high level of integration between high degree of co-operation and integration between the Design Department and the Production Department and Senior Management actively seek to identify specialist skill shortages and capability gaps and seek to correct them. The study identifies management capabilities that are considerably more advanced than the notional growth stage of the firm as an essential prerequisite for its continued growth along with high levels of "*Adaptability*" as a catalysing factor. Other retarding and catalysing factors are also examined including collaborative relationship with external entities including academia and its impact on the *capability development* process.

Keywords: SME, resource-based view, adaptability, process research, capability, capability development process.

1. Introduction

This paper is focused on understanding the process of capability development in an SME Manufacturing firm and strategies that underpin it, whether pursued proactively or as a consequence or side-effect of other strategies. As Capability Development in SMEs is an underexplored topic, it sought to understand the modalities of capability development in an engineering SME through a longitudinal study of the firm's operations, in light of relevant theories and concepts from academia.

The research was carried out at an engineering SME based at Bideford, North Devon. The company is typically involved in small or medium scale engineering projects and occasionally works on large projects (>£100,000 order value). However, since 2019, the company has been involved in increasingly larger projects with bulk orders being received for several complex items. However, as similarly faced by many SMEs, resource allocation in terms of time, human resources and budget are severely limited for each individual project and the focus of the company is on day-to-day operations. *capability development* in the company happens in this context and it is this situation that that the research intends to explore in-depth. At the time of writing, the company continued to grow at a robust pace and the presence of the primary researcher on the premises since 2019 and continued access at all management levels presented a unique opportunity to conduct the present research effort.

The rest of the paper is organised as follows: Section 2 gives a brief literature review of the relevant topics while section 3 describes the methods used in this research and their rationale. Section 4 gives the conclusion and growth prospects of this research project.

2. Literature Review

This section reviews the major concepts that come into play in *capability development* of firms. This includes the characteristics of SMEs, SME life cycle, the resource-based view of the firm and *adaptability*.

2.1 Small and Medium Enterprises

Small and Medium Enterprises (SMEs) are a specific class of businesses by virtue of their sizes. The UK Government (Department for Business, Innovation & Skills, 2012) defines an SME as any company satisfying two or more of the following

characteristics: a turnover of less than £25 million, less than 250 employees and gross assets of less than £12.5 million. The European Commission (2016) defines a small business as one with less than 50 employees and less than €10 million in turnover or assets while a medium business is defined as having less than 250 employees and €50 million turnover or €43 million in assets.

SMEs tend to have certain common characteristics which have serious implications on innovation and capability development. These can be both quantitative and qualitative in nature. While they are often highly innovative, flexible, and capable of delivering highly personalised service, SMEs usually operate under tight resource constraints, primarily in terms of capital and human resources (Wong and Aspinwall, 2004; Durst and Runar Edvardsson, 2012; Zieba et al., 2016; Durst and Bruns, 2018; Henschel and Heinze, 2018). This has serious implications as any errors are likely to be of far-reaching consequence. Many SMEs are owner-run and tend to be defined by his/her qualities and experiences (Terziovski, 2010). They are also characterised by a flat hierarchy with relatively informal interaction and procedures between management and staff (Zieba et al., 2016; Durst and Bruns, 2018). Formal planning is often absent and is considered to be a feature of larger enterprises (Kraus et al., 2008). Terziovski (2010) considered 5 independent drivers of SME performance and found that innovations strategy and formal structures were the key drivers. However, there are contradictory opinions among scholars regarding the importance of Formal Structures in SMEs with regard to innovation. SMEs are also intent on occupying a niche market in terms of customer, technology or product and are often willing to take considerable but carefully calculated risks (Fiegenbaum and Karnani, 1991).

2.2 SME Lifecycle

Growth of SMEs is generally treated in theory as a series of stages, with the transition points between them often defined as a crisis or as a set of accumulated problems that must be solved for the business to grow further (Steinmetz, 1969; Barnes and Hershon, 1976; Churchill and Lewis, 1983; Scott and Bruce, 1987).

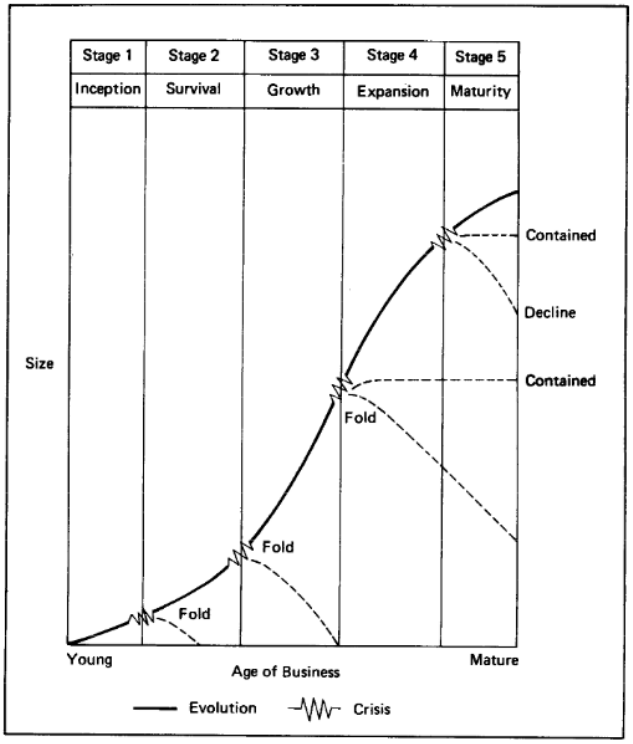

Fig. 1. SME Growth Model presented by Scott and Bruce (1987, p. 3).

Scott and Bruce presented a general model of SME growth, as shown in Figure 1, which divides SME growth into 5 stages: (1) *Inception*, (2) *Survival*, (3) *Growth*, (4) *Expansion* and (5) *Maturity*. In the *Inception* stage, the focus is very much on the firm establishing itself in the market (with often a very limited product range) and making sure that sufficient funds are available for continued operation. While there might be some limited delegation, the founder(s) are in direct control of all major operations. As the firm seeks to move into the *Survival* stage, the need for further profits, increased administrative workload and demands on the founder-manager's time are possible sources of crises. In the *Survival* stage, there is more competition to the nascent firm while continued provision of working capital remains a critical challenge. Overtrading and changes in management style due to more delegation and coordination can be the source of crises and the firm may also struggle to control and organise the increased flow of information due to the increasing scale of operations. As the company enters the *Growth* stage, it is profitable, but nearly all profits are being used to finance the working capital demands. The management style tends once again towards further delegation and decentralisation (to more professional managers) as the scale and size of the operation becomes too large for the founder-manager to

supervise directly. As competition stiffens from larger competitors, product differentiation or expansion into new markets become necessary to maintain competitiveness. The product differentiation strategy trades off market share for margins while expansion into new markets allows competition on a more even basis as it enables economies of scale that larger competitors may possess. If a product differentiation strategy is employed, it could mean staying in the *Growth* stage for an extended period. Overtrading remains a key source of problems at this stage while the founder-manager maybe unwilling to make the necessary changes to his/her management style. If the firm successfully manages these crises, then it reaches the *Expansion* stage. This stage is characterised by much more formal control of operations and information coupled with even more decentralisation of power to professional managers. While access to long-term capital may improve, if growth is managed poorly, then the firm may regress to the previous stage. The firm may need to pay more attention to customer needs at this stage and allow for further changes to management style to enable this. Continued growth in the *Expansion* stage results in the firm entering *Maturity* stage, though as an SME, growth continues at this stage. At this stage, productivity and expense control are key priorities and the Marketing function also assumes an important role. While profits are generally healthy at this stage, long term finance may still be necessary before the firm transitions into a large company from an SME. It is important to note that poor management of a transitional crises in any of these stages can result in the winding up of the SME.

These models that delineate growth into stages are not without critics, with Storey (2016) commenting that the models are often inaccurate predictor of real-world events as many founders (and consequently their businesses) are unwilling to grow further once they have reached a desired level of growth. He categorises these firms, which do not add to job creation consistently as the “trundlers” while the ones that grow significantly as the “flyers” (2016, p. 119). This potential for “extended stay” in a particular stage of growth is acknowledged by many authors including Scott and Bruce (1987) and Churchill and Lewis (1983). Another point of criticism is the possibility that the management style of an SME might be more advanced than the nominal stage of growth it might be in (Storey, 2016). Storey rejects the stage models’ validity and instead argues that a set of factors related to the enterprise, its’s founder and the strategy employed are more reliable indicators of growth or lack thereof.

2.3 Resource-based View

Resource-based View (RBV) traces its origins from the work of Penrose in the 1950s and was given in its current (and widely accepted) form by Barney in 1991. RBV sees a firm as a collection of resources, that may or may not contribute to competitive advantage to the firm (Barney, 1991). These resources are classified into three main types: (1) Physical capital resources; (2) Human Capital Resources and (3) Organisational Capital resources and includes all “firm assets, capabilities, organizational processes, firm attributes, information, knowledge etc. controlled by a firm” (1991, p. 101). Barney posits that resources enable sustainable competitive advantages in a firm when they are (1) Valuable, (2) Rare, (3) Inimitable, and (4) Non-substitutable.

The Valuable aspect refers to the ability of the firm to craft a competitive strategy around the resource and that which improves its efficiency and effectiveness vis-à-vis its current or potential competitors. A Valuable resource that is Rare, i.e., not available to a current or potential competitors, allows the firm to build its competitive advantage around it while denying that option to other firms. However, a Valuable resource that is common to several firms allow these firms to maintain competitive parity with each other. In order to build a sustainable competitive advantage, the other 2 attributes given by Barney are important as well. If current or potential competitors can obtain these (Valuable and Rare) resources, then the competitive advantage is lost and Barney comments that the “unique historical conditions” of the firm play a key role in the imitability (or lack thereof) of a resource (1991, p. 107). Similarly, the existence of a similar resource with competitors will also negate any competitive advantage that may be derived from Valuable and Rare resources.

Later extensions of the theory, by Barney himself and others included another key facet to the theory: that of effective organisation of resources. Sirmon, Hitt and Ireland (2007) enumerate three separate but related activities in this organisation process: structuring, bundling and leveraging. Structuring involves “acquiring, accumulating, and divesting” of resources while bundling involves integrating the available resources to form capabilities (2007, p. 273). Leveraging involves “mobilizing, coordinating, and deploying” these capabilities to exploit specific market opportunities.

A related aspect is the capacity of the firm to respond to rapidly changing competitive and economic environment and this is known as its Dynamic Capability or Adaptability. The literature on this has been reviewed in Section 2.4.

2.4 Adaptability

Adaptability of business is a widely recognised concept in business studies with a variety of definitions and related concepts. *Adaptability* (in the context of an organisation) is defined by Hodgson as "the inbuilt capacity of an organization to change its strategies, structures, procedures or other core attributes, in anticipation or response to a change in its environment, including changes in relations with other organizations" (2017, p. 6). Related concepts include "*organisational resilience*", "*dynamic capability*" and "*flexibility*" (Hodgson et al., 2017). Teece et al. defines *dynamic capability* as "'the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (1997, p. 516) while *organisational resilience* concept emphasises the ability of an organisation to handle shocks and recover successfully (Vogus and Sutcliffe, 2007). *Flexibility* has been defined as the "responsiveness of the organisation" coupled with "sufficient managerial capabilities" to deal with emerging challenges (Volberda, 1996, p. 361) and to make best use of serendipitous opportunities, also called luck (Ma, 2002). *Flexibility* can also involve having the organisational structure necessary to support grassroots initiatives that could provide a benefit to the company. Similar points are also made by Reeves and Deimler (2011), with dispersion of decision rights being called for to boost adaptability.

While all these concepts are overlapping to some extent, they are also complementary: For e.g., some authors emphasise the importance of adaptability in surviving challenges, others emphasise its importance in benefitting from accidental events or opportunities through entrepreneurship and luck (Ma, 2002; Ong et al., 2012). As they are all relevant to the present discussion, *Adaptability* will be used as an umbrella term to refer to all the above concepts.

Reeves and Deimler (2011) argue that *Adaptability* can be the basis of competitive advantage with the ability to detect and act on signals of change in the business environment and the ability to experiment with new products, services and strategies quicker than competitors being two key aspects (also echoed by Hodgson (2017)). This also indicates a degree of tolerance of failures in the results of these experiments.

Another aspect of *adaptability* is the ability to manage multiple stakeholders, both internal and external. Awareness of the environment and stakeholder management involves working closely with customers and suppliers through frequent interaction and trust-building.

Vogus and Sutcliffe (2007), dealing primarily with *organisational resilience*, contends that while monitoring of the business environment is important, monitoring current system performance versus its performance limits and quickly managing any deviations from the norm is even more so. This also involves creating the capability, attitudes and a reserve of resources to deal with the unexpected and these factors can be construed as enablers of organisational resilience. Effective use of existing resources is also a key determinant of the degree of resilience of an organisation. These findings on attitudes as resources are echoed by Hodgson et al. (2017) as well.

Hodgson et al. (2017), from the survey of 909 firms, find that firms with greater adaptability, particularly in Production and Administration (including HR) aspects exhibit a small improvement in its chances of survival. This study was done during the peak of the 2008-09 Financial Crises and the sample of firms contained a mix of all sectors with 12.8% being Manufacturing firms.

However, *adaptability* comes with a cost (Vogus and Sutcliffe, 2007; Reeves and Deimler, 2011; Hodgson et al., 2017) particularly in terms of investment and this may be unacceptable to many of the stakeholders of the business. There is also an element of uncertainty involved in formulating the degree and nature of the adaptability of the organisation. Hence there maybe instances where *adaptability* must be balanced by caution and continuity (cf. Stadler, 2007).

In the present context, *capability* can be considered to be a logical outgrowth of *adaptability* (as defined above), as a firm with high levels of *adaptability* should be able to change and develop its resources and its configuration to support its chosen competitive strategy. The concept of *capability* has been defined in many different ways and there are considerable differences between these definitions as well as sector-specific definitions (Tell, 2014). However, for the present application *capability* can be best defined as the ability of the firm to exhibit the different facets of *adaptability* to support and execute its competitive strategy effectively.

3. Methodology

In this section, the methods used in this study are discussed in detail along with the rationale for their use. The methods adopted in this study are primarily a function of its nature and context.

As mentioned previously, this study seeks to describe and (to a slightly lesser degree) explain the process of Capability Development within a small and medium engineering firm over a considerable period, with the primary focus between 2015 and 2021 while events before that are investigated to set the context for the later ones. The authors' intentions were to accurately capture the pathways in which Capability Development takes place in rich detail while identifying catalysing and inhibiting factors. This would enable comparisons to existing theories on SME growth as well as interpretation of the facts observed based on relevant theories including resource-based view (RBV) and Organisational Learning (OL).

Hence, a longitudinal Process Research-based case study methodology was adopted in this project. Case study would be appropriate here as the emphasis is very much on investigating a contemporary "complex social phenomenon" (Yin, 2013, p. 38) within its context (in this instance, the chosen SME) while seeking to answer questions such as "how" and "why" with the researchers having limited control over the events being described. Yin (2013) also recommends a case study-based approach when the boundaries between the phenomenon under investigation and its context are unclear. All these requirements hold true in the present case. Considering the subject matter and the context of the study, no other feasible method was available to describe, explain on SME Capability Development within the constraints of this project.

As a research method, case study has been subjected to a few criticisms from scholars with the possibility of subjectivity in the collection and interpretation of data, lack of rigour in the research design and lack of generalisability being the most prominent ones (Patton and Appelbaum, 2003; Yin, 2013). To avoid or mitigate such issues, Yin (2013) suggests a systematic method of data collection and analysis, hence the present study follows this recommendation. The *case study roadmap* proposed by Patton and Appelbaum (2013) has been adopted in this research with suitable adaptations. This roadmap consists of 5 steps: "(1) determine the object of study; (2) select the case; (3) build the initial theory through a literature review; (4) collecting and

organizing the data gathering; and (5) analysing the data and reaching conclusions" (Patton and Appelbaum, 2003, p. 66,67). In this study, the object has consistently been the thorough exploration of the capability development process in an SME. The selection of case was guided by the fact that the two authors had been with the Company for many years, and this would enable access to both the personnel and documentation that would be required for a thorough longitudinal investigation. The third step was carried out through the literature review given above, considering the relevant theories and models on SMEs and their life cycle, the resource-based view of the firm and *adaptability*. The fourth and fifth steps were carried out through a combination of interviews, document analysis and participant observation within an overall Process Research approach as described below.

Within the overarching case study, Process Research method was chosen as this would enable the researchers to fully describe the events observed over the course of the period chosen along with all the complex strategic decision-making processes behind it within the organisational setting of the Company (Langley, 1999). It was envisioned that Process Research method would enable the researchers to make sense of the events from a high-level perspective. Two specific Process Research strategies were used in this study: (1) Narrative strategy and (2) Visual Mapping strategy. In the Narrative Strategy, a detailed narrative is formed from the data collected through various means and this strategy is more appropriate when dealing with a small number of cases or even one (Langley, 1999). The Visual Mapping strategy involves creating graphical representations of a large quantity of data and can be used to show parallel processes happening within the same time period. This can then be used for identifying relationships between processes and is often a prelude to further conceptual development (ibid.).

In this study, as the project deals with just one case (but with multiple sub-processes within it) over a long period of time, it was considered appropriate to combine the two strategies to be as coherent as possible while setting the stage for conceptual development.

To build the Process data, three methods were primarily used: (1) unstructured and semi-structured interviews, (2) document analysis, (3) participant observation. As all high-level decisions regarding capability development are taken either by the

Managing Director or the Production Director, use of interviews was inevitable in this study.

Unstructured interviews were used to identify background information regarding the Company, including (but not limited to) the broad priorities of the two directors (regarding the Company) prior attempts at *capability development* and setbacks. These were free-flowing conversations with only a broad theme being defined by the interviewer. Based on these initial interviews, interview questionnaires were prepared for further 30-minute-long semi-structured interviews with each of the two directors. The questions for these were designed to bring out detailed information on specific topics identified from the previous unstructured interviews. The responses were recorded and summarised and then used to develop a detailed picture of the (1) history of the company (with post 2015 information being prioritised); (2) assessment of current capabilities and weaknesses; and (3) future plans. As the interviews were semi-structured, specific themes that were of particular interest to the study (for example personnel strategy and near-to-medium term equipment procurement plans) were developed further. Document Analysis was used to augment and corroborate the data gained from interviews and to fill in gaps where necessary (Yin, 2013). This use of document analysis is supported by Bowen (2009) as well, especially when used in conjunction with other methods such as interviews and questionnaires. Document analysis was used primarily in assessing the Knowledge Management and Organisational Learning aspects of the firm and in developing the three sub-cases given in Sections 4.2, 4.3 and 4.4. Finally, participant observation was used as well as the Primary and Secondary authors have been with the Company as design engineers since 2019 and 2015 respectively and have been participants in the execution of many of the Capability development projects described in this paper. It was considered that a mix of data collection methods would allow for more detail to be collected about each individual event while enabling verification of data collected through any one method with the others.

Here, the two Process Research strategies (i.e. narrative and visual mapping) have been used complementarily: Data collected through interviews and document analysis were primarily used to develop the narrative of capability development while data from participant observation were used to make a list of capability developments that occurred in the period under consideration, which were then classified and given as a

timeline (Fig. 3 below). However, this distinction is not perfect as data from interviews have contributed to the timeline while data gathered through document analysis have contributed to the narrative. Both the narrative developed as well as the timeline derived through the visual mapping strategy has been used to arrive at the findings of this study. As mentioned above, the rationale for employing the two strategies was to present as complete and coherent picture of the capability development process as possible.

4. Case Study

4.1 Company History till 2015

The Company in which the study was undertaken is a bespoke engineering SME which has 4 major product/service offerings: heating, ventilation and air conditioning (HVAC) (production and installation), laser cut sheet metal parts, bespoke engineering equipment and on-site servicing and maintenance of equipment (own or third party).

The Company was established in 1986 and from the very outset, focussed on high-end bespoke stainless-steel work along with HVAC production and installation. This was in line with the founder's vision and professional background and the Company registered steady growth until 2005. By this time, it had added a laser cutting and machining capability, allowing for end-to-end fabrication capability for most bespoke industrial equipment. These design and manufacturing capabilities were leveraged to gain a presence as a reliable supplier for such equipment to food and pharmaceutical industries and this focus has remained unchanged since then. Despite this, diversification of products and of customer-base has continued with on-site servicing and maintenance of equipment becoming a distinct line of business post 2005 along with increased volume production of standardised Laser cut products.

While the business continued to remain profitable, between 2006 and 2009, the Company went through two rounds of painful restructuring brought on by reduced profitability, loss of key clients and a much more restrictive lending environment. This in turn led to a pause in capability development (caused in part due to exodus of certain design personnel) and consequently a freeze on further development of the product portfolio. However, from 2010, growth resumed (albeit slowly) on nearly all relevant

metrics and new clients were added along with a few returning ones in the years between 2010 and 2015.

Beginning in 2015, the Company started focussing on increasingly complex machines with much more intensive engineering and compliance work involved in it. In some cases, the working concept itself was novel or had never been implemented in the market segment in question and in others, it was a highly improved version of a pre-existing concept. Specifically, the Company initiated development on (1) Bespoke machinery intended for use in hazardous environments (i.e., ATEX-rated machines); (2) Industrial drying solutions intended for food and pharmaceutical industries with a focus on efficiency both in terms of energy and space. Neither of these niche products were available off-the-shelf and until then developed and produced only by much larger firms. As such, these initiatives represented a leap in the engineering and manufacturing capability of the Company.

Three of these orders (all drying solutions) have been described briefly below and serve to represent the changes in capabilities of the Company. These cases have been chosen for their similarities in working principle but with increasing levels of technical complexity. Hence, these (subordinate) cases give a representative example of capability growth within the firm as it tracks the growth in a specific vertical of the Company and allows for a like-for-like comparison.

4.2 Industrial Fish Poacher (Case 1)

The Fish Poacher project was started in 2015 for a food processing firm catering to UK supermarkets. The aim was to design and deliver a product that could poach up to 0.5 tonnes of fish within 2 hours within an ambitious footprint. It used superheated steam to effect drying of fish fillets placed in it. While simple in concept, it took detailed modelling and simulation of the flow (in a basic CAD/CAE environment) within it and then creating precision components to accomplish that flow. The complexity of the PLC-based controls to control the process was also relatively high (for the firm) and took considerable effort to develop and integrate.

Figure 2 gives an isometric view of the Industrial Fish Poacher with its lid open and with the stand for the products visible.

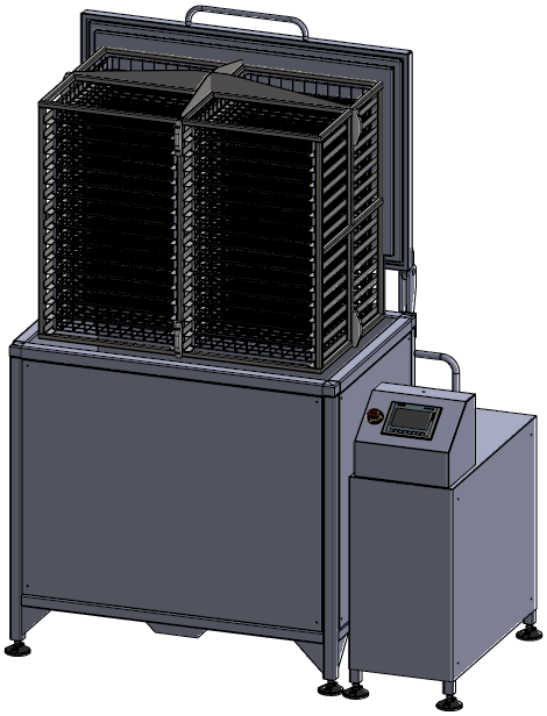

Fig. 2. Industrial Fish Poacher (Copyright Reserved; Used with permission)

The product was highly successful and while the machine itself was a one-off requirement, it led to further large orders from the same customer.

4.3 Oven Modification Project (Case 2)

The Oven Modification project was initiated in 2019, not as a full-scale product development project but as a Research effort. The objective was to support a key Customer who was looking to develop more information for future improvement projects. However, as the project demonstrated a high level of success, it morphed into a product development effort and the resulting product was eventually integrated into the Customer's production system.

The project involved modifying a commercially available baking oven to suit a drying process for a pharmaceutical product. The concept to be used was similar to the Fish Poacher (i.e., directing heated air on to the product to be dried) though the working temperatures were considerably lower (between 40 and 65°C) and could not be changed due to the nature of the process. These twin constraints were critical in determining the extent to which modifications could be carried out and necessitated a "trial and error" approach. This would involve modelling and simulating possible modifications on CAD software, selecting the most promising ones and implementing them, either individually or in a suitable combination. Then a series of trials would be

conducted with samples to be dried and the performance gain (or lack thereof) would be compared against the oven's initial performance. This was repeated several times (over a course of 2 months) before an acceptable set of modifications were arrived at. Once installed in its final form, the modifications were found to be extremely successful and reduced drying times by 60% (when compared to the previous process), resulting in a decision by the Customer to directly integrate the solution into their drying process.

Such a protracted and complex development process with relatively open-ended objectives was unprecedented in the history of the firm and the level of dependence on CAD/CAM software to make design decisions was also novel. This order directly led to the follow-on project described below and for other ancillary equipment to be used along with the modified oven.

4.4 Small Oven Project (Case 3)

The Small Oven Project was initiated in early 2020 and was primarily an attempt to replicate the drying performance of the modified oven while using only 50% of its power requirement and 40% its footprint. The working concept was similar to but more advanced than the modified oven. The design called for heated air to be directed through a single inlet into a tubular drying chamber and creating a vortex around the parts to be dried. The part itself would be revolving in the drying chamber on purpose-built jigs for easy loading and unloading.

The design was finalised after in-house simulation and prototyping efforts lasting about 3 months. Through this development effort, it became increasingly clear that the existing software tools were insufficient to simulate the behaviour of certain aspects of the product. Help was sought from other sources, including from a master's student at a university, though some of these efforts came too late to make a difference in this project as key design specifications had been frozen by then. The drying solution itself performed acceptably well, though it was recognised by the Directors that significant scope for growth existed in the basic design.

The novelty to the firm in this project was two-fold: (1) Complex airflow patterns needed to be modelled with greater accuracy than in any previous project as certain aspects of the project simply could not be subject to the "trial and error" pattern heretofore used for reasons of cost and time; (2) As other complex projects were also running

concurrently due to the continued growth of the firm, the time pressure on the designers was unprecedented.

4.5 Resulting Growth

The focus on building the capability to design, manufacture and deliver complex bespoke products such as the ones above has translated itself into robust growth in revenue and profits on a year-to-year basis, with revenue growing from £1.8 million in 2018 to £4 million in 2021 and continuing to rise at the time of writing.

5. Findings

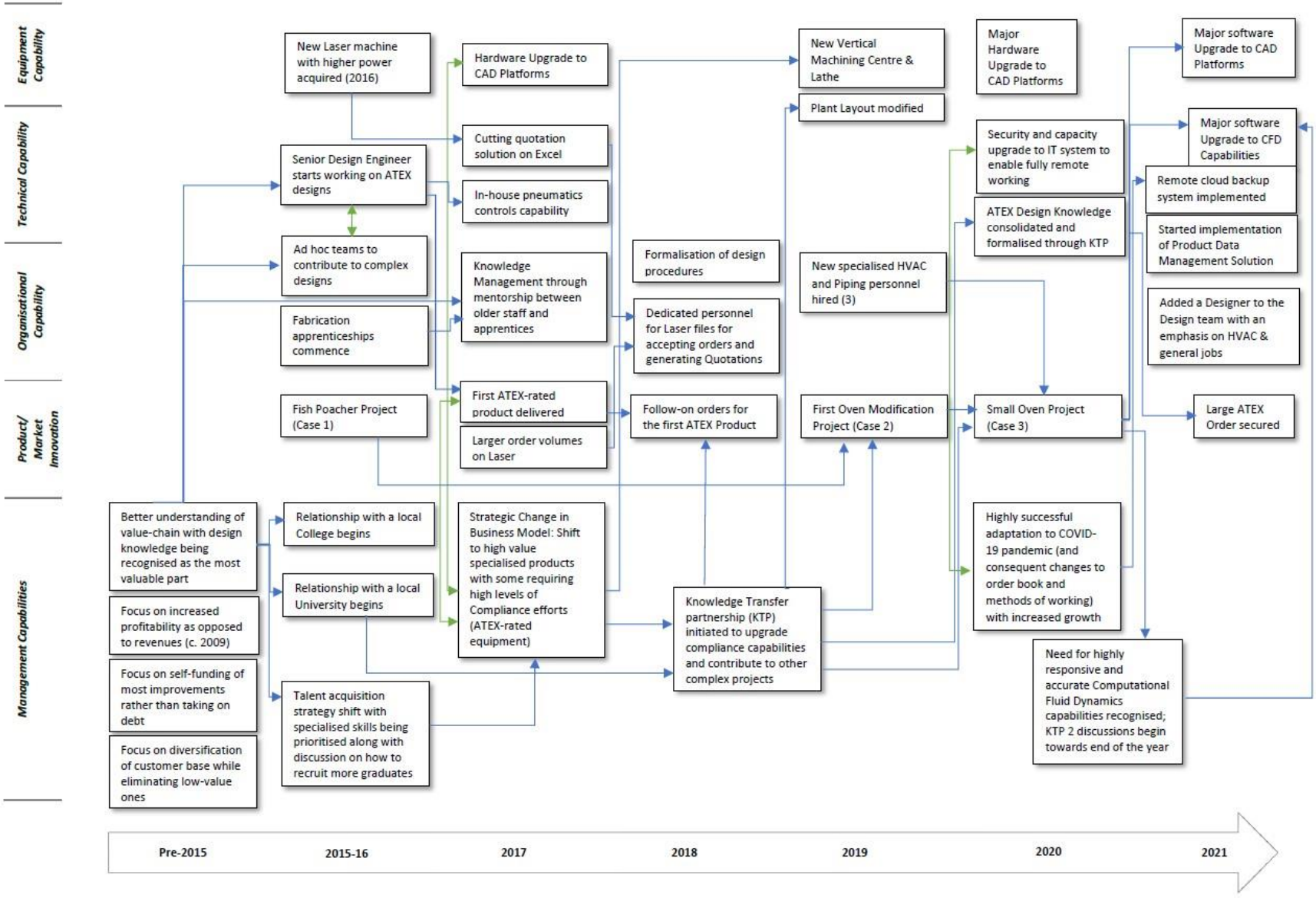

Fig. 3. Timeline of Capability Development

This section gives the findings of this study. It combines evidence from the experiences of the two authors while working with the Company (one of whom has been with the firm since 2015 and the other since 2019), the 3 cases and other similar projects the authors have been involved in and from the interviews with the two Directors of the Firm.

The findings have been presented as a timeline in Figure 3 above, to give a better overall idea of the timescales involved and the most important findings have been summarised following that.

As seen above, the timeline distinguishes between 5 types of capability development: (1) equipment (new or upgraded ones), (2) technical (knowhow to implement a particular feature or to fully leverage existing capability), (3) organisational (improvements that introduce new or improved capability within the organisation, particularly with reference to training and procedures), (4) product/market innovation, (5) management (changed or improved priorities that allows the organisation to grow and is a demonstration of improved management capability). This classification was developed to account for the different aspects of capability development that were discovered over the course of the data collection effort. While other classifications were available (Breznik and Lahovnik, 2016), these were considered inadequate to describe the present data.

A key (and somewhat surprising) development was the change in management priorities that preceded the high levels of capability development post-2015. This was largely found through the interviews with the two Directors and seemed to have been heavily influenced by the setbacks of the previous decade. The two most important ones among these were the decision to stop focussing on revenues as a benchmark for measuring Company growth and a better understanding of the value chain, including recognition that the design knowledge held by talented personnel as its most valuable part. A major portion of the capability additions or improvements mentioned elsewhere in the timeline emanate from these two decisions by the two Directors. Aversion to taking on debt to fund improvements was also a major outgrowth of the experience of previous years and one that seems to have had a major influence on the pace of capability development within the Company. A decision was also taken (sometime in 2010) to stop focussing on a small number of high value customers and

to diversify the customer base while dropping customers with low profitability (based on previous orders).

Following these decisions, in 2015-16, the talent strategy at the Company went through an important shift. This was two-fold and involved both design engineers and shopfloor workers. As the decision to move into the design and manufacture of complex machines had been taken, the Directors focussed on recruiting design personnel with specialised skills while initiating a conversation with a local University on how to recruit more graduates. The focus shifted very much into recruiting engineers with well-rounded technical and project management skills as opposed to draughtspersons. Relationships with external controls engineers were also established at this stage with a medium-term outlook. On the shopfloor, it was recognised that a majority of the workforce was over 50 (and a significant minority over 60) with several on the cusp of retirement. This posed a severe risk of skill and knowledge attrition within the firm on a medium-term basis. Hence the previous strategy of hiring only experienced personnel was complemented by initiating apprenticeships in cooperation with a local College. The Directors followed and encouraged the professional growth of the new apprentices very closely and this talent strategy remains in place at the time of writing.

On the technical capability front, 2015-16 saw groundwork being laid for the design of products that work in hazardous environments (ATEX-rated products) along with the first drying solution order to be processed (i.e., Industrial Fish Poacher). A significant upgrade to equipment was made in the form of a new higher-powered Laser cutting machine and this enabled the Company to increase order volumes on laser-cut parts by two to three times (depending on demand) in the following years.

2017 and 2018 were primarily years of consolidation, with several procedural and technical improvements being carried out to better support the new product strategy and higher order volumes on the Laser machine. Among this was the formalisation of design procedures (with the primary aim of enabling teamwork among design engineers as opposed to each designer working independently) and the development of an in-house pneumatics controls capability. These allowed the Company to deliver its first ATEX-rated machine in 2017 and gather more orders for such machines the following year.

In 2019, a Knowledge Transfer Partnership was started in conjunction with the above-mentioned University and a graduate was recruited with a view to consolidate and formalise the ATEX Knowledge and optimise the plant layout in a project spanning 2 years. The project also contributed to the success of the Oven Modification and Small Oven Projects described above. New Vertical Machining Centre, Lathe and Bar feeder were also acquired in 2019 to boost the volume production capacity of the machine shop and produce more complex designs.

These changes (particularly the focus on high-end bespoke machines) allowed the Company to adapt successfully to the COVID-19 pandemic and continue to grow even during the most challenging times of the lockdown without any major impact on its order book with more clients being added throughout 2020. A major order for regular supply of automotive turntables was received in 2020 which leveraged the new machining capabilities of the Company. This was also the first order of this kind to have *vendor managed inventory* arrangements, and this is ongoing at the time of writing. The Company also took advantage of the slight slowdown in new orders in for a brief period in 2020 to upgrade its IT infrastructure and setting the stage for a deep upgrade of CAD and CAE software upgrades in 2021. The rationale behind these upgrades is explained below.

From the interviews with the two Directors, it was clear that they each had a clear vision for the future direction of the firm but at different levels of planning, with the MD focussed much more on the strategic aspects and the Production Director focussed more on the capabilities of the Production Department along with adding more sales channels. This was entirely in-line with their differing roles and responsibilities.

From the cases described above and from the interviews, three major findings can be distilled which are outlined below. These findings do not exist in isolation from each other but combine to form a unique set of competitive advantages to the company and can be said to have been instrumental in its growth post 2015.

Firstly, there is a high degree of co-operation and integration between the Design Department and the Production Department and with certain external contractors. This is particularly true in large projects [roughly, any project with a per unit cost greater than £100,000 would be considered large] where the Production Department staff would be closely involved right from the costing and quoting stages of the proposed

project. This integration is often critical in determining the manufacturability of a given design and confirming key design features. Another major outgrowth of this is the close involvement of production personnel in testing and systems integration efforts. This is true for both true prototypes and the final production unit in most cases. While in most firms, these activities are likely to be carried out solely by R&D personnel, the degree of involvement of the production personnel in the present case allows for “quick and dirty” modifications to be proposed, designed, and implemented.

In particular, 3 in-house relationships were found to be key in the large projects—the close working relationship between the Senior Design Engineer and the senior most Fabricator and with the Machinist and finally with the Lead Metalworker (who operated the Laser Machine and the Press Breaks). Several key design decisions in such projects could be traced to the input from these key personnel. Another key relationship was with 2 controls engineers, who while external to the company, nonetheless worked very closely with in-house personnel in developing control systems and programming solutions for various projects. This close relationship eventually resulted in the development of an inhouse pneumatics controls capability that would contribute to the company developing expertise in the design and manufacture of non-electrical equipment suitable for niche applications including ATEX-rated products.

Such close integration between Design and Production personnel, while not unique to the firm (especially considering its status as an SME), was found to play a key role in its capability development. The relatively flat organisational structure also helps in facilitating these relationships. This is recognised by the Directors and encouraged as much as possible. The highly cooperative nature of the relationship(s) also gives Senior Management clear feedback as to the gaps in the firm’s production capabilities. While the information may not be acted upon immediately, they are often the starting point for medium/long-term Capital projects.

Secondly, the Senior Management tends to actively seek to identify specialist skill shortages and capability gaps and seek to correct them**.** This attitude stems primarily from their assessment of the evolution of the value chain of the SME and its business environment. The skill gaps detected involved both the design & engineering as well as the production aspects of the business. (However, this is not universal and the pace

and manner in which they deal with this aspect of management is governed by multiple factors. This nuance is dealt with more fully in the Discussion section below).

On the R&D aspect, between 2015 and 2017, as the number and scope of projects ramped up rapidly, senior management at the company identified a lack of specialist skills regarding compliance and to a lesser degree, lack of appropriate technical documentation impeding the recording and dissemination of technical knowledge relating to complex projects. Consequently, a strategic decision was made to develop these skills while making periodic upgrades to production capabilities.

The previously mentioned close relationship between the company and the local University, and the Knowledge Transfer Partnership (KTP) was initiated with this objective. Through this Partnership, these specialist compliance capabilities were absorbed within the firm successfully with documentation capabilities also being improved. The decision to train new apprentices and to institute a Knowledge Management strategy by mentorship by older workers was also aimed at retaining and extending specialist knowledge at the shop-floor level.

As the KTP progressed, the orders described in Cases 2 and 3 were received and worked on. This work led to a further identification of specialist skill shortage: that of advanced Computational Fluid Dynamics (CFD) simulation capabilities. While not a market-qualifying capability with the two orders, it was recognised by Senior Management that current capabilities would not be sufficient if further orders of a similar nature were to be processed on a more competitive basis. It was also recognised that specialist help would be needed to gain this capability. As described above, the relationship with the University was once again used to receive specialist help (through a Masters' student) in Case 3. However, coupled with that, a more comprehensive effort was started to bring this capability within the firm. This took the form of a two-pronged approach of buying commercial-grade CFD simulation software and initiating a follow-on KTP with CFD as one of its major focus areas and with access to high performance open source CFD simulation software.

In terms of gaps in production capability, three major issues were identified in the 2015-16 timeframe. Firstly, as order volumes and complexity increased, the machining capability of the company was found to be severely inadequate. Jobs had to be turned down frequently and design choices were often limited by the limitations of the existing

mill and lathe. A prime example of this was a sparge pipe design for the Fish Poacher machine (Case 1) where the programming limitations would have made the work prohibitively time consuming. In addition, finish quality was often inconsistent and downtime excessively high. While the issues were identified early on, new machines were acquired only in late 2019 as other capabilities were considered more critical to competitive advantage. In the interim, a mix of sub-contracting arrangements and design reviews (involving the Machinist) to ensure machinability were implemented to mitigate problems. The new machines (a Vertical Machining Centre, Lathe and Bar Feeder) not only solved these problems, but also increased the volume production capability of the Machine Shop. Secondly, it was noticed that with increasing order volumes, quality of HVAC and piping work could be inconsistent with rework often being necessary before handover. A major customer in the food sector also communicated their intention to start working on an expansion of existing plant facilities in late 2018. Hence HVAC and Piping personnel with specialist skills (in particular, expertise in creating and working in cleanroom environments) were recruited in 2019. This too has resulted in a significant capability upgrade.

This identification of specialist skill shortage is a continuous process, both at the Senior Management level and among the Design Engineers. A specialist skill shortage that has affected large projects in 2020-21 is the capacity constraints faced by the use of the two external controls engineers for all electrical controls work. As these engineers are often working at capacity from other (independent) projects, this constitutes a capability gap in responding to customer requirements on the controls front. It also creates a Single-vendor situation, and this could be regarded as a systemic risk to the firm. Solutions to this skill shortage are actively being considered at the time of writing.

Finally, there is a heavy emphasis on *relationship marketing* between the Senior Managers of the firm and counterparties at customer firms (and to a lesser degree, supplier firms). The firm's directors handle most of the promotional activities of the firm directly and through this, they can communicate directly to the customer firms the complexities of initiating, managing, and completing a large engineering project. The engineering background of the Directors and their keen awareness of the capabilities of the firm allowed realistic promises to be made (and kept) on a much shorter turnaround time than many competing firms. In many cases, orders for complex

machinery came from long-standing customers who had hitherto contracted for basic items with much shorter development and manufacturing turnaround times. This solid track record formed the basis for further (more complex) orders. In the case of this firm, the lack of dedicated marketing personnel/function seems to have been beneficial in securing larger orders.

It was recognised early in the growth phase described in this study that a close relationship between engineers (and other senior personnel) at the customer firm and the Engineering team would be key to the success at several critical junctures within projects, particularly in the management and resolution of setbacks in the development effort. Hence the Directors were careful to nurture these relationships very carefully and take a personal stake in their development. They also made efforts to communicate (and demonstrate through pilot/small scale projects) the integration of new capabilities into the firm on a regular basis to key customers. This has paid rich dividends in terms of projects successes and follow-on orders from these customers.

6. Discussion

From the above findings, the salient features of *capability development* within the firm can be described along with challenges faced in this process.

Firstly, significant evolution has happened in terms of the management capabilities of the firm since its founding, but most especially since the last round of restructuring in 2009. An important (and from the authors' perspective, most surprising) finding was that most of the development in management capability occurred much before the actual addition of new capabilities within the firm. Specifically, the emphasis on profitability and a more focussed talent strategy have been key factors in the capability development of the firm. On further consideration of the facts and when coupled from insights from literature, this was not as surprising as it seemed at first sight.

Interpreting the growth story of the firm on the basis of the model given by Scott and Bruce (1987), it is clear that the firm spent the transitional years between the last restructuring to its' current growth phase in a slow transition from '*Survival*' stage to '*Growth*' stage. There are strong indications that this was deliberate and that the Directors saw this long transition as a means of recovery from past setbacks and as an opportunity to change the direction of the firm. In this transitional stage, a

combination of risk factors from both '*Survival*' and '*Growth*' stages were present. This long transition allowed the Directors to hone their skills in managing key risks identified by Scott and Bruce, (including overtrading and pressure from competitors—both old and new) and focus on a more appropriate benchmark for growth while modifying its talent strategy. In short, it spent these years developing a management capability that could be considered advanced for the stage it was in, while consciously pursuing a "product differentiation" strategy vis-à-vis larger and more established competitors. This points to the limitations of the "Stage-Growth" models and is in line with Storey's (2016) criticisms of these models.

Another aspect of management within the firm is its generally reactive nature in the short to medium terms. As the firm's capability and size have improved, this is slowly changing with more planning being done to adjust to the changed situation. This indicates a desire to change from a 'trundler' to a 'flyer' as per Storey's (2016) classification and the development in management capabilities outlined above could be seen as a logical outgrowth of that desire. While this reactive nature of management may be suboptimal from an operational planning perspective, it is often instrumental in identifying and exploiting emerging opportunities. Several key projects owe their origins to this reactive mindset and a tendency to look for opportunities that competitors deem relatively unattractive or infeasible.

Secondly, there is an in-built bias within the firm towards better leveraging of current capabilities for competitive advantage rather than adding new ones. This is closely related to the reactive nature of the management mentioned above. A key aspect of this reactive nature is the inherent operational flexibility it endows to the firm. This usually takes the form of decentralisation of design and (sometimes production) decisions and use of ad hoc cross functional teams and play a key role in creating high levels of *adaptability* within the firm (Reeves and Deimler, 2011). Hodgson (2017) presents evidence that *adaptability* in terms of production and HR (or in other words talented personnel) is a major factor in ensuring firm survival and this could point to the Company's advantages in these aspects in ensuring its survival during setbacks and laying the foundations for its later growth.

This *adaptability* has been put to good use by the firm in its *capability development* despite the inefficiencies this often entails. However, it is not so much the *adaptability*

in the firm that matters in terms of *capability development* as the outgrowths from initiatives to fix short-term problems that eventually becomes the starting point for a *capability development* initiative. On the other hand, the confidence that management has in the adaptability often contributes to a slow pace of *capability development* initiatives. This slow pace of development initiatives and the heavy emphasis on use of in-house resources can be regarded as a mitigatory measure with regard to financial risks as well and seems to trace its origins to the early growth phases of the firm.

In general, this overall approach is supported in literature, though the Directors of the company have pursued this strategy by experience, rather than due to any theory-driven considerations. This approach is consistent with Newbert's (2007) finding of a considerable body of work, which suggests that the organisation and deployment of resources is just as important as its existence in ensuring competitive advantage to the firm. Stadler (2007) argues that exploiting before you explore and being conservative about change are key planks of long term success i.e. exploiting existing assets and capabilities to the fullest before developing new ones and taking extreme levels of care and planning before implementing change initiatives. This "Go slow" approach also serves to mitigate financial risks caused by external shocks and similar strategies are used in larger firms as well (Vogus and Sutcliffe, 2007).

However, as seen clearly in the timeline in Fig. 3 (Page 43), in the period preceding the current phase of growth, the Directors have modified this "in-house only" approach to some degree, recognising that collaborative partnerships (such as KTPs and partnerships with controls engineers) are required for growth. The evidence collected during this study clearly indicates the benefits of this hybrid approach in effecting growth within the firm, both in terms of *capability development* and in profits. However, the focus of the Directors remains the internalisation of these new capabilities within the firm as quickly as possible rather than continuing dependence on these external partners.

In RBV terms, the factors that play a key role in the capability of the firm can be attributed to the presence and effective use of three major resources: (1) management capabilities that are advanced for the growth stage that the firm is in and that is capable of effectively combining and deploying the various resources of the firm (both rare and common); (2) adaptability to cater to both changing business needs and weather

external shocks; (3) talent and partnership strategy that has been developed (and tweaked regularly) to ensure medium to long-term growth. None of these resources, taken in isolation constitutes the basis for a sustainable competitive advantage in the RBV of the firm. But a careful examination of the evidence collected strongly suggests that taken together, they constitute a set of strategic resources that are Valuable, Rare, Inimitable, and Non-substitutable that in turn enables a virtuous cycle of slow but consistent *capability development* within the firm.

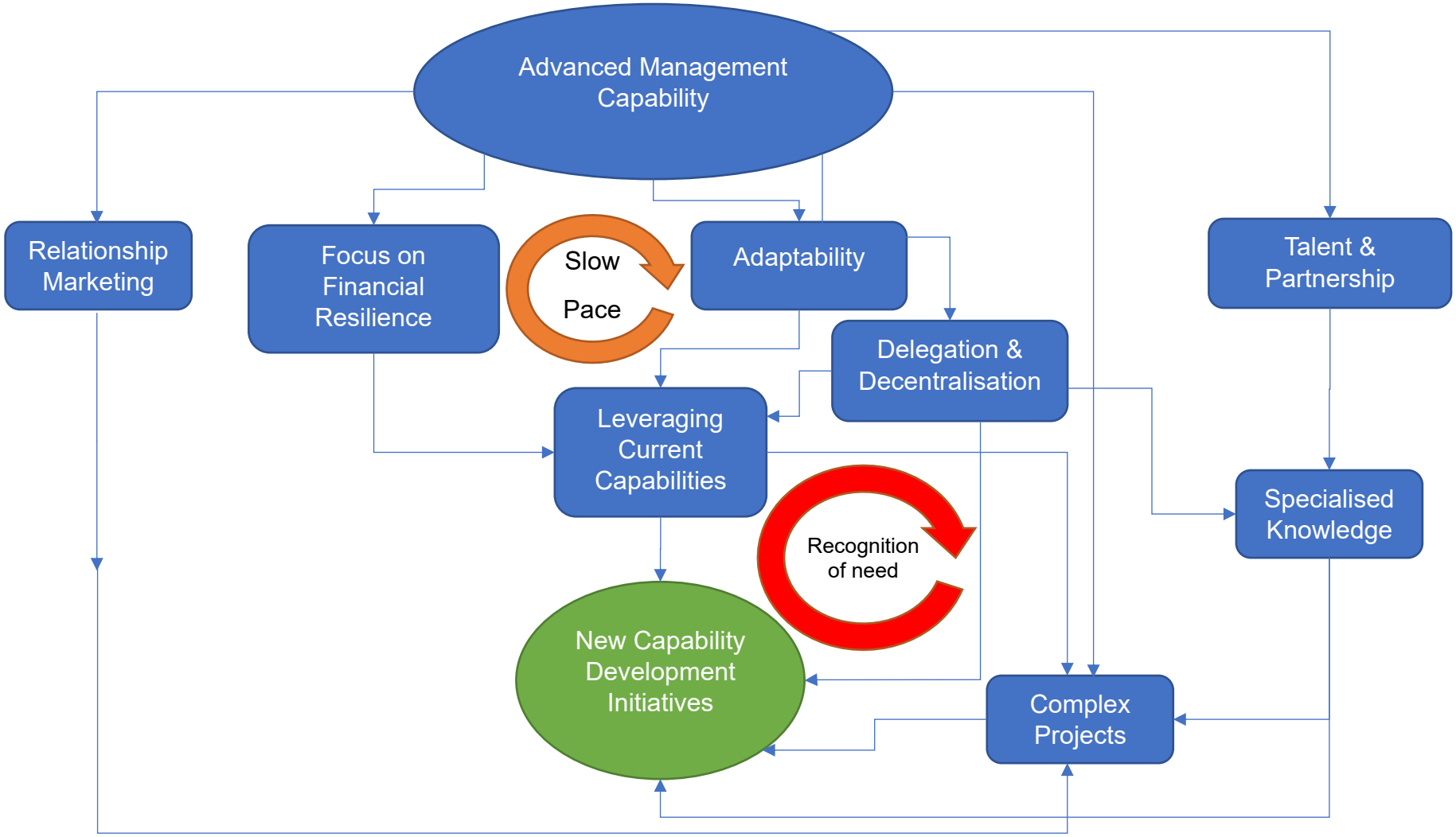

Fig.4.Capability Development Process in the chosen SME

Based on the factors given above and combining it with the Findings from the 3 cases, it is possible to develop a unified view of the *capability development* Process within the SME. Figure 4 above gives a graphical description of the Process as identified in this study. As mentioned earlier, the management capabilities of the firm have developed considerably compared to its initial state and this factor underpins the rest of the process.

These advanced management capabilities are most impactful in the relationship marketing, financial resilience, adaptability, and talent & partnership strategy aspects of the firm and contribute to the initiation of complex projects. It also acts as an enabler to delegation & decentralisation of authority. The twin priorities of ensuring financial resilience and adaptability means that leveraging current capabilities takes a higher priority than developing new capabilities. This explains the slow pace of the process. Delegation & decentralisation of decision making contributes to complex projects as an enabler of rapid and effective decision-making. Specialised knowledge developed through the recruitment of highly qualified personnel and collaborative partnerships enables development of complex projects while relationship marketing often provides the opportunity to engage in complex projects in the first place. It is usually within the context of a complex project that capability gaps are recognised, and a determination is made by the Directors that ad hoc initiatives to leverage current capabilities are longer sufficient to cater to business needs. Specialised knowledge acquired during the project coupled with individual employees (or small groups) acting on their own initiative play a key role in advancing the *capability development* initiative.

This cycle tends to repeat itself though the pace itself is primarily controlled by the Directors based on the current order book, projected orders, the larger business environment, and their long-term strategy.

While *capability development* in a continuous process within the firm, challenges associated with new capabilities acquired by the firm have also started to emerge (at the time of writing). With the increase in both the volume and complexity of orders, traceability (of parts and labour) and quality control are becoming more challenging. This is further complicated by the engagement of subcontractors for specific aspects of work, especially on site as in-house personnel are not available due to the increase in order volumes. Initiatives to deal with this appropriately are being formulated at the time of writing. As the specialised

knowledge held by the firm personnel increases with project, finding (and retaining) subcontractors who can work in tandem with in-house personnel is becoming a major constraint in preparing bids for complex projects. This has the potential to reduce profitability and adversely affect the long-term growth of the Company.

Evidence gleaned from the interviews indicate that strategy formulation within the firm continues to be informal and largely owner driven. While more planning and formal procedures have been used for operational planning for many years, the top-level strategic decisions continue to be planned and executed on a personal basis and is entirely in line with the practices of most SMEs. This is not indicative of a lack of strategic vision or plan as there is clear evidence of an overall strategic plan with significant scope for flexibility and adaptation to changing circumstances. However, there is evidence that this informal and personal form of strategic management may have outlived its usefulness as the firm gets larger and the need to ensure strategic clarity at all levels becomes a pressing necessity.

A related aspect (also seen from the interviews) is that the Company, while constantly acquiring and storing knowledge from current and past projects, does not seem to have put in place any formal mechanism for effecting Organisational Learning (OL). While some formal Knowledge Management initiatives have been undertaken with regard to specialised design knowledge (as indicated in the timeline) and informal Knowledge Management initiatives are carried out on a regular basis at the grassroots level, the lack of systematic OL initiatives at the highest levels may be a factor in the slow pace of *capability development* and/or stifling the full potential of existing capabilities. This may result in useful knowledge being "lost" and thus unavailable to decisionmakers. Another downside maybe the persistence of the reactive mindset, which while useful at responding quickly to emerging opportunities in the near term, may result in less effective improvement initiatives over the long term (Matthews et al., 2017). Changing this to a more optimal balance may be of particular interest to the Company as it continues its present growth as Knowledge Management literature clearly supports the link between innovation and OL (Gomes and Wojahn, 2017; Thomas et al., 2017). Spicer and Sadler-Smith (2006) also identifies higher order (double loop) learning as a key driver in company growth while Hsu and Fang (2009) find a strong link between intellectual capital and new product

development performance with organisational learning capabilities in a mediating role. Hence improvements in OL capabilities may be the next appropriate avenue for improvement for the firm to ensure continued improvements in other aspects of Capability.

7. Conclusion

This study traces the growth of a manufacturing SME over a substantial period of time. As such it includes periods of sustained growth and that of extreme challenges, though none in the period under consideration threatened the survival of the firm.

Based on the evidence considered in this study, development of management capabilities to an appropriate level with a right mix of financial and technical knowledge constitute a necessary but not sufficient conditions for sustained capability development in an SME. Reactive initiatives when combined with proper management support and appropriate long-term partnerships can lead to incremental capability development that can drive the process over the medium-to-long term. However, the study also indicates that for the pace of growth to be maintained and for the firm to take full financial advantage of the newfound capabilities, management capability should evolve further alongside it. Partners who are capable of supporting ambitious projects are a key factor in developing and maintaining new capabilities and finding and retaining them as partners can be highly challenging.

The core strength of this study is the highly unusual perspective it delivers in terms of the "*Growth*" stage of an SME over a period of 6 years from the authors who have been intimately involved in the projects and initiatives under consideration in this study. The challenges associated with capability development have not been explored in depth in this study. Challenges associated with traceability and quality control and make or buy decisions all constitute excellent avenues for future research work based on this study. Organisational Learning that happens within the context of Capability Development forms another potentially rewarding area for future work.

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Article 2: New KM Tool for Manufacturing SMEs Working in Strictly Regulated Sectors

Abstract

The present research effort is centred on creating a new Knowledge Management (KM) Tool for manufacturing SMEs working in strictly regulated sectors based on a research effort that was carried out in a manufacturing SME that deals with ATEX-rated and ATEX-compliant equipment. Thus, this project included acquiring, synthesizing and extending the knowledge underpinning the development of machines that are compliant with the ATEX Directives of the European Union (EU). A literature review has been carried out to explore the theoretical understanding regarding Knowledge Management and its practice, particularly in Small and Medium Enterprises, engineering and manufacturing firms and in environments with strict compliance requirements. KM in these sectors have certain unique challenges that require a novel approach that is relatively simple and with minimal resource usage. The Methodology Section explores the techniques used to execute this project and their justification in this context. The project uses Unstructured and Semi-structured interviews within an abductive reasoning approach. The Case Study gives in-depth details regarding the project and the structure of the ATEX Library created. The Framework developed based on this is explained in the Section 6.

Keywords: Knowledge Management, KM Tool, KM practice, ATEX, strictly regulated sector

1. Introduction

The present research effort is centred on creating a new Knowledge Management (KM) Tool for manufacturing SMEs working in strictly regulated sectors based on a research effort that was carried out in a manufacturing SME that deals with ATEX-rated and ATEX-compliant equipment. Thus, this project included acquiring, synthesizing and extending the knowledge underpinning the development of machines that are compliant with the ATEX Directives of the European Union (EU).

ATEX stands for "*Atmospheres Explosibles*" and the ATEX Directives (viz. 94/9/EC, 99/92/EC and 2014/34/EU) of the EU regulate the use of equipment that are to be used in hazardous environments. The broad nature of the ATEX Directive(s) (European Union, 2014) poses a major challenge from a Knowledge Management perspective.

The research was carried out at an engineering SME based at Bideford, North Devon, UK. The Company is typically involved in small or medium scale engineering projects and has only recently (i.e., in the last 2 years) started working on ATEX and ATEX-related projects. The complexity and breadth of ATEX regulations represented a distinct challenge to the Company. The project was considered highly important to the Company mainly because it believed (and continues to believe at the time of writing) ATEX-rated equipment represented a long-term growth opportunity and consequently, devoted considerable resources to it. However, as with many SMEs, resource allocation in terms of time and budget were severely limited by operational considerations and the focus of the company was on a project with quick turnaround, maximum flexibility and low complexity which would, as a whole be useful in day-to-day operations.

Cumulatively, this resulted in a KM initiative that involved the creation of operational tools meant to be used appropriately by a designer who is leading any stage of an ATEX project (i.e., from initial proposal generation and quoting to maintenance and support). Hence, the local aim was to create a common baseline from which all ATEX programmes start, i.e., a knowledge sharing aid that allows the creation of a shared context within the firm. Thus, the research effort included both traditional Knowledge Management, but also an attempt to extend it based on the present knowledge to meet the rapidly growing needs of the business by creating a best-practice guide regarding

ATEX. The proper dissemination and utilisation of this knowledge within the organisation represents an important secondary consideration. Based on this effort, a framework has been created which serves as a useful guide in creating a new KM tool for manufacturing SMEs working in strictly regulated sectors. This tool should allow the creation of a body of knowledge that deals with complex legislations and standards in a highly user-friendly way while ensuring compliance and safety.

The rest of the report is structured as follows: Sections 2 and 3 deal with KM in theory and in practice respectively. Section 2 introduces Nonaka's theory on Knowledge Management while Section 3 describes the challenges of KM in an SME, in engineering and when dealing with legislation. Section 4 gives the Methodology while Section 5 details the case study undertaken at the Company. Section 6 describes the framework being introduced and Section 7 gives the Conclusion.

2. Knowledge Management

In this section, the major theoretical aspects of Knowledge Management are explored. A brief history of KM, definitions of the various commonly used terms, the dominant theory in KM are covered in this section, along with the divergent views among scholars on the theoretical treatment of KM. Methods and tools used in KM, organizational learning and its role in KM are also covered in this section.

Knowledge Management, as a modern discipline, is relatively new (Darroch, 2005; Zack et al., 2009; Dalkir, 2013) and Organisational KM traces its origins to a 1991 article by Nonaka titled, "The Knowledge Creating Company" (Crane, 2013). Subsequent work by Nonaka and his associates have also been extremely influential in the development of the KM discipline (Virtanen, 2011). However, it can be argued that the origins of KM go back even further. Darroch (2005) and Alavi and Leidner (2001) trace the origins of KM to the resource-based view of the firm as expounded by Penrose in 1959 and links it to Nelson and Winter's (2004, originally published in 1982) concept of a "coordinating mechanism" in firms. Dalkir (2013) contends that KM derives from the ideas of management theorists like Peter Drucker, Wiig and Senge who preceded Nonaka, in some cases from the 1960s onwards. He also links the rise of KM as a distinct discipline to the parallel development in Information Technology (IT) which allowed the "systematic, deliberate leveraging of knowledge assets"

(Pemberton and Stonehouse, 2000; Dalkir, 2013, p.14). This includes development of expert systems, databases, virtualisation systems, algorithms, artificial intelligence (AI) approaches etc. (Kendal and Creen, 2007)

The relative novelty of the discipline and its broad multi-disciplinary nature has given rise to a multiplicity of views regarding basic taxonomy (among others) in KM. This extends even to what many scholars regard as the building blocks of Knowledge: data and information. The most common view regarding data, information and knowledge is that of a three-tier hierarchical view that is described below. Dissenting opinions are covered later in this section.

Davenport and Prusak define data as "*a set of discrete, objective facts about events*", (1998, p.2) i.e. it is devoid of context. Kendal and Creen use a similar definition and consider data to be composed of *raw facts and figures* while information is defined as *'refinement of data for the purposes of human use'* (2007, p.4). Drucker defined information as '*data endowed with relevance and purpose'*(1988, p.4). Other authors use terms such as *structure, meaning, context, message* and *analysed data* in distinguishing data from information (Wiig, 1993; Davenport and Prusak, 1998; Kendal and Creen, 2007; Dalkir, 2013). Davenport and Prusak (1998) posit that when data is subject to certain methods, it undergoes value accretion and turns into information. They consider contextualisation, categorisation, calculation, and condensation as the main methods by which this transformation happens.

When information is organised in a way to support useful decision-making, it is transformed into knowledge (Kendal and Creen, 2007; Fai Pun and Nathai-Balkissoon, 2011). However, there is no particular point where information is suddenly turned into knowledge (Wiig, 1993). What constitutes knowledge is person-dependent (Davenport and Prusak, 1998; Alavi and Leidner, 2001; Kendal and Creen, 2007), though knowledge is considered to be "broader, deeper, and richer than data or information" (Davenport and Prusak, 1998, p.5). In short, the information becomes actionable and acquires even more value. This typically happens when comparisons and connections to similar situations are made and expert opinion and commentary is added to better frame the information that is already available. Thus, the major factors that distinguish knowledge from information are: (1) value accretion, (2) actionable nature and (3) person dependence.

There are several strands of thinking within academia and practice with regards to the exact definition of KM (Darroch, 2005; Fai Pun and Nathai-Balkissoon, 2011; Crane, 2013; Dalkir, 2013). Dalkir (2013) identifies three distinct views on KM: the *business perspective*, the *knowledge science perspective* and the *process/technology perspective.* Crane (2013) takes a broad sample of KM theory and classifies it into a continuous schema of personal knowledge versus organisational knowledge and knowledge as an object versus knowledge as a social action.

As per Dalkir (2013), the business perspective of KM is that of putting in place the strategy, policies and practices of best utilising the intellectual assets owned by a firm into favourable business results. It also encompasses a 'collaborative and integrated approach' towards the intellectual assets within the firm (Dalkir, 2013, p.4). The knowledge science perspective views KM as an enabler for intelligent behaviour and focusses on the tangible and intangible manifestations of knowledge. The process/technology perspective focusses on the storage of data with a view to making them easily available and as an enabler of effective decision-making.

Nonaka's (2007) (originally published in 1991) theory regarding a "Knowledge-Creating Company" has the *"Spiral of Knowledge"* concept at its core. The Spiral of Knowledge concept explores the possible combinations in which types of knowledge can be combined and synthesised. He identified two broad types of knowledge: *tacit* and *explicit*. Tacit knowledge (also referred to as intangible knowledge) is usually very personal and hard to formalise and communicate while explicit knowledge (also called tangible knowledge) is readily available in a codified form, in regulations, databases, design diagrams or other forms (Nonaka and Takeuchi, 1995).

Nonaka argue that tacit knowledge must be converted to explicit for it to become truly useful to the firm. They believe that proper management of knowledge is dependent upon ensuring the availability of individual insights and intuitions to the wider organisation. Nonaka argues that extension of knowledge (and thus innovation) to the firm's benefit occurs primarily in the interplay between the realms of tacit and explicit knowledge and that this is the purpose of KM and in a broader sense, of the firm.

The *Spiral of Knowledge* or *SECI Cycle* (*socialisation, externalisation, internalisation* and *combination*) concept considers four primary modes of knowledge conversion: (1)

Socialisation—Tacit to Tacit; (2) Externalisation—Tacit to Explicit; (3) Combination—Explicit to Explicit; and (4) Internalisation—Explicit to Tacit. The *Spiral of Knowledge* can be given in the graphical form, as below in Fig. 1.

	Tacit Knowledge *To*	Explicit Knowledge
Tacit Knowledge *From*	**Socialisation**	**Externalisation**
Explicit Knowledge	**Internalisation**	**Combination**

Fig. 1: SECI Cycle as given by Nonaka and Takeguchi, (1995, p.62)

The first step in the *SECI Cycle (socialisation)* involves the transfer of Tacit Knowledge from one person to another through shared experiences. Examples of this mode of Knowledge conversion can include on-the-job training for an apprentice by an expert, informal meetings between colleagues, and observation, imitation and practice of an expert's way of approaching a process or problem. The second step of the *SECI Cycle (externalisation)* involves the conversion of Tacit Knowledge to Explicit Knowledge. This conversion happens primarily in the context of concept creation and the Tacit Knowledge is converted into "metaphors, analogies, concepts, hypotheses or models" (Nonaka and Takeuchi, 1995, p.63). The *externalisation* step is highlighted in the theory as being instrumental in the creation of Knowledge. The third step (Combination) involves combining different forms of Explicit Knowledge and then using that in novel ways including in the creation of new concepts. Combining mid-level concepts with a view to creating a grand concept of strategic implications (by top managers) is cited as an example of this step. In the fourth step (Internalisation) of the SECI Cycle, individuals imbibe the Knowledge present in documents, manuals and other explicit sources of information and internalise this for future use. In many cases, this leads to the creation of a "*tacit mental model*" (Nonaka and Takeuchi, 1995, p.70) and the knowledge becoming a part of the organisational culture of the company. This cycle is iterative and gives rise to different kinds of knowledge in different steps.

As mentioned above, the three-tier hierarchical view of data, information, and knowledge and Nonaka's theory have been heavily criticized by several scholars. Much debate has occurred between scholars as to the true nature of Knowledge and its differences from data and information. Alavi and Leidner (2001) reject the hierarchical view and contend that information can be converted into knowledge only in the minds of individuals. They also criticise the elevation of Explicit Knowledge over Tacit Knowledge as being unsubstantiated by evidence. The necessity of conversion of tacit knowledge to explicit knowledge is a highly contentious point (Virtanen, 2011; Dalkir, 2013). Virtanen (2011) observes that most projects that focus on externalisation of knowledge using ICT Tools report a high failure rate. Others (Blackler, 1993; Blackler, 1995; Gourlay, 2006) are critical about the treatment of knowledge as an object or a commodity.

This fundamental difference regarding the nature of knowledge is reflected in approaches to KM as well. There are two primary approaches or strategies to KM to be found in literature: Codification and *personalisation* (Shu et al., 2013). Codification refers to acquiring data from the subject experts and then storing them in a database for reuse at a later date (Hansen et al., 1999). Thus, this knowledge is successfully depersonalised and stored. This approach corresponds to the commodity view of knowledge (McMahon et al., 2004). Codification tends to work best when the work done is relatively standardised and highly reusable. By contrast, the *personalisation* strategy focuses on the development of networks of people within the firm for the delivery of highly innovative solutions to a problem or project at hand. Each of these strategies requires a slightly different economic model to be operated by the firm to be successful (Hansen et al., 1999).

While Nonaka's theory has been subjected to intense criticism and alternative scholarly views are widely available, it remains the most influential one in the KM field (Fai Pun and Nathai-Balkissoon, 2011). While rooted in Japanese management practices, it demonstrates elegance and simplicity in capturing all the essential characteristics of knowledge as used at a practical level within a firm. This deep-rooted realism has allowed this theory to be remarkably resilient in the face of criticism. On comparing the different perspectives on KM as given by Dalkir (2013), at an operational level, it is often the business perspective in combination with the process

technology that has proved its relevance. It can be observed that Nonaka's theory captures the business perspective of KM very effectively.

Despite the divergent views in literature as to the true nature of knowledge and what constitutes KM, there is broad evidence that KM initiatives are beneficial to firms which effectively practice it. KM initiatives improve efficiency, innovativeness and general firm performance (Davenport and Prusak, 1998; Darroch, 2005; Zack et al., 2009; Rašula et al., 2012). They also help drive down costs by allowing standardised solutions to be reused, allowing for quicker service (Hansen et al., 1999). This is true even in purely knowledge-based firms such as consulting practices. KM can contribute to the market value of a firm. In an empirical study conducted by Choi and Jong (2010), they found that markets reacted positively to firms announcement of their KM strategies.

However, KM initiatives have the potential to create problems within an organisation. Knowledge Capture is a time-consuming and expensive task. Tacit Knowledge must be converted into Explicit Knowledge if it is to be shared successfully with a wider audience (Nonaka, 2007). Many KM initiatives fail because of low usage and usability (Schütt, 2003; Dalkir, 2013). As a result, dissemination of knowledge does not happen, and much investment is wasted. This is especially true when such initiatives are poorly thought out and planned and often with perverse incentives. Cooper (2003) points out that a successful knowledge strategy requires careful attention to the content to be stored and its organisation.

However, simply owning the knowledge resource is not enough for it to be used effectively to create an advantage to the firm (Darroch, 2005). The way it is managed and used makes a crucial difference. This is closely related to the concept of Organisational Learning. Organisational learning as a concept, is closely related to KM. However, as is the case of KM, it too suffers from a wide variety of definitions as scholars approach it from different perspectives (López, 2005). This has resulted in complementary and overlapping definitions (Wang and Ahmed, 2003; Fai Pun and Nathai-Balkissoon, 2011). Wang and Ahmed (2003) points out 5 different perspectives in Organisational Learning literature. Despite this diversity, in general, it can be taken as the organisational "culture, structure and infrastructure" that "facilitate and nurture learning" (Pemberton and Stonehouse, 2000, p.184). It is also connected closely with Argyris' (1991) concept of single-loop and double-loop learning, with the single-loop

being connected to problem solving while the double-loop concept being the creation of a reflective mindset within the members of an organisation. Other authors have called for even higher levels of learning (Wang and Ahmed, 2003; Fai Pun and Nathai-Balkissoon, 2011). Despite the considerable attention it has received (and continues to receive), there is evidence to suggest that many organisations, particularly SMEs have not made appropriate changes to facilitate organisational learning, with much of the learning happening incidentally and much being at a risk of loss (Matlay, 2000; Gomes and Wojahn, 2017).

A common thread connecting many leading journal articles and forums is the high level of focus on larger companies and their efforts to create a viable KM Strategy. (This observation is supported by many including Wong and Aspinwall (2004), Coyte et al.(2012), Durst and Runar Edvardsson (2012), and Massaro et al. (2016)). Such techniques are often not suitable or redundant in an SME context and some require expensive knowledge infrastructure to implement them.

3. Knowledge Management in Practice: SMEs and the Manufacturing sector

3.1 KM in SMEs

Small and Medium Enterprises (SMEs) are a specific class of businesses by virtue of their sizes. The UK Government defines an SME as any company satisfying two or more of the following characteristics: a turnover of less than £25 million, less than 250 employees and gross assets of less than £12.5 million (Department for Business, Innovation & Skills, 2012). The European Commission (2016b) defines a small business as one with less than 50 employees and less than €10 million in turnover or assets while a medium business is defined as having less than 250 employees and €50 million turnover or €43 million in assets.

SMEs tend to have certain common characteristics which poses distinct challenges from a KM perspective. These can be both quantitative and qualitative in nature. While they are often highly innovative, flexible, and capable of delivering highly personalised service, SMEs usually operate under tight resource constraints, primarily in terms of capital and human resources (Wong and Aspinwall, 2004; Durst and Runar Edvardsson, 2012; Zieba et al., 2016; Durst and Bruns, 2018; Henschel and Heinze, 2018). This has serious implications as any errors are likely to be of far-reaching

consequence. Many SMEs are owner-run and tend to be defined by his/her qualities and experiences. They are also characterised by a flat hierarchy with relatively informal interaction and procedures between management and staff (Zieba et al., 2016; Durst and Bruns, 2018). There is also a high focus on day-to-day operations, leaving insufficient time to work on strategic issues such as KM.

Due to resource constraints, systematic KM approaches are lacking in most SMEs (Wong and Aspinwall, 2004; Durst and Runar Edvardsson, 2012). Zieba et al. states that the scholarly consensus regarding KM in SMEs is that they are characterised by an "informal, short-term approach" (2016, p.294). Desouza and Awazu (2006) posit that when taken in the context of Nonaka's *SECI cycle*, the Socialisation aspect dominates in SMEs with the other three facets of the *SECI cycle* being completely overshadowed by Socialisation (supported by Cerchione et al.(2016)). Combination of knowledge is done by the owner him/herself and Internalisation occurs through apprenticeship-based training. This is connected to the fact that owing to the lack of systematic KM approaches, most knowledge resides in the mind of key individuals and in some cases, with the owner him/herself (Wong and Aspinwall, 2004; Cerchione et al., 2016). There is generally a lack of explicit knowledge repositories in SMEs and there is a limited reliance on technology for knowledge management (Desouza and Awazu, 2006). Despite this relative lack of focus on KM, it remains hugely significant to SMEs as it forms the basis for its competitive advantage. In SMEs, the potential for knowledge loss is a distinct possibility as knowledge restricted to one person or a few persons at most and this could pose an existential threat to the company. Most SMEs try to counter this threat through redundancy in knowledge storage, i.e. there is a serious emphasis on creating deep levels of common knowledge in employees at different levels of the organisation, so that the business is not severely affected by any one person leaving the organisation (Desouza and Awazu, 2006; Coyte et al., 2012). Coyte et al. (2012) maintain that KM guidelines intended for SMEs are often inappropriate as they treat SMEs as similar organisations to large firms and do not consider inherent characteristics that underpin their competitive advantage, especially responsiveness and flexibility.

The limited availability of resources in an SME has a detrimental effect on their innovation capabilities. Consequently, internal sources of innovation are unlikely to be sufficient to effect change. Hence, innovation efforts (including the planning and

execution of KM) are likely to include a deep partnership with a third-party with proper and targeted support being given to the firm, as in this case. Philpson (2020) comments that in such cases, the firm need not have knowledge regarding solutions, but should have the skills needed to assess the solutions being put forth.

3.2 KM in Engineering and Manufacturing

Knowledge Management is an important activity in modern manufacturing firms. KM in engineering and manufacturing represents an important facet of a firm's competitive advantage (Shu et al., 2013; Tan and Wong, 2015). Gunasekaran and Ngai (2007, p.2392) identifies the "ability to manage and exploit knowledge" as the main source of competitive advantage in manufacturing.

KM in manufacturing firms tends to be extremely wide-ranging and is present in nearly all the functional aspects of manufacturing, including design, production, supply chains and IT/IS (Gunasekaran and Ngai, 2007; Salmador Sánchez and Ángeles Palacios, 2008). The sector is characterised by heavy emphasis on protecting technical and process knowledge and this is often challenging in an open communications environment. As with other sectors, the growth of IT and networking has been a major supporting factor in the increase in KM initiatives in engineering and manufacturing firms.

In a cross-sectional survey, Tan and Wong (2015) found that all respondents (206 firms) perceived KM activities to be contributing to improvements in manufacturing performance in their respective firms. In the same study, they found clear correlation between KM and manufacturing performance. They considered different aspects of KM in their study, including the various knowledge resources the firm has, KM processes as well as strategic factors that act as enablers for KM (which they called Knowledge Management Factors). They found that there was a strong correlation between manufacturing performance and all 3 factors. However, it was the Knowledge Management Factors that showed the greatest correlation. This includes the support of top management in KM initiatives and this observation is supported by Salmador Sánchez and Ángeles Palacios (2008)

Despite widespread recognition of the importance of KM in the sector, most companies do not place as much emphasis on knowledge assets as the physical assets (Gunasekaran and Ngai, 2007; Shu et al., 2013). Shu et al. identifies 3 issues in

manufacturing firms that impede effective KM: (1) knowledge islands, where knowledge is siloed in various functional units of an organisation and there is no sharing , (2) low efficiency of knowledge systems (particularly in large organisations) and (3) knowledge lock effect, where employees are locked into certain positions and roles and this results in the decline in communication between people in different roles and a decrease in the overall efficiency.

In general, most authors who deal with KM in Manufacturing treat knowledge as an object while not discounting the other aspects of knowledge. They also make heavy use of the SECI Spiral model (Salmador Sánchez and Ángeles Palacios, 2008; Shu et al., 2013). In this respect, they exhibit a strong adherence to Nonaka's theories.

3.3 Challenges for KM in Strict Compliance Environments

Knowledge Management is highly useful tool in environments where strict regulations are in place. Based on extant literature, Ontology-based systems are the most used KM tool in ensuring compliance to strict regulations. KM in strict compliance environments also has a heavy focus on automation while relying on the Knowledge of domain experts.

Boella et al. (2012) describes the development and working of a domain-specific legal ontology, tailored for the use of the financial industry in Italy. This is mainly geared toward banks and insurance companies and is a highly sophisticated tool that seeks to capture both descriptive and prescriptive aspects of compliance to complicated legislation. The tool allows user to search for particular aspects of the law based on topic and simplifies the approach towards compliance. It requires significant backend support as the underlying legislation is frequently updated and/or amended. Sesen et al. (2009; 2010) describes an Ontology-based compliance management system for pharmaceutical industry called OntoReg. It uses the OWL language to create a representation of the regulatory data while specifying relations and constraints using Semantic Web Rule Language (SWRL). Governatori et al. (2016) describe a Semantic Modelling system that conceptualises complicated regulations using LegalRuleML and facilitates automated compliance checking. They note that modelling of legal norms requires "substantial effort" even with their approach. Dimyadi and Amor (2017) compare three approaches to modelling of regulations for regulatory compliance purposes, primarily from a construction industry perspective. Certain approaches

require programming knowledge in that language while DBMS based systems have certain limitations in the way they model regulations.

From literature, it can be seen that ontology-based solutions are powerful tools that can effectively capture knowledge surrounding legal compliance while being capable of supporting multi-level legal concepts with an intuitive interface. They can serve to reduce error and reduce labour requirements in the actual compliance management process (Sesen et al., 2009; Sesen et al., 2010; Governatori et al., 2016). However, it requires extensive support from legal experts, not only for their initial development, but also for continued updating (Boella et al., 2012; Governatori et al., 2016). This inherently makes it more suitable for large businesses with a larger resource-base and with the necessary scale to take advantage of the tool. The problem is exacerbated when the regulations in question are updated frequently. Also, general legal ontologies often prove insufficient for specific sectors and domain-specific ontologies may be necessary in such cases (Boella et al., 2012). Sesen et al. (2009; 2010) also indicate that tailoring is necessary for different user groups.

4. Methodology

4.1. The Context

The methodology adopted in this research effort has been informed by requirements along three major lines: (1) ensure compatibility with the size, scale and nature of the manufacturing SME; (2) ensure the integrity of the research in terms of established best-practices in KM and allied fields; (3) ensure that the unusual nature of the primary subject-matter is taken into consideration.

The focus of the manufacturing SME was to have a body of knowledge regarding ATEX regulations and standards that could be used as an operational tool/aid to streamline the design, manufacture, and compliance of ATEX-rated or ATEX-compliant equipment within the company's product portfolio. The requirements were consistent with the characteristic nature of KM in SMEs as identified in literature with the KM initiative being considered complementary to the high degree of socialisation within the firm. The resource-constrained nature of the firm also ruled out any use of advanced techniques such as an ontology-based solution or even a strict modelling approach.

In terms of using the best practices within the KM discipline, the focus was to ensure that the Knowledge Management approach taken was sound and consistent with the SECI Model from Nonaka's Theory and with proven KM methods contained in literature. (This relationship will be elaborated further in Section 5). In a typical KM initiative, it is common to use a combination of several data collection methods and combine the data collected into a cohesive whole for the creation of the Knowledge Base (Dalkir, 2013). This approach is well supported in literature (Yin, 2013) and this has been adopted in this project as well, as seen below. This is to ensure that both Tacit and Explicit Knowledge is captured and the two often require different approaches for effective Knowledge Capture (Dalkir, 2013). The capture and consolidation of Tacit knowledge was of particular importance as it is considered to be rich and detailed information on factual, conceptual, expectational and methodological fronts, as per the classification given by Wiig (1993). This includes personally held observations, judgements, hypotheses and reasoning strategies that may be held unconsciously. In ensuring compliance to highly complex regulations and standards, the tacit knowledge held by experts is critical in ensuring an effective approach to the problem. As Dalkir points out, the "explicit knowledge tends to represent the final product, whereas tacit knowledge is the know-how or all of the processes that were required in order to produce that final product" (2013, p.8).

While the unusual nature of the subject-matter is explained more thoroughly in Section 5 of this paper, a brief note is pertinent here. A key factor in this KM initiative was the legally sensitive nature of the subject matter and the need for complete adherence to all relevant standards. The standards applicable in an ATEX-related project come from several different sources including EU Directives and from industry standards produced by several different sources with worldwide, European, or British jurisdictional foci. There are also a wide variety of sources (internal and external to the firm) that provide information regarding ATEX compliance. These sources deal with the topic with varying degrees of authoritativeness and subjectivity. This has high relevance in the application of a standard and could vary from case-to-case.

4.2. Research Methods

The proposed framework for KM in SMEs is derived from these (often competing) requirements and a case-study based qualitative method was considered the most appropriate approach to cover all the different requirements given above. A case-study

based qualitative approach is primarily useful in addressing questions of “how” and “why” and this is especially true when an “extensive and in-depth” description is required (Yin, 2013, p.37), as is true in this case. The market dependent and consequently unpredictable nature of ATEX-related development work within the firm made the use of other approaches highly problematic. The case study method allows the use of an abductive reasoning approach that would be needed to create a best practice guide incorporating disparate sources of information. With further development, a novel framework for KM in SMEs with stringent compliance needs could be created from this.

Within the overall case-study based abductive-reasoning approach the primary methods used were (1) Unstructured and semi-structured interviews and (2) Document Analysis. As most Knowledge is tacit and personal in the initial stages of development (Zucker et al., 2001), the use of interview is indispensable in capturing this Knowledge. New Knowledge is often known only to a small number of experts or even just one (Dalkir, 2013). As a result, several interviews with experts are necessary in KM projects, both to understand various requirement and for the actual knowledge acquisition. It was understood that initial interviews would have to be unstructured and focussed on understanding the needs and priorities of the Company while later interviews would be semi-structured with questions being focussed more on the ATEX regime itself and on the various methods of compliance associated with it. Document Analysis is another well-established method in qualitative studies. Kendal and Creen (2007) comment that literature-based sources of knowledge represent the one of the best options for capturing domain-specific technical knowledge and that the practitioner should make maximum use of them. In this project, this importance is still higher as the subject matter involves regulatory compliance to specific high-level legislation with or without the use of specific standards. Document analysis can be extremely useful as information contained in documents are stable and specific (Yin, 2013) and it tends to be highly cost-effective (Bowen, 2009). While information contained can be biased and lacking in detail, Bowen contends that document analysis represents an extremely useful method especially in conjunction with other methods and to augment and corroborate information from other sources (Yin, 2013).

4.3. KM and Organisational Learning

An often-overlooked aspect in KM initiatives is the relative lack of emphasis on deep integration of Organisational Learning efforts into the project resulting in the failure of the initiative (Schütt, 2003; Dalkir, 2013). The connection between KM as a process of creation of organisational knowledge and the organisational learning capability has been emphasised by many authors (e.g. Mbengue & Sané, 2013; Gomes and Wojahn, 2017). This present paper also explores how the KM initiative can be integrated into a wider organisational learning strategy by leveraging the SMEs in-built strengths. As innovation plays a key role in ensuring competitive advantage to an SME, incorporation of new knowledge is critical in the continued success and growth of the firm. This is supported by Hsu and Fang (2009) who find a strong link between intellectual capital and new product development performance with organisational learning capabilities in a mediating role. The fact that this study is based on highly sophisticated technology (IC design) firms amplifies its relevance to the present case. An empirical study by Gomes and Wojahn (2017) among 92 SMEs also support the link between innovation and organisational learning capability.

5. Case Study

5.1 Overall Approach and Adherence to SECI Cycle

Nonaka and Takeuchi (1995) believed that the creation of organisational knowledge was as much a practical endeavour as a theoretical one, in light of the culture of innovation exhibited by Japanese companies that he used as a basis for his work and the SECI model (Nonaka and Takeuchi, 1995). The overall approach in this Case Study towards organisational knowledge creation was to operationalise the SECI cycle within the Company.

As a result, the case-study was divided into three phases which are(1) Planning; (2) Implementation and (3) Consolidation & Continuing Work. The Planning stage corresponds roughly to Socialisation step of the SECI cycle while the Implementation stage corresponds roughly to Externalisation and Combination steps with the final product being a body of knowledge suitable for easy Internalisation. This correspondence is by no means perfect as each stage contained all four elements of the SECI cycle in varying degrees. The correspondence indicated is based on the

predominant step in each stage. The detailed steps given in sub-section 5.3 are reflective of this and indicates the nuances involved.

The outputs of the Case Study will be described in detail in sub-section 5.4 though some of the information gleaned through Background research and review of Primary Legislation (Step 1 in Planning) is given in sub-section 5.2 for better contextualisation of the subsequent work.

5.2 ATEX

[NOTE: This section uses Directive 1999/92/EC and Directive 2014/34/EU (both produced as statutory documents by the EU) as primary sources. Quotes are specifically cited while other sources are cited as usual. A much more comprehensive treatment of the regulations is given in the compiled body of knowledge, as described in next sub-section 5.4.]

The ATEX Directives of the European Union (EU) represent a major pillar of EU Safety law and deals with the safety requirements in Hazardous Environments. This includes, mines and hazardous environments created as a result of explosive gases, vapours, mists and dust (European Union, 2014). ATEX Directives consists of two distinct but closely related directives from the EU: One that deals with Hazardous Workplace environments (Directive 1999/92/EC, commonly known as the ATEX Workplace Directive) and a second one (Directive 2014/34/EU, commonly known as the ATEX Equipment Directive) that deals with the Equipment to be used in Hazardous Environments. The Equipment Directive replaced a previous directive (Directive 94/9/EC) that imposed essentially the same requirements with a few changes and additions.

The common theme in both these Directives is the Principle of Integrated Explosion Safety, which set out the following principles in ensuring safety, in descending order of priority: (1) Prevent the formation of an explosive atmosphere; (2) Prevent the ignition of an explosive atmosphere (mainly by tackling any sources of ignition); (3) Mitigate the effects of an explosion, if it does occur and/or contain it. These principles act as the guiding philosophy behind the entire ATEX regulatory regime and the system gives wide latitude in achieving this outcome, subject to certain requirements. Some of these are briefly explained in the following sections.

The Workplace directive defines what constitutes an explosive atmosphere and sets out a zone classification system that classifies hazardous work environments into distinct zones based on the likelihood of the presence of an explosive atmosphere. It also sets out the employer's responsibilities in ensuring the safety of workers in such environments and imposes specific responsibilities on the employer including appropriate training and clothing, a work permit system governing the work to be carried out and the need to carry out a comprehensive explosion risk assessment (which is to be documented) before the hazardous workplace is put into operation. The explosion risk assessment that is carried out must take into account (European Commission, 1999, p.59; Jespen, 2016): (1) the likelihood that explosive atmospheres will occur and their persistence; (2) the likelihood that ignition sources, including electrostatic discharges, will be present and become active and effective; (3) the installations, substances used, processes, and their possible interactions; (4) the scale of the anticipated effects. The Workplace Directive also imposes other related requirements on the employer.

The Workplace Directive divides gas, vapour and mist (or G) environment and dust (or D) environment into three distinct zones based on the likelihood of the presence of the explosive atmosphere. Zone 0 indicates a continuous or frequent presence of a gas, vapour or mist atmosphere, while Zones 1 and 2 indicate occasional presence and presence for short period respectively. The equivalent zones for dust environments are Zones 20, 21 and 22 respectively. The Directive imposes strict requirements on the types of equipment (by specifying *categories* of equipment) that can be put into operation within each zone.

The Equipment directive has a very broad focus and deals primarily with Manufacturers, Importers, Distributors and in some cases the Authorised Representatives of these parties who are dealing with equipment designed for hazardous environments. The Directive imposes certain requirements on them, the most important of which is the Essential Health and Safety Requirements (EHSR). EHSR is a set of requirements that each *Category* of equipment must satisfy including Conformity Assessment Procedures, documentation required along with the equipment and specific markings to be placed on the equipment which must be done before the equipment is made available within the Single Market or put into service within it (Jespen, 2016). The Equipment Directive also contains provisions to regulate

the working of Notified Bodies which are required to verify the compliance of certain *categories* of equipment. While the Equipment Directive is broad, it does specify many excepted classes of equipment to which it does not apply. These include medical devices, vehicles (when used as a means of transport rather than in an industrial hazardous environment), explosives and unstable chemical compounds, and equipment intended for domestic and non-commercial environments.

The Equipment Directive allows the use of *Harmonised Standards* to comply with the EHSR contained in it. These standards consist of ISO, IEC or European Standards (EN) that have been harmonised for use across the Single Market and which may be used with a presumption of conformity to EU Directives (European Commission, 2016a). The harmonised standards listed by the European Commission have an extremely broad focus, with some dealing with general requirements for compliance while others dealing with a particular type of ignition hazard/hazards. These Harmonised standards need not be self-contained. They can have subsidiary standards that deal with a certain aspect of the main standard.

While Harmonised Standards can be used for complying with the EHSR contained in the Equipment Directive, they are not the only way. Any standard(s) that meets the essential requirements may be used for compliance. This gives significant discretion to manufacturers in ensuring compliance while maintaining a minimum standard on safety.

Non-compliance with the ATEX Directive imposes strict penalties on the firm and on its designers, with the primary consequence being the loss of access to the Single Market and a likely prison sentence and fine for the designer (Department for Business, Energy & Innovation Strategy, 2016). Hence, compliance with ATEX Regulations can be regarded as a market qualifier for many products.

A major challenge while dealing with ATEX-related information is the large number of overlapping standards that can be used for ensuring compliance. Also, standards themselves can be extremely complicated. This is unsurprising given the broad nature of the Directive. In this context, finding and applying standards that apply to the Company is a key challenge.

5.3 ATEX Library Creation

As mentioned above, the steps taken in creating the body of knowledge on ATEX Regulations and Standards were divided into 3 main phases: (1) Planning; (2) Implementation and (3) Consolidation and Continuing Work. This 3-phase approach is described in detail below.

5.3.1 Planning Phase

In the Planning Phase, one of the main objectives was to capture as much background information on ATEX Regulations as possible. The second objective was to collect information on the company's priorities (both commercial and technical) to understand the possible use cases of a body of Knowledge on ATEX. This was done so that the mode of Knowledge Capture as well as its organisation could be tailored to match this and the characteristics of the regulatory regime.

To achieve these objectives, the following steps were carried out in the Planning Phase: (1) Background research and review of all Primary Legislation; (2) Unstructured interviews with Primary Knowledge Capture subject (the Chief Designer) and the Managing Director to assess the Company's Priorities and previous ATEX Projects; (3) Review of documentation of previous ATEX Projects; (4) Formulation of detailed steps regarding Knowledge Capture and its organisation.

The Background Research step was carried out based on Primary Legislation from the European Commission website while the Review of Documentation (Step 3) included selected Secondary Legislation and Standards already compiled by the Company. Assessment reports from Notified bodies on previous projects and articles from Trade Magazines on Hazardous Environments were also included in this step. The review of Primary Legislation was extremely high importance as it was vital to understand the essential characteristics of the European regulatory regime before proceeding with the rest of the project.

From Steps (2) and (3), the main requirements of the company regarding the study were established. They were listed as follows:

a) Capture pre-existing knowledge regarding ATEX effectively.
b) Ensure that the knowledge captured represents a good balance of safety, compliance to legal obligations and cost-effectiveness.
c) Develop and advance this knowledge so that there is comprehensive coverage of current and prospective product portfolio.

d) Organise it into manageable body of knowledge so that it can be shared throughout the engineering department (and if necessary, the wider organisation)
e) Be highly usable so that all personnel can quickly familiarise with it.
f) Have scope for growth as the company's portfolio expands and more knowledge regarding ATEX is generated.

It was also established from steps (2) and (3) that relatively higher emphasis needs to be placed on the legal obligations arising from the Equipment Directive rather than the Workplace Directive as the Company is engaged in the manufacturing of equipment for use in Hazardous Environments rather than as the employer. However, sufficient detail on the Workplace Directive is needed to ensure that the Company can understand Customer Requirements and interpret them appropriately while being in full compliance of both Directives.

From the Planning Phase of the case study, it was clear that the Company's focus was on a KM effort of low complexity, quick turnaround, maximum flexibility and high growth potential to account for future needs. Access to resources was also limited as in-house expertise on ATEX Regulations was found to be case-specific and narrow. All of this was consistent with the evidence found through the literature review regarding the typical characteristics of SMEs. Hence, a solution based on Ontology was ruled out as access to experts on ATEX would be lacking and the required IT solutions would also be resource intensive to develop.

Based on this, it was decided to proceed with a KM effort centred on codification of the ATEX Knowledge to create a body of Knowledge called the "ATEX Library". This Library would contain the procedures and processes currently used by the company to deal with ATEX development programmes along with their rationale, coupled with an array of supporting information. Wherever possible, these procedures and processes would be refined based on new Knowledge acquired through a detailed analysis of new information with a view to be as efficient as possible. The outputs of the KM effort are discussed in detail in sub-section 5.4.

5.3.2 Implementation Phase

The Implementation Phase involved the creation of the ATEX Library based on the priorities listed above.

In the Implementation Phase of the work, the first step was the collection and analysis of Secondary Legislation, which consisted primarily of standards and guidance documents, mainly from the European Commission, and the Health and Safety Executive, UK. Guidance Documents from reputed trade bodies, Notified Bodies and scientific journals were also collected (hereafter referred to as 'associated literature'). As mentioned before, the standards form one of the most essential aspects of the ATEX regime as Directive 2014/34/EU (Equipment Directive) comes under the New Legislative Framework of the EU and as such depends primarily on *Harmonized Standards* to ensure compliance. Also, the quality and relevance of these documents are very high as they are industry-wide standards produced by IEC, ISO and BSI etc. These were collected based on the information received in the Planning Phase and analysed according to their relevance to the Company's product portfolio.

In the next step, the actual Knowledge Capture was carried out. Topics of Interest were identified from the Primary and Secondary Legislation and associated literature, based on the priorities identified in the Planning Phase. This was a complex process with several standards dealing with the same topic in varying degrees of detail. At this stage, several semi-structured interviews were carried out with the Chief Designer to ascertain the level of detail needed in the ATEX Library as it was considered important to find the appropriate balance between usability and comprehensiveness.

Once the level of detail required was established, formulation of Operational Procedures was carried out along with a further collection of Associated Literature to ensure that the procedures had ample supplementary information (including the rationale behind key steps), should the user of the Library decided to review and/or modify them at a later date. This step was carried out based on a thorough analysis of the strict requirements of the Primary and Secondary Legislation regarding the activity under consideration. Further semi-structured interviews were carried out with the Chief Designer to establish the relevance (with respect to the company and its intended product portfolio) and integrity of the Operational Procedures developed and to derive input as to the logical organisation of these procedures in the Library. There was a significant amount of iterative activity between this step and the previous one, when the formulation of procedures often revealed a new Topic of Interest that required the collection of further knowledge and supporting information regarding it.

In the final step of the Implementation Phase, the formulated procedures were organised into four handbooks (Quick Reference, Design, Conformance and Manual Preparation) with appropriate commentary and with an associated library of supporting documents.

5.3.3 Consolidation and Continuous Improvement Phase

In this Phase, intended as an ongoing effort with the Company appointing a Compliance Lead, the ATEX Library is used by the Engineering Team with the Compliance Lead acting as a Single point of contact with regard to all ATEX Compliance efforts, thus facilitating Organisational Learning. In essence, the Compliance Lead must be the first in the Organisation to Internalise the codified Knowledge and act as an enabler for other colleagues to do the same. The Compliance Lead holds the responsibility for ensuring that the changing priorities and demands of the Company and its customers are accurately reflected in the contents of the ATEX Library and that lessons learned from new products and projects are added to it. At the time of writing, the Researcher himself acts as the Compliance Lead within the Firm.

5.4 ATEX Library—Structure and Description

The ATEX Library consists of four handbooks and a collection of associated literature. The four handbooks are:

1. Quick Reference Handbook (QRH)
2. Design Guidelines Handbook
3. Conformance Handbook
4. Manual Preparation Guidelines

Figure 2 (below) shows the components of the ATEX Library and a brief overview of their contents.

The QRH is designed to be the high-level reference document for all matters relating to ATEX. As such, it introduces the major terms and concepts relating to ATEX and gives the scope and limitations of the ATEX Library. It lists the legal obligations of the manufacturer under the ATEX Regime and describes the contents of the ATEX Library in some detail. It also includes a condensed version of information dealt with in detail elsewhere in the ATEX Library.

The Design Guidelines Handbook gives the General Design Principles and the design procedures needed to design an ATEX-rated or ATEX-compliant equipment from scratch. Desirable and undesirable elements with the design are also given.

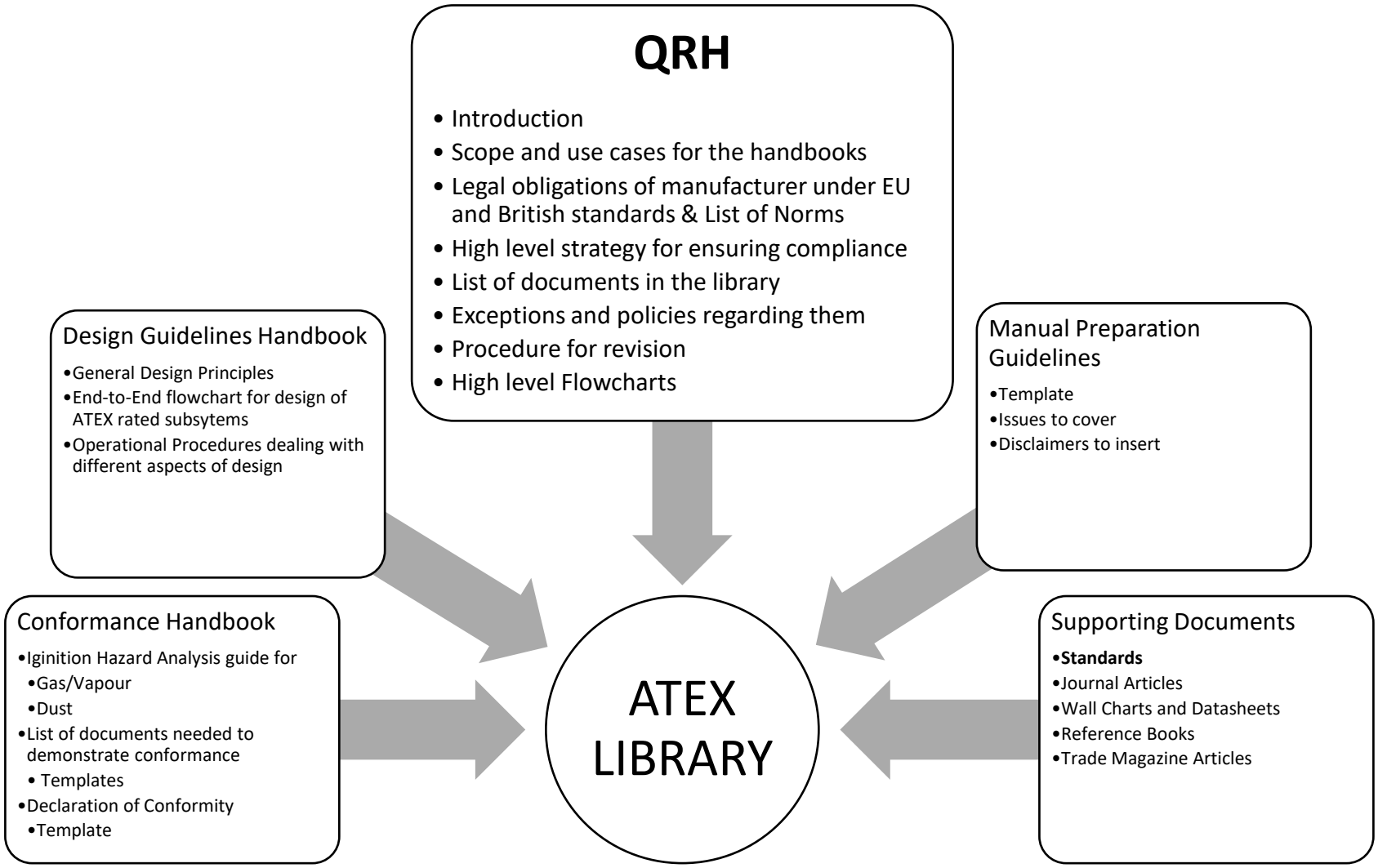

Fig. 2. ATEX Library and its contents.

The Conformance Handbook gives a highly detailed description of the ATEX Regime and serves as *ab initio* guide to newcomers in the field. It also details the procedure to conduct an Ignition Hazard Analysis, the completion of which is critical in ATEX compliance of non-electrical equipment. The document also gives the appropriate templates for all the documentation necessary to demonstrate conformance.

The Manual Preparation Guidelines deal only with the preparation of an Instruction Manual for ATEX-rated and ATEX-compliant equipment and comes with a customisable template for the same.

6. Framework for KM in SME Environments

Based on the successful KM effort described above a new framework for Knowledge Management in manufacturing SMEs can be proposed. This framework is intended to create a body of knowledge that can used as a tool in operational settings. The framework is centred on the codification of knowledge and seeks to be as lightweight and usable as possible. It is also designed to ensure relatively low levels of resource expenditure in its creation and use. The major tenets of the proposed framework are described below.

Collection of Background Information: The logical starting point for the proposed framework is the review of the Primary Legislation(s) that governs the regulatory regime under consideration. At this stage, it is essential to capture the nature and intent of the legislation rather than its strict requirements. It is also important at this stage to accurately understand the Client's needs and priorities and connect it with the requirements of the legislation. While there is likely to be an inherent tension between the two, any irreconcilable issues identified, must be flagged at this stage, and resolved in conjunction with the Client. The fine objectives of the project must be established at this stage, i.e. what the body of knowledge will enable the company to do or not do. While minor modifications might need to be made, these objectives should remain relatively constant for the duration of the KM project, to ensure consistency in terms of the information collected and procedures formulated. In terms of intangible factors, it is vital to establish as close a relationship as possible with all stakeholders and particularly with the Primary Knowledge Capture subject(s).

Initial Planning: Once the background information has been collected it is necessary to decide on the major methods of Knowledge Capture. This requires a careful consideration of the background information collected, with the complexity of the Knowledge to be captured assessed against the resources being made available to the researcher by the Client and/or Third Parties. As the resource allocation might be subject to change due to operational considerations, it is useful to plan for contingencies with regard to the timeline and methods for Knowledge Capture.

Knowledge Capture and Synthesis: In this stage, the chosen method or mix of methods are deployed to effect the collection and organisation of Knowledge both from human experts and from other sources, with heavy emphasis on identifying Topics of Interest within the general ambit of the subject. Collection and segregation of supporting information is also a major priority in the Knowledge Capture stage. The creation of a supporting library of information begins at this stage and is continued for the rest of the KM Project. Portions of high relevance (i.e. those dealing with the Topics of Interest) should be emphasised and noted for reference in the subsequent stages of the KM Project. This is done in light of the commercial, technical and legal priorities found through the parsing of the background information.

Of particular importance at this stage, is the need to connect the Tacit Knowledge collected from the subject expert(s) with those contained in other sources, thereby contextualising it. This Tacit Knowledge includes the rationale for the decisions taken in similar projects to date and knowledge of actions of other firms in a similar environment. Precedents and any justifications used in compliance activities are highly important and these are often available only as Tacit Knowledge from subject experts. This is intended to feed into the next stage.

Formulation of Operational Procedures: In this stage, the previously found Topics of Interest are converted into Activities. It might be necessary to combine or separate the Topics of Interest in order to create a coherent set of Activities for which Operational Procedures can be formulated. These Procedures must be streamlined and comprehensive and they should cover the most frequently carried out actions with extra emphasis on the challenging aspects of it. They should also delineate the extent of legal obligations (if any). They must include

pointers as to where extra information can be found along with commentary on the reliability of the said source.

When there are multiple layers of standards on which a certain Activity is based on, it is necessary to take a top-down approach with frequent cross-referencing between standards (i.e. the standard at the highest level is considered first). This might be an iterative process if there are multiple subsidiary standards covering different aspects of the chosen Activity and if new Topics of Interests are identified during the formulation of procedures.

Usability is of extreme importance and to promote this, the creation of these procedures must have high levels of practitioner involvement (from within the Client firm). Information must be given in very simple terms so that anyone with basic engineering knowledge can quickly grasp them. The formulated procedures must then be organised along major Groupings of Activities to form handbooks based on input from practitioners, among other factors. The creation of the procedures should also consider any future plans to integrate the KM project into Ontologies or databases.

Organisational Learning and Continuous Improvement: In this stage, the results of the codification effort are to be disseminated among key personnel, with an empowered person appointed to take the lead in this. Parallel to this, the procedures must be updated based on the evolving business needs and regulatory circumstance.

Long-term utility of the body of knowledge created using the framework is likely to come from the supporting information that has been collected and organised and from the precedents recorded rather than the Operational Procedures. These serve to equip future decision makers with the necessary information to recreate or modify procedures if and when circumstances change. The Operational Procedures are mainly to streamline day-to-day running of the chosen Activities.

7. Conclusion

As the ATEX regulatory regime represents a highly complicated regulatory environment with dozens of interlinked standards with slightly differing

recommendations, this framework has already served to simplify this complicated regime. Hence, it can be regarded as a valuable tool in dealing with rules and regulations of similar breadth and complexity.

The above framework is particularly appropriate for strictly regulated industries and for manufacturing SMEs that are operating with relatively minimal resources in terms of time, investment, and expertise. As there are a number of such firms trying to enter sectors with strict regulatory environments, this framework should act as a valuable aid in reducing the entry barriers to such sectors for SMEs. It takes a narrow-focus approach towards the regulations with the most important ones being identified from the KM Client's perspective and procedures and processes being formulated to ensure compliance with those.

The narrow-focus approach, while beneficial in reducing resource use at SMEs, can be a limiting factor in the usefulness of the framework where more resources can be made available and especially where significant IT capability exists to create a more automated solution. It also requires the final product to be subject to much more frequent update cycles than would otherwise be necessary. Also, more work remains to be done in developing the framework for different sectors and applications as opposed to its current focus on manufacturing and regulatory compliance.

On balance, it can be summarised that the present KM framework for manufacturing SMEs represents a valuable tool in the hands of skilled personnel, reducing complexity of regulatory regimes and thereby having a major impact on development time and budget of new projects.

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