Sara Tilabi

How to apply technology, knowledge and operations decision models for strategically sustainable resource allocation?

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Julkaisun nimike
Kuinka soveltaa teknologiaan, tietoon ja tuotantoon liittyvän päätöksenteon malleja strategisesti kestävään resurssien allokointiin?

Tiivistelmä

Teknologia tuo kilpailuetua, joka voi auttaa yritystä menestymään kilpailijoitaan paremmin, jos yrityksen teknologiastrategia on yhdenmukainen sen yleisen liiketoimintastrategian kanssa. Koska yritysten resurssit ovat rajalliset ja teknologia on yleensä resursseja vaativa investointi, on sopivan teknologian löytäminen ensisijaista strategisessa päätöksenteossa. Väitöskirja keskittyykin tämän priorisointiongelman ratkaisemiseen.

Väitöstutkimus on yhdistelmä neljästä edellä aihetta tarkastelevasta julkaisusta. Väitöskirjan tuloksena on ehdotus tekniikasta, joka helpottaa teknologiaan ja osaamiseen liittyvää päätöksentekoprosessia toiminnan johtamisessa ottaen huomioon myös kilpailuedun. Ehdotetussa tekniikassa otetaan huomioon sekä ulkoiset tekijät (kuten tuotteen elinkaari) että sisäiset tekijät (esimerkiksi yritysten resurssit), jotka vaikuttavat teknologiapäätöksiin. Tutkimuksessa tarkastellaan kolmea erityyppistä teknologiaa yrityksissä. Ne perustuvat tuotteen elinkaaren eri vaiheisiin: perusteknologia, ydinteknologia ja keihäänkärkiteknologia. Tämä tutkimus soveltaa hiekkakakun nimellä tunnettua pyramidimallia teknologian kehittämiseen ja investointeihin.
Väitöskirja laajentaa aiempaa tietämystä resurssipohjaisesta tarkastelusta, kilpailuedusta ja hiekkakakkumallista, jotka luovat perustan kaikille väitöskirjan tutkimuksille. Väitöskirjan tulokset auttavat johtajia seuraavilla alueilla: (1) investoitavan teknologian löytäminen (2) teknologian ja vaadittavan osaamisen ostopäätös (3) yritysten kilpailuetuihin liittyvien mahdollisten kehitysalueiden löytäminen (4) sen arvioiminen, millaisia mahdollisuuksia edistyneellä teknologialla on tuottaa kilpailuetua ja muuttaa kilpailun sääntöjä.

Asiasanat
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How to apply technology, knowledge and operations decision models for strategically sustainable resource allocation?

Abstract

Technology is a primary source of competitive advantage that can help a firm to outperform its competitors if the firm's technology strategy is aligned with its overall business strategy. Because firms' resources are limited and technology is usually a resource-intensive investment, finding suitable technology in which to invest is of paramount concern to strategists. This doctoral thesis focuses on tackling this prioritization problem.

This dissertation is the combination of four publications that examine the topic above. The outcome of this dissertation is the proposal of a technique that facilitates the technology and knowledge decision-making process in operations management, with consideration given to the notion of competitive advantage. The proposed technique considers both external factors (e.g., product life cycle) and internal factors (e.g., firms' resources) that affect technology decisions. The research considers three types of technology in firms based on different phases of the product life cycle: basic, core and spearhead. This research applies the sand cone approach to technology development and investment.

This dissertation extends existing knowledge of the resource-based view, competitive advantage and the sand cone model, all of which serve as the foundation of the studies featured in the dissertation. The findings of this dissertation help managers in the following areas: (1) to find the right choice of technology in which to invest, (2) to outsource the technology and knowledge requirement, (3) to detect the potential development areas regarding their firms' competitive priorities and (4) to evaluate the potential of advanced technology in bringing competitive advantage and in changing the rules of competition.

Keywords

Technology and knowledge; sustainable competitive advantage; operations management; risk and uncertainties; resource allocation; sand cone model

به راه بادیه رفتن به از نشستن باطل

وگر مراد نیابم به قدر وسع بکوشم

سعدی شیرازی

Going down the path of wasteland is better than sitting idly
Even though I might fail my desire, I would try my best

Saady of Shiraz

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Espoo, June 2020
Sara Tilabi

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Abbreviations

AHP	Analytical Hierarchy Process
AM	Additive Manufacturing
BCFI	Balanced Critical Factor Index
CFI	Critical Factor Index
I/O	Industrial Organization
KBV	Knowledge Based View
MDA	Maximum Deviation
MAPE	Mean Absolute Percentage Error
RBV	Resource Based View
RMSE	Root Mean Square Error
SCA	Sustainable Competitive Advantage
SCFI	Scaled Critical Factor Index
SWTO	Strength Weakness Threat Opportunity
VarC	Variability Coefficient
VRIN	Valuable Rare Imitable Non-substitutable
VRIN/O	Valuable Rare Imitable Non-substitutable Organization

Publications

[1] Tilabi S., Helo P., Takala J., (2018). What is the potential of additive manufacturing in supply chains? a narrative literature review approach. Proceeding of the 27th Annual Conference of the International Association for Management of Technology (IAMOT), Birmingham, UK, Aston University[1].

[2] Takala J., Tilabi S., (2018). Towards developing a decision making tool for technology and knowledge priorities. Management and Production Engineering Review, 9(3), 33–40[1].

[3] Tilabi S., Tasmin R., Takala J., Muazu MH., Aziati N., Shafiee AR., Kaprawi N., Che Rusuli MS., (2019). Assessment of technology factor in companies' business strategy with the use of sense and respond method. Management and Production Engineering Review, 10(3), 81–89[1].

[4] Tilabi S., Tasmin R., Takala J., Palaniappan R., Hamid N.A.A., & Ngadiman Y., (2019). Technology development process and managing uncertainties with sustainable competitive advantage approach. *Acta logistica*, 6(4), 131–140[2].

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1 INTRODUCTION

This chapter presents an overview of the entire dissertation. First, the current research in the field of technology is presented along with a research gap in the existing literature; second, research objectives and questions are articulated; and last, the structure of the study is described.

1.1 Overview of the current research and the research gaps

Technology is a multidisciplinary concept, and the literature on the subject spans many different fields. Porter (1985) studies the concept of technology in the context of competitive advantage and mentions that technology is not important for its own sake; instead, it is important if it can help firms to gain and sustain a competitive advantage. Antoniou and Ansoff (2004) studied technology in the context of strategy, and they assert that the management of technology is the responsibility of general managers and technicians. Further, the authors maintain that the main problem in decision-making processes involving technology is the result of different perceptions of technology. Antoniou and Ansoff emphasise the correct amount of investment in technology, which is vital for innovation, though excessive innovation would simultaneously pose a risk. Technology also increases the risk of "profitless prosperity", in which the rate of launching new products is too frequent to provide a satisfactory return on investment (Ansoff, 1980). Therefore, determining the optimal amount of investment in technology is always a paramount concern for strategists. Two different factors influence this delicate equation: external and internal variables. External variables include product life cycle, technology life cycle, technological progress and industry competitive dynamics, while internal factors comprise firm resources, organizational structure, leadership roles and power centres. Leadership roles determine companies' positions in the market in terms of technology; a company could be a leader, a follower or an imitator. Likewise, power centres determine the department, e.g., marketing, production, research and development, or general manager, within the firm that oversees technology development. Understanding and considering both internal and external factors will lead to the best choice of investment in technology. In order to reach this goal, managers should consider the following steps: first, they should forecast future technological needs; second, they should evaluate their firms' current technological requirements; third, they should determine their firms' potential future gaps in technology; and last, they should act to fill these gaps and technological development (Antoniou & Ansoff, 2004).

Some literature addresses the role of technology strategy in managing technology and firms' competitiveness (Walsh & Linton, 2011). The goal of technology strategy is to determine effective investment in technology towards achieving sustainable competitive advantages (Pires & Aisbett, 2003). According to Teece and Chesbrough (2002) technology strategy should consider all scenarios for future technology and guarantee technological control (Teece & Chesbrough, 2002). Therefore, technology decisions are business decisions (Maidique & Patch, 1982). Skinner (1982) emphasised that a company's technology strategy is addressing its technological weakness, and its strength is linked to company's business strategy. Successful technology strategy planning consists of a four-step process involving assessment of the present technology situation, development of a technology portfolio, integration of business and technology strategy, and determination of priorities for technology investment. Pappas (1984) also emphasised the consideration of both external and internal factors in the assessment process of firms' technology situations. Alignment of external and internal factors in planning a company's business strategy and methodology is not unique to Pappas; Katz, du Preez, and Louw (2016) make a similar recommendation. In his study, Pappas proposed a 2×2 matrix in which technology importance and relative technology position constitute the vertical and horizontal axes, respectively. This is depicted in Figure 1:

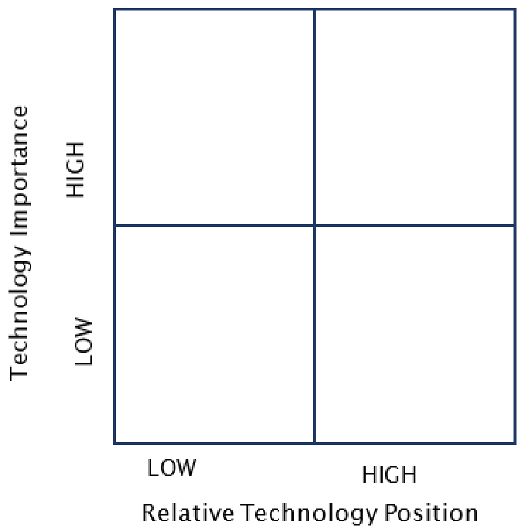

Figure 1. Technology profile development (adapted from Pappas , 1984)

In the above figure, "technology importance" indicates the relative importance that a particular technology has in a specific industry. Likewise, "relative technology position" pertains to a firm's willingness to invest in a specific technology, and this standard can be determined by evaluating the gap between current and future technology requirements. In the above matrix, the upper left quadrant is the proper place for an organization; ranking in this quadrant demonstrates a firm's strength and leadership in the industry where technology is crucial. Technology strategy should thus be consistent with a company' business strategy (Chiesa & Manzini, 1998), which can be mapped in a business portfolio, a 2×2 matrix where attractiveness and competitive position constitute the vertical and horizontal axes, respectively (Figure 2). In other words, if the technology portfolio and business portfolio are not compatible, a firm runs the risk of launching a potentially attractive strategy based on financial data without including the technological requirement to achieve that goal.

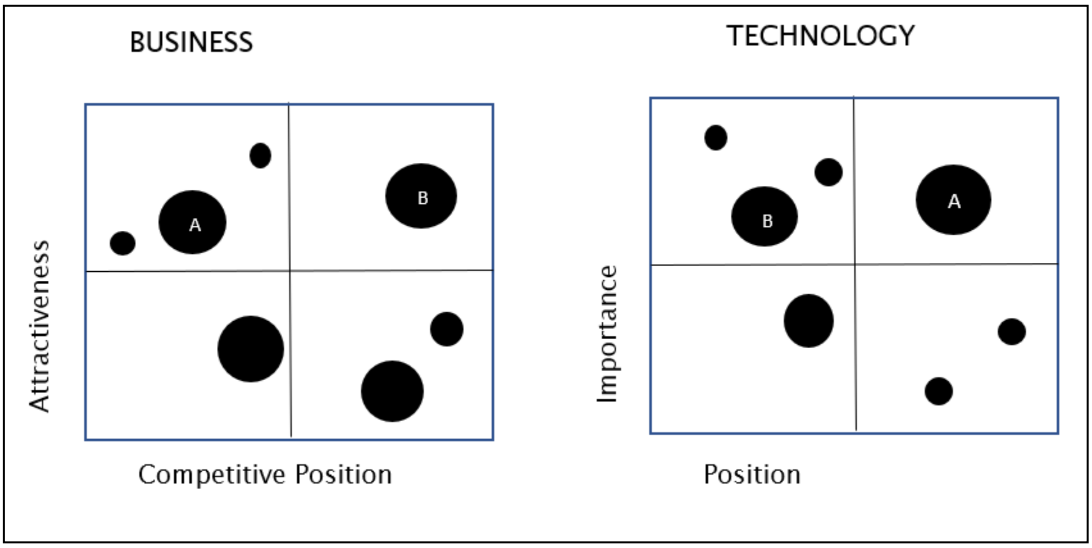

Figure 2. Matching business and technology portfolios (Pappas, 1984)

After matching a technology portfolio with a firm's business strategy, the final stage in planning technology strategy is setting priorities for technology investment. In this step, firms contend with questions such as what kinds of resources are needed to realize business strategic objectives, what are the level and rate of technology investment and what kinds of additional investments and actions are needed to achieve company business goals (Skinner, 1982).

Based on the above discussion, technology and related choices form an integral part of business strategy. Previously, some effort was done to map and support the decision-making process with technology in order to align this process with company business strategy. However, these efforts hardly connected technology choices with firms' competitive positions and the associated limited resources. Additionally, these efforts were mainly based on qualitative analysis. This dissertation endeavours to fill in this gap and proposes a technique that facilitates the technology-related decision-making process considering firms' specific competitive positions. A firm's competitive position is based on both external and internal factors and resources, and therefore, this dissertation chose a resource-based view (RBV) as its theoretical framework.

1.2 Research objectives and questions

The objective of this doctoral dissertation is to propose and validate a technique that facilitates the technology and knowledge decision-making process in operations management, keeping in mind the notion of competitive advantage. Based on this objective, the main research question of the study is thus:

> RQ: What is the role of technology in firms' competitive position?

In order to address this main research question, the following sub-questions are formulated:

> RQ1. How could the decision-making models related to technology and knowledge investments be applied for strategically sustainable operations?
>
> RQ2. What is the role of advanced technology in high-tech companies and conventional industries?

1.3 Structure of this dissertation

This dissertation is an operations management thesis. The scope of operations management in this research extends from the role of technology and knowledge to sustainable competitive advantages and resource allocations. This thesis contains two main parts (Table 1), the first part is a summary that comprises five chapters. The first chapter introduces the study, presents both the objective of this study and research questions, and provides the context and structure of the dissertation. The second chapter discusses the theoretical concepts used in this dissertation and explains the analytical models that are used in this study; this chapter serves as the theoretical and analytical foundation for this dissertation. The third chapter explains the philosophical stance of the research and describes the chosen philosophy, research approach and data accumulation for this dissertation. In the fourth chapter, the included articles as well as the contribution of the author are all summarized. Finally, the last chapter analyses the results, answers research questions, presents the theoretical contribution of the thesis, explains the implications and future areas for research and details the limitations of the study.

Table 1. Outline of the dissertation

Part I: Summary	**Chapter 1: Introduction** • Overview of the current research and the research gaps • Research objectives and questions • Structure of this dissertation
	Chapter 2: Theoretical foundation • Strategy as a source of sustainable competitive advantage • Definition of technology and technology's effects • Resource-based view of sustainable competitive advantage • Analytical models used in this study
	Chapter 3: Research methodology • Research paradigm and philosophical stance • Case study • Constructivism and pragmatism as the paradigms of this study • Reliability, validity and ethical aspects of the dissertation
	Chapter 4: Summary of the publications • Contributions of the candidate • Publication 1: A brief summary • Publication 2: A brief summary • Publication 3: A brief summary • Publication 4: A brief summary
	Chapter 5: Findings • Integration of the publications: Answering the research questions • Theoretical contributions • Managerial implication • Limitations and future research
Part II: Research publications	Publication 1: What is the potential of additive manufacturing in supply chains? A narrative literature review approach (Addresses research question 2)
	Publication 2: Towards developing a decision-making tool for technology and knowledge priorities (Addresses research questions 1 and 2)
	Publication 3: Assessment of technology factor in companies' business strategies with the use of sense and respond method (Addresses research question 1)
	Publication 4: Technology development process and managing uncertainties with sustainable competitive advantage approaches (Addresses research question 1)

The second part of this dissertation comprises four scientific publications that address the research questions presented in the first part (Table 2). Publication 1 defines the context of this study. The paper chose 3D printing technology as an advanced technology and, using literature review and current studies, investigates how the choice of technology influences different performance measurements such as cost, customization, lead time and the level of inventory. These performance measurements are connected directly to competitive priorities including cost, quality, time and flexibility. The paper thus illuminates the effect that the choice of technology has on competitive advantage. The first paper investigates the technology effects on firms' supply chain management, an umbrella under which operations management falls, and therefore, any improvement or suggestion regarding technology on the supply chain ultimately has an operational impact (Perez-Franco, Phadnis, Caplice, & Sheffi, 2016). Publication 2 proposes a model of technology prioritization and the choice-based competitive priorities mentioned above. The paper applies the sand cone concept in modelling. Publication 3 extends the model and incorporates it with sense and respond and with resource allocation. Last, Publication 4 develops the model even more by considering the firm's entire development cycle, which is product and process development. In contrast, Publications 2 and 3 consider only the product development curve in the technology investment process.

The analytical and empirical part of this dissertation is based on case studies and literature review. The cases are chosen from different firm sizes: small, medium and large enterprises. In terms of the level of technology applied, the cases are chosen both from high-tech and conventional industries alike and in both Europe and Asia. The latter three publications investigate the technology factor from an operations management and strategy point of view, while the first publication evaluates the effect of 3D technology as an advanced technology on firms' supply chains based on literature review and secondary data. Publication 1 is a peer-reviewed conference paper while the remaining publications are peer-reviewed journal articles. This information is summarized in Table 2.

Table 2. Overview of the articles used in this thesis

Publication	Title	Research theme	Research design	Publication
1	What is the potential of additive manufacturing in supply chains? A narrative literature review approach	Study the effect of 3D printing technology on firms' competitive priorities	Literature review	Proceeding of the 27th Annual Conference of the International Association for Management of Technology (IAMOT), Birmingham, UK, Aston University.
2	Towards developing a decision-making tool for technology and knowledge priorities	Proposing a model for prioritizing technology and knowledge requirement for the firm based on sand cone theory	Case study	Management and Production Engineering Review
3	Assessment of technology factor in companies' business strategy with the use of sense and respond method	Extended modelling and incorporating sense and respond method	Case study (gathering data via sense and respond questionnaire)	Management and Production Engineering Review
4	Technology development process and managing uncertainties with sustainable competitive advantage approach	Extended modelling and expanding the model to both product and process development cycle	Case study (gathering data via sense and respond questionnaire)	Acta logistica – International Scientific Journal about Logistics

2 THEORETICAL FOUNDATION

2.1 Strategy as a source of sustainable competitive advantage

The literature suggests that there is no consensus on the definition of strategy (Buggie, 2001). There are two reasons behind this inconsistency: first, the term “strategy” is multidimensional in nature, and second, the term is situational and pertinent to the industry (Hambrick, 1980). However, scholars agree that strategy is an inseparable part of organizations and helps organizations to react properly to changing environments (Rodriguez Cano, Carrillat, & Jaramillo, 2004). Additionally, scholars agree that firms deal with two levels of strategy: corporate strategy, which entails the choice of a business sector, and business strategy, or how to compete in the chosen business sector (Chaffee, 1985). The focus of this dissertation is the latter strategy.

Chaffee (1985) defined strategy based on three models: linear, adaptive, and interpretive. Based on a linear model, strategy constitutes integrated decisions and plans that help organizations to attain their desired goals. Associated measures regarding this definition of strategy are formal planning, segmentation, market focus and product diversity. In contrast, an adaptive model of strategy focuses mainly on tools, aims to find a balance between risk and opportunities in external environments, and explores internal resources and capabilities in order to seize those opportunities. Measures such as product differentiation, adaptiveness, price, risk taking and integration are associated with the adaptive model, which encompasses three areas of concern: an organization can face an entrepreneurial problem in which the organization struggles to find the target market for its products, the organization must contend with the choice of technology to be used in production or distribution, and an administrative problem that constitutes organizational development and policy processes may arise (Conant, Mokwa, & Varadarajan, 1990). Finally, the interpretive model, which is based on a social construct and assumes that reality is subjective, defines strategy as a metaphor that allows the organization to define itself. These three models are not totally exclusive, and there are similarities among them. This doctoral dissertation mainly follows the adaptive model of strategy and aims to propose a technique that facilitates risk control, resource allocation and wise investments in technology.

Quinn (1978) as one of the scholars who follow the adaptive model of strategy, defines strategy as “the pattern or plan that integrates an organization’s major goals, policies and action sequences into a cohesive whole”. Porter (1996) defines strategy as the “creation of a unique and valuable position involving a different set of activities”, and he believes that strategy is the sum of competitive forces that shape company strategy. The more intense the competition is in an industry, the more profitable that industry is. Porter (1989) further lists five competitive forces: the threat of new entrance, the bargaining power of customers, the bargaining power of suppliers, the threat of substitute products or services, and industry structure. Competitive forces shape company business strategy and guide companies to choose proper positions (Porter, 1989, 2008). In Porter’s definition of strategy, positioning is the key, and he emphasises that a company can win over its competitor only if the company can preserve its position, i.e., sustain its competitive advantage. Business strategies are classified in three main categories: differentiation, overall cost leadership and segmentation. When following a differentiation strategy, a company tries to provide superior products and services to customers; under an overall cost leadership strategy, a company offers its products or services at the lowest price according to process optimisation or economy of scales; and in implementing a segmentation strategy, a company satisfies the whole or some part of the needs of the chosen segment of customers (Berkes & Davidson–Hunt, 2007; Tanwar, 2013). Strategic positioning aims to attain sustainable competitive advantages and determine the best direction for operational effectiveness. This tactic also creates fits among companies’ activities. Porter (1996) argues that business strategy and positioning theory force companies into trade-offs in order to remain competitive. In other words, every positive step forward that a company made would come at a cost (Berkes & Davidson–Hunt, 2007).

Another adaptive model of strategy is Miles and Snow’s typology, in which firms can choose their strategy regarding their market, product, technologies and operations. Based on these authors’ model, there are four different business strategies: prospector, analyser, defender and reactor (Miles & Snow, 1978; Miles, Snow, Meyer, & Coleman, 1978; Snow,1992). Prospectors, also known as designers, try to explore new markets and product opportunities constantly; therefore, their idea of the standard business environment is uncertain and dynamic, and they remain flexible in order to master this turbulent environment. Defenders are the opposite of prospectors. Companies following this strategy perceive the business environment as stable and certain, and therefore, they try to attain maximum efficiency while maximizing stability. Their strength comes from their high degree of centralization and their focus on limited segment of the market. Between these two extreme points, there are analysers, who strike a balance between flexibility and stability. Analysers have a strong ability to imitate prospectors while keeping their operations efficient. Finally, there are reactors, who do not embody any particular strength. In fact, this type lacks a consistent strategy and is not clear on how to respond to environmental changes (Parnell & Wright, 1993).

This dissertation applies Miles and Snow's adaptive typology to Porter's idea of gaining a sustainable competitive advantage, particularly in terms of technology choice, resource allocation and operations optimisation.

2.2 Definition of technology and technology's effects

Since technology is an emerging and transdisciplinary field, the literature on the topic is relatively heterogeneous. Therefore, there are different definitions of technology and its transformation from each disciplinary perspective (Afriyie, 1988). Zhao and Reisman (1992) defined technology based on four disciplines: economics, sociology, anthropology and management. They argued that each discipline exhibits a different perspective towards technology and its transformation based on technology's perceived role and taxonomy.

Economics holds that technology is one of the main requirements for growth and economic development. Adam Smith was the first who comprehensively examined manufacturing technology in 1776, and since then, many scholars have tried to identify the impact of technology on productivity (Zhao & Reisman, 1992). Some economists define technology as generic knowledge and information required to design and produce a given object (Laughlan, 1989). Defining technology as information leads to the conclusion that technology is reusable and reproducible freely for everyone; however, the majority of economists, like Teece (2003) do not consider technology to be a free resource. According to the economic perspective on technology, technology could be either exogenous or endogenous, and each approach towards technology results in different economic models (Findlay, 1978; Krugman, 1979; Grossman & Helpman, 1991; Bilbiie, Ghironi, & Melitz, 2012; Bloom, Draca, & Van Reenen, 2016). There are different classifications of technology based on economists' perspectives: embodied versus disembodied, per Mansfield (1975), or product versus process technology, according to Hall & Johnson (1970). From these perspectives, appropriate technology is defined as the kind of technology that makes possible the production of a chosen product at a price equal to or cheaper than the current global price according to factors such as exchange rates, shortage and opportunity costs, rates of interest and discounts (Robinson, 1979). The World Bank asserts that appropriate technology provides the highest net present value in relation to capital investment (Reddy & Zhao, 1990).

In sociology, technology is distinct from innovation. While innovation is defined as a new idea for production, technology is an instrument that assists in the reduction of uncertainty. Because most new ideas are technology based, some sociologists consider “technology” and “innovation” to be synonyms (Vinet & Zhedanov, 2011). Sociologists focus on social aspects of technology and believe that any development in technology, either at the individual level or the national level, increases knowledge and awareness. Technology could thus be classified as social and natural taxonomies (Zhao & Reisman, 1992). Sociologists have identified six different elements for technology: people, operational experiences, organizations, problem detection, solving mechanisms and required attitudes (Dunning, 1981).

Anthropologists emphasise culture, and they consider technology in the context of cultural evolution (Pfaffenberger, 1992). In anthropology, technology is nothing by itself, but it has meaning when people use it, and its impact on human life is of paramount importance (Mesoudi et al., 2015). Anthropologists define technology as a means of doing things, and therefore, they consider technology a structural system that connects human beings with their environment. Because anthropologists have a concrete understanding of technology and study it individually, the taxonomy of technology, including medical, agricultural, educational, and other forms of technology, in this discipline is functional (Zhao & Reisman, 1992).

In the field of management, technology is a strategic asset (O’Connell & Zimmerman, 1979). According to management theory, technology is one of the stimulators and sources of innovation (Berry & Taggart, 1994; Reik & Lindemann, 2014; Pacione, 2015) Management scholars treat technology as a fount of competitive advantage (Frohman, 1985; Porter, 1985; Fagerberg, 1996 and Pires & Aisbett, 2003). Porter (1985) investigates the impact of technology on firms’ competitive advantage, emphasizing that technology is not important by itself but gains importance if it can help a company to differentiate or reduce cost. He also claims technology is important because it can affect the structure of an industry and define new rules of competition. A firm’s competitive position is based on both external (Porter, 1989) and internal factors, such as resources, and therefore, explaining ther resource-based view (RBV) in the next sub-chapter is crucial.

2.3 Resource-based view of sustainable competitive advantage

While scholars in the field of strategic management have developed the majority of current research on RBV, this view has its roots in economics. Penrose (1953) proposed RBV for the first time, but initially, it was not accepted widely by industrial organization economists (I/O) because the view assumed that firms were heterogeneous within an industry. In contrast, I/O considered heterogeneity temporary and held that homogeneity would ultimately dominate an industry (Kor & Mahoney, 2004). The RBV approach received little attention until Wernerfelt (1984) emphasised the importance and usefulness of analysing a firm according to its resources rather than its products. According to Wernerfelt (1984) ”resources and products are two sides of one coin” because production requires multiple resources while a single resource could be used in multiple products. He defined firms’ resources as tangible and intangible assets, all of which are semi permanently tied to a firm. These assets enable firms to implement strategies that increase the firms’ effectiveness and efficiency. In this definition, efficiency means the number of resources applied to gain organizational goals, and effectiveness means the extent to which an organization achieves its goals (Daft, 2015). There are different classifications of firms’ resources, one of which splits resources into tangible (building, infrastructure, warehouse and capital) and intangible (skills, knowledge and brand name) resources (Amit & Schoemaker, 1993; Barney, Wright, & Ketchen, 2001). Another classification of resources is the four-way division into physical, organizational, financial and human (Barney & Hesterly, 2006; Barney & Hesterly, 2006). Later on Barney (1991) introduced resources as sources of competitive advantage for firms, arguing that previous work on the concept of competitive advantage, like Porter's (1989; 2008) “five forces” model, only explain the attributes related to attractive industries, i.e., industries with greater opportunities and fewer threats. Barney (1991) identified the clear connection between the traditional SWTO (strength, weakness, threat and opportunity) model of strategy and RBV concepts, claiming that internal analysis, or strength and weakness, is in fact the pillar of the RBV model (Figure 3).

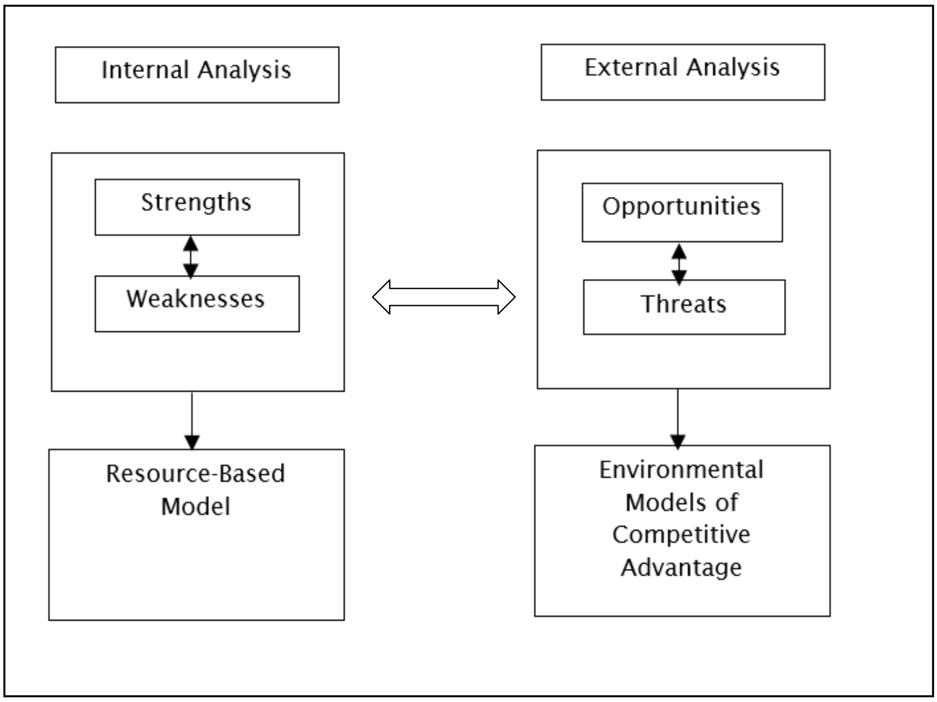

Figure 3. The relationship between SWTO analysis, the RBV model and the environmental model of competitive advantage (Barney, 1991a)

Barney (1991a) assumed two assumptions for the RBV model that other scholars in the field of strategic management had previously neglected: first, the resources are distributed heterogeneously among firms within one industry, and second, the resources are immobile across firms, which guarantees heterogeneity as a long-lasting premise (Wernerfelt, 1984; Rumlet, 1984; Wernerfelt, 1989). Considering this assumption, Barney (1991b) asserted that RBV's core metaphor is Ricardian and claimed that not all of a firm's resources are sources of competitive advantage. In order to be a source of competitive advantage, one resource should have four main characteristics: it should be valuable (V) in a way that helps a firm to absorb opportunities and avoid threats, it should be rare (R) in a way that prevents easy access by current and potential competitors of the firm, it should not be imitable (I) and it should be non-substitutable (N). Additionally, the firm should have an organization (O) that can attract and use these resources, and all these criteria, collectively called VRIN/O, must be met for a resource to be a source of competitive advantages (Barney, 1991a, 1995) These rules are applicable as long as the "role of the game" within an industry remains unchanged. When the environment changes, such as by the diffusion of new technology or the emergence of new markets, the value of the resource can change drastically (Barney, 2002). Peteraf (1993) and Peteraf & Barney (2003) defined four attributes of a resource that can guarantee a firm's competitive position: heterogeneity, *ex post* limits to competition, *ex ante* limits to competition and imperfect mobility. In an RBV of sustainable competitive advantage (SCA), information about the future value of a resource is asymmetrically distributed among firms. If a firm's manager is fortunate or is able to predict the high value of a resource in future better than the firm's rivals can, the manager can provide *ex ante* sources of SCA for the firm. Likewise, *ex post* sources of SCA entail the development of isolating mechanisms that prevent competitors from operating above normal profit (Rumlet, 1984b; Mahoney, 1995). Considering the VRIN/O characteristics of resources, intangible resources such as in-house knowledge, skills and management capabilities are more likely to be source of competitive advantage. Because there is ambiguity in evaluating the impact and benefit of these resources, their imitation and substitution is more difficult (Hitt, Bierman, Shimizu, & Kochhar, 2001; Hitt, Bierman, Uhlenbruck, & Shimizu, 2006).

While Barney (1991a) emphasised the characteristics of VRIN for a resource to be a source of competitive advantage, the literature in strategic management research argues that resources alone are not sufficient; a firm should manage resources effectively in order to gain competitive advantage. In this regard, resource management, which encompasses both tangible and intangible resources in this context (Sirmon, Hitt, & Ireland, 2007), includes structuring a resource portfolio, creating capabilities by bundling resources and implementing proper strategies that are appropriate for those capabilities and resources. Likewise, the research in the field of operations management emphasises selecting, developing and bundling the resources in achieving competitive advantage (Grewal & Slotegraaf, 2007) and provides evidence that the value of each resource is determined by its compatibility and integration with other firms' resources (Jeffers, Muhanna, & Nault, 2008).

Although previous research in this field tried to delineate between firms' resources and capabilities, there was some confusion about these two terms (Leiblein, 2011). For example Barney (2001) used the words "resources" and "capabilities" interchangeably in defining resource-based theory while Amit & Schoemaker (1993) defined "capabilities" as a firm's ability to apply its resources to produce the desired output. Likewise, Makadok (2001) considered capabilities to be non-transferable, specific resources that assist firms in enhancing the productivity of other resources. These two definitions clearly consider capabilities as processes that enable firms to transform input (their resources) into output (their goals). Therefore, though resources and capabilities belong to different bodies of knowledge, they are both core constructs of resource-based theory (Kozlenkova, Samaha, & Palmatier, 2014). In fact, the concept of capability is used in dynamic capabilities research, and the theoretical perspective of the research in this field extends our understanding of RBV. Teece, Pisano, & Shuen (1997) define “dynamic capability” as constructing capabilities based on a firm’s need to gain competitive advantage. Considering RBV and dynamic capability, there may appear to be an overlap between managing resources and capabilities, Sirmon, Hitt, Ireland, & Gilbert (2011) showed that these two concepts complement each other. In this regard, resource management should support managerial action that turns a resource portfolio into capability. However, Sirmon, Hitt, Arregle, & Campbell (2010) suggested the definitions of “resource”, “capability”, “strength” and “weakness” should be clear and precise in order to describe how firms respond to resource shortages and weaknesses.

Although RBV improves the SWTO analysis in business strategy (Malek et al., 2015), there is some criticism that the RBV assumption is applicable in static environments (Shuen, Feiler, & Teece, 2014) and does not include the potential influence of environment (Priem & Butler, 2001). Another critique is related to the applicability of RBV and whether RBV is equally applicable both to large firms with significant market power and to smaller firms with limited resources (Connor, 2002). Kraaijenbrink, Spender, & Groen (2010) reflected Connor’s points and argued that including non-tangible resources in RBV enables small firms and start-ups to surpass their large competitors. An additional applicability-related critique is related to “sustainability–attainability” and dependency within RBV. This argument suggests that only firms with VRIN resources can obtain additional resources; otherwise, rivals could obtain these resources with equal ease. In other words, the resources that a firm needs to guarantee its competitive position are those resources that are hard to obtain in the first place (Miller, 2003).

Another critique is whether RBV is a theory. Based on Bacharach (1989) theory is falsifiable. However, Bromiley & Rau (2016) argued that RBV did not result in many testable hypotheses; what kind of data and analysis would refute RBV as a theory, and what are the dependent and explanatory variables in RBV as a theory? If a firm’s resources constitute an explanatory variable and competitive advantage is a dependent variable, how can these variables be measured? For example, if competitive advantage involves surpassing a rival according to criteria such as cost and time, what is the difference between competitive advantage and performance (Bromiley & Rau, 2016). Hitt, Carnes, & Xu (2016) addressed these critiques and argued that, while some of them are valid, these critiques cannot reduce the usability and applicability of RBV in operations management research.

2.3.1 Resource-based view in operations strategy

Operations management is related to effective management of input towards producing output that can help a firm to attain its corporate goals. These goals include flexibility, quality, speed, product reliability, profit and after-sale services (Ahmed, Montagno, & Firenze, 1996). This operations strategy connects operations with corporate strategy. Implementing proper operations strategies that align operations capabilities can significantly enhance the performance of a firm and its competitive strength. Scholars argue that, if operations are embedded within the firm in a way that is difficult to imitate, a firm will have the support that it requires in order to surpass its rivals (Hayes & Upton, 1998).

Hitt, Xu, & Carnes (2016) claim that the application of RBV can add value to operations strategy research in two different ways. First, because operations are considered a strategic process including competitive positioning of resources and capabilities, RBV complements operations strategy research due to RBV's emphasis on bundling strategic resources to create capabilities that assist firms in gaining competitive advantage. Second, operations strategy encompasses a synergistic process that integrates operations and business (Shah & Ward, 2003), and because RBV likewise focuses on the synchronization of the processes involved in bundling and acquisition, operations strategy facilitates the acquisition and bundling of operations resources (Pilkington & Meredith, 2009).

Gagnon (1999) argues that emphasis on firms' unique operational resources can both increase the firms' profits as well as change the rules of the game. In a similar vein, there are some studies that show how a particular resource, such as transactional and relational technology, information and process activities, and ERP systems, supports firms in gaining competitive advantages (Hendricks, Singhal, & Stratman, 2007; P. F. Johnson, Klassen, Leenders, & Awaysheh, 2007; Vaidyanathan & Devaraj, 2008; Stratman, 2009). Additionally, some research shows that some capabilities, such as alliance capability, diversity and multicultural capabilities, and resource management, are more likely to be VRIN. Therefore, these resources can boost the competitive advantage of a firm (Vivek, Banwet, & Shankar, 2008; Ang & Inkpen, 2008; Hitt, 2011).

2.3.2 Resource-based view in supply chain management

Supply chain management entails the effective and efficient planning, implementing and controlling of the flow of goods, services and information from supplier to end customer. The goal of supply chain management is to create value for customers and increase profitability (Sweeney, Grant, & Mangan, 2018). Since each activity in a supply chain requires particular resources and capabilities, RBV provides a valuable lens for analysing supply chains and examining their activities (Williams, Maull, & Ellis, 2002). However, the challenge here is the incorporation the current resources and capabilities in the supply chain in such a way that it guarantees competitive advantage. To achieve this goal, a firm may decide to look outside its company, i.e., beyond its suppliers and customers. If the firm is successful in realizing how it can apply its resources and capabilities to reduce cost, improve quality and minimize time, the firm could achieve more effective and efficient outcomes. Integrating supplier and customer capabilities into the firm's capabilities produces competitive advantage, which is more difficult for rivals to imitate because the rivals perceive the causal effect as ambiguous (Hitt, Xu, et al., 2016).

In the applicability of RBV to supply chain management, purchasing is a controversial capability. For example, Ramsay (2001) claims that purchasing could be a temporary source of competitive advantage, and if one firm recognizes the value of purchasing, the firm's rival could quickly imitate the firm's purchasing with ease. However, Barney (2012) argues that a supply chain, including purchasing, could be the source of temporary or sustained competitive advantage. There are at least two reasons behind this: first, the valuable purchasing decision is the result of high-quality private knowledge that allows a firm to recognize the value of special resources, and second, purchasing and all supply chain activities are valuable due to their integration with the rest of a firm's activity. Therefore, a rival firm could not possibly imitate the firm's activity (Barney, 2012). Likewise, Greer & Theuri (2012) evaluate the roles of supplier and customer, i.e., supply and demand, in attaining sustainable competitive advantage. Considering this, both supplier and customer could be the sources of competitive advantage especially if they are properly integrated into the system.

2.3.3 Knowledge-based view as an extension of resource-based view

A knowledge-based view (KBV) of firms has emerged from RBV, considering knowledge as the most strategic resource of a firm. Advocates argue that knowledge is an intangible resource that is difficult to imitate, it is socially complex and its casual effect is not clear. KBV assumes that that knowledge can guarantee firms sustainable competitive advantage over the long term (Grant, 1996; Conner & Prahalad, 1996).

In older literature, knowledge is defined as "justified true belief" (Liebeskind, 1996). Based on this definition, knowledge is a kind of information, the validity of which has been proved through empirical evidence. This definition of knowledge considers knowledge to be objective, context independent and universally applicable. However, modern management science does not consider knowledge as truth; modern management science differentiates among data, information and knowledge. In detail, experts in this field refer to data as a sign, to information as the data that is understood and to knowledge as an active concept that includes both information and the impact of information. Clearly, this definition includes human nature in defining and creating knowledge; it considers knowledge subjective. Therefore, knowledge entails a particular attitude and practical application (Kirsimarja & Aino, 2006).

Knowledge management research defines many different classifications of knowledge (Alavi & Leidner, 2001). One of the most useful classifications is based on the criterion of "transferability". Considering RBV, transferability is an important characteristic that is applicable both within firms and between firms, and it both measures the degree at which one kind of knowledge is transferable to another person or organization as well as evaluates the mechanism of transferring knowledge across individuals, time and space. Transferability classifies knowledge based on its nature, i.e., if the knowledge is subjective or objective or if it relates to "knowing how" (also called tacit knowledge) or "knowing about" (also called "explicit knowledge"). In explicit knowledge, communication plays the main role in acquiring and aggregating knowledge, while tacit knowledge is revealed through coding and application. If tacit knowledge is not codified and documented, its transmission between people can be costly, slow and uncertain (Grant, 1996).

Considering the role of knowledge in gaining competitive advantage, the primary goal for any firm should be the creation of new knowledge (Nickerson & Zenger, 2004). The key to creating valuable knowledge, is selecting and solving a particular problem, because new knowledge does not exist by itself. The problem-solving approach in creating new knowledge entails intensive technological development (Fleming & Sorenson, 2004), and technological development is the primary factor influencing competition in highly intensive industries (Brown & Eisenhardt, 1995). Therefore, technology and its development constitute an important factor in a firm's competitive position (Macher, 2006).

2.4 Analytical models used in this study

2.4.1 Analytical hierarchy process (AHP), a tool for complex decision-making problems

The analytical decision-making process is a tool for decision making that Saaty (1980) introduces. AHP allows for the mathematical modelling of complex, real-world, decision-related problems considering qualitative and quantitative criteria and making trade-offs. The basic premise of AHP is that our conception of reality is important, following Descartes' position that the human mind is the first principle of creating knowledge and that what we consider knowledge is primarily our understanding of existence. The mathematics behind AHP is based in matrix algebra and eigenvalues (Saaty, 1990, 2008). Although AHP was initially introduced to solve problems in the field of psychology, this process currently applies to money management across a variety of fields such as business, education, government, health care, supply chains and localization (C. R. Wu, Lin, & Chen, 2007; Deniz & Metin, 2009; Deniz & Metin, 2009; Saracoglu, 2013; C. R. Wu, Chang, Chueh, & Yu, 2013). The application of AHP in different fields has further increased exponentially in recent years (Emrouznejad & Marra, 2017).

In order to use the AHP method, five main steps should be taken: choose the problem and identify the objective, define the criteria and the sub-criteria, determine the constraints and the alternatives in the hierarchy, compare the criteria in pairs, and synthesise the results and choose the proper alternative. The steps constitute the hierarchy model that is presented in Figure 4:

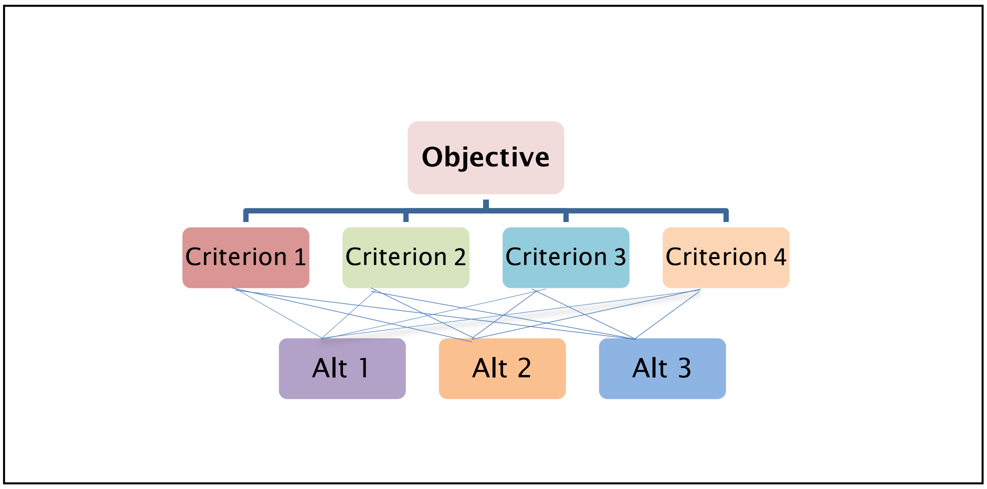

Figure 4. The presentation of AHP (adapted from Wikipedia.org)

The first level of AHP is defining the goal and objective of the problem. The second level presents the main criteria regarding the goal, and the level below represents sub-criteria that pertain to each main criterion. The final level displays alternatives to the defined problem.

When the model is constructed, the next phase is pairwise comparison of criteria A and B. This step is carried out in two stages: first, one criterion must be determined to be of greater importance, and second, that degree must be measured based on a scale from 1 to 9. Table 3 defines each numeral:

Table 3. An explanation of the AHP scale (adapted from Saaty, 1990)

Scale	Definition
1	Equally important
2, 3	Moderately more important
4, 5, 6	Of strong importance
7, 8	Of very strong importance
9	Extremely important

Pairwise comparison provides a means to identify the existing interrelationship among criteria, and logic plays an important role in breaking down an important and complex problem and identifying the interrelationship through deductive process. However, this modelling accepts some small amount of inconsistency in reflecting the real-world situation. Suppose that one respondent decides that A>B and B>C; therefore, logic says A>C. This conclusion is, however, not always applicable to reality. Suppose that there are three football teams: A, B and C. Even if A beat B and B beat C, there is no guarantee that A beats C. AHP allows this type of modelling and inconsistency in its framework. The accepted number for inconsistency is under 0.1, which can also guarantee the reliability of the answers (Saaty, 1988; Saaty & Vargas, 2005).

In this dissertation, we built our model according to the following: the objective is gaining competitive advantages, and the criteria are the competitive priorities, i.e., quality, cost, time and flexibility. The AHP model used in this dissertation is presented in Figure 5:

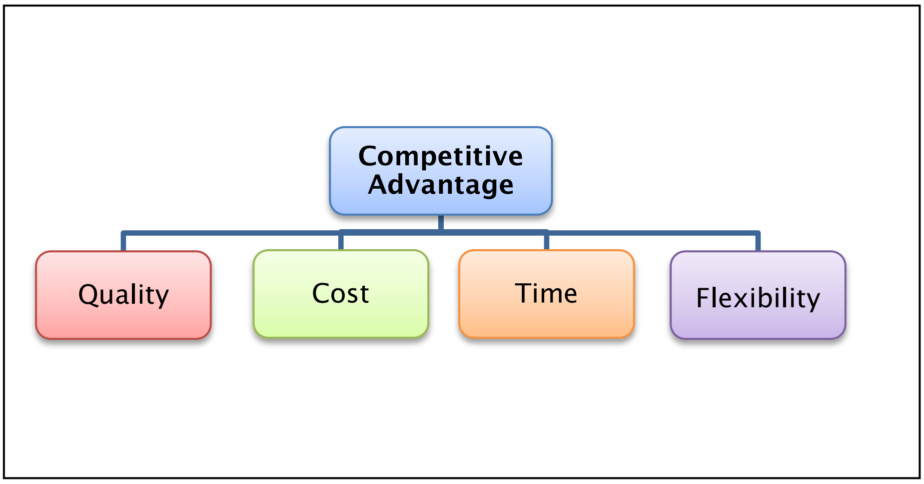

Figure 5. The AHP model used in this study

In order to determine competitive priorities and the weight of criteria, pairwise comparison and the judgment of respondent are added in the Expert Choice software. In Expert Choice, eigenvalues are calculated, and the software provides two important results: consistency ratio (CR) and the weight of criteria, i.e., priorities. An example of the software results is presented in Figure 6:

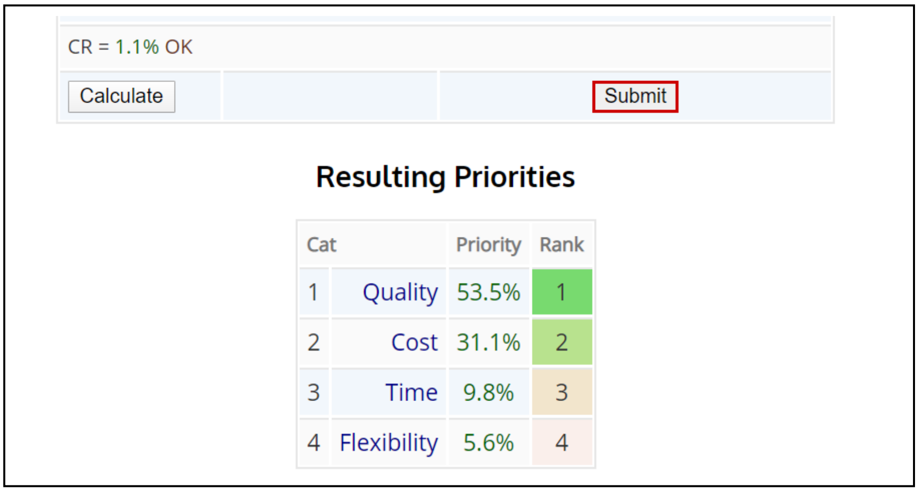

Figure 6. Expert Choice's result of the model used in this dissertation

2.4.2 Manufacturing strategy index

Manufacturing strategy index (MSI) is the model that converts the four competitive priorities listed above into Miles and Snow's (1978) typology of business strategy, which considers four business strategy types: prospector, analyser, defender and reactor. In this model, MSI is calculated according to the weight of quality (Q), cost (C), time (T) and flexibility (F). Therefore, the function $MSI = f_{MSI}(Q, C, T, F)$ is calculated as follows (Takala, Kamdee, Hirvela, & Kyllonen, 2007):

$$1.\ Q' = \frac{Q}{Q + C + T}$$

$$2.\ C' = \frac{C}{Q + C + T}$$

$$3.\ T' = \frac{T}{Q + C + T}$$

$$4.\ F' = \frac{F}{Q + C + T + F}$$

The weights of these criteria can be calculated using the results of AHP (described in the previous section) or sense and respond and CFIs calculation, which are explained in the next section. Formulas 1 through 4 are used to normalize the weights. After normalization, the following formula is applied to calculate MSI for each strategy group:

Manufacture strategy for the prospector group:

$$5.\ MSI_p = 1 - \left(1 - Q'^{\frac{1}{3}}\right).(1 - 0.9\ \times T').(1 - 0.9 \times C') \times F'^{\frac{1}{3}}$$

Manufacture strategy index for the analyser group:

$$6.\ MSI_A = 1 - (1 - F') \times (abs \begin{Bmatrix} 0.95 \times Q' - 0.285) \times \\ (0.95 \times T' - 0.285) \times (0.95 \times C' - 0.285 \end{Bmatrix})^{\frac{1}{3}}$$

Manufacture strategy index for the defender group:

$$7.\ MSI_D = 1 - (1 - C'^{\frac{1}{3}}) \times (1 - 0.9\ \times T') \times (1 - 0.9 \times Q') \times F'^{\frac{1}{3}}$$

2.4.3 Sense and respond

Bradley and Nolan (1998) introduce the sense and respond method, which provides a means for developing dynamic business strategies. Having applied the sense and respond method, companies are able to form an image of the future and anticipate customer needs in real time. This approach, which developed in contrast to traditional manufacturing strategy (i.e., make and sell), enables firms to implement more dynamic strategies and react faster and more properly to market change (Bradley, 1998).

Ranta and Takala (2007) developed a tool to apply the sense and respond approach to increasing service quality and customer satisfaction, articulating that service quality is contingent on customers' expectations and experiences; if the experienced quality meets a customer's expectations, the quality is perceived as good. Additionally, competitors' impressions and direction of development should be considered. Based on the above argument, Ranta and Takala created a simple questionnaire to sense customer needs in order to respond to these needs properly. Their questionnaire, a sample of which is presented in Figure 7, is clear, short and easy to answer, which guarantees the reliability of the proposed tool. In addition, providing simple questions motivates more respondents to answer, enhancing the validity of their questionnaire.

	Expectation (1-10)	Experiences (1-10)	Compared with competitor			Direction of development		
			Worse	Same	Better	Worse	Same	Better
Attribute 1								
Attribute 2								

Figure 7. Sample of sense and respond questionnaire (Ranta & Takala, 2007)

Having gathered data from respondents, the next stage is to determine which attributes require development and should be taken into the consideration. This can be done via the calculation of critical factor index (CFI). The initial CFI calculations evolve into BCFI and SCFI (Liu & Takala, 2012). Formulae 8–10 present different CFI calculations.

$$8. CFI = \frac{b^*}{a^*}$$

$$9. BCFI = \frac{b^* \times Performance\ index}{a^*}$$

$$10. SCFI = \frac{C^* \times performance\ index}{a^*}$$

Where:

$$Gap\ index = \left|\frac{Avg(Experience) - Avg(expectation)}{10} - 1\right|$$

$$Direction\ of\ development\ index = \left|\frac{Better\% - Worse\%}{100} - 1\right|$$

$$Importance\ index = \frac{Avg(expectation)}{10}$$

$$a^* = importance\ index \times Gap\ index \times Development\ index$$

$$b^* = \mathrm{Std}(experience) \times \mathrm{Std}(expectation)$$

$$c^* = \sqrt{(\tfrac{1}{n} \times \textstyle\sum_1^n [\mathrm{experience(i)} - 1]^2\ )} \times \sqrt{(\tfrac{1}{n} \times \textstyle\sum_1^n [\mathrm{expectation(i)} - 10]^2\ )}$$

Once the CFI calculations for different attributes are ready, the next step is normalization. In this step, the weight of each competitive priority is calculated through the assignment of each attribute of the sense and respond questionnaire to one of the four competitive priorities (quality, cost, time and flexibility). In order to determine which competitive priority is applicable, one must rely on expert opinion regarding the relativity and share of one criterion to the competitive priorities. Finally, to calculate the weight of each competitive priority, the corresponding numbers for each CFI calculation are added. This weight is used to calculate MSIs based on the formula in section 2-4-2.

The final stage is to calculate SCA indices, which show the deviation between resource allocation and a firm's strategy and can be determined based on different error calculations as follows:

Based on mean absolute percentage error (MAPE):

11. $MAPE = 1 - sum(\frac{|BS-BR|}{BS})$

Based on root mean square error (RMSE):

12. $RMSE = 1 - (\sqrt{sum(\frac{BS-BR}{BS})^2}$

Based on maximum deviation (MDA):

$$13. MDA = 1 - Max(\frac{BS - BR}{BS})$$

In Formula 11-13, BS stands for the calculation of MSI, and BR stands for the calculation of CFIs. The closer that the result is to 1, the more sustainable the resource allocation is. This approach applied later in evaluating business strategy and resource allocation in different industries (Takala, Hirvelä, Liu, & Malindžák, 2007; Si, Takala, & Liu, 2009; Si, Liu, Takala, & Sun, 2010; Takala, Shylina, & Tilabi, 2014; Tasmin et al., 2016).

2.4.4 The sand cone model for technology choices

In trade-off theory, manufacturing systems and executive managers have to inevitably compromise their competitive priorities and choices in order to use their limited resources well (Leong, 2000), and they must carefully consider the management of general capabilities, i.e., cost, quality, dependability and flexibility (Hill, 1993). Schmenner and Swink (1998) argue that improving one capability is possible, but only at the cost of other capabilities. For example, if a company chooses to improve the quality of its production, and if this proves successful, the company's cost-efficiently or flexibility would be decreased. In other words, a company or business sector can not do well in more than one capability which is called trade-offs and limit what business sector can offer (Berkes & Davidson–Hunt, 2007). Two separate studies (Ferdows, Miller, Nakane, & Vollmann, 1986; De Meyer, Nakane, Miller, & Ferdows, 1989) have questioned this point of view, which prevails in business strategy. Having studied well-performing manufacturing units (in the absence of slacks) in North America and Europe between 1985 and 1987, the authors of both of the above studies realized that the number of companies that improved in more than one capability was significant. Another important finding from these studies was that the development of different capabilities is not symmetrical. For example, while the improvement of quality ultimately leads to enhanced cost efficiency and improves flexibility for Japanese companies, the reverse is not correct (Ferdows & De Meyer, 1990). Therefore, the authors conclude that, in contrast to trade-off theory, competitive capabilities are cumulative in some cases. In their theory of competitive advantage, Ferdows and De Meyer (1990) accept that cost efficiency is the ultimate goal of any manufacturing sector, but in order to achieve this goal, companies should reach a certain level of quality. Only afterwards can companies seek to improve dependability, speed and cost. The sand cone model, which details the development of competitive capabilities, implies that improvements in cost require exponential effort in the improvement of quality. This model is depicted in Figure 8 (Ferdows & De Meyer, 1990):

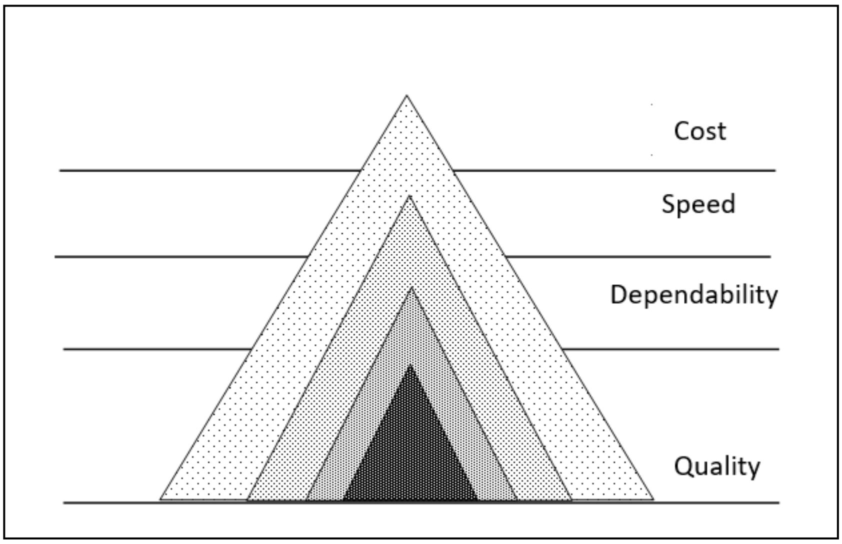

Figure 8. Sand cone model for manufacturing capabilities (adapted from Ferdows & De Meyer, 1990)

In the sand cone model, the sand represents resources and management effort. Based on the figure above, to improve competitive priorities, companies must first create a stable function: quality. Pouring more sand (more resources and more effort on the part of management) into the company enlarges the quality foundation and improves the dependability of the company's operations. By pouring even more sand and investing more resources, the company is able to expand the sand cone in size, indicating a simultaneous improvement in all capabilities (Ferdows & De Meyer, 1990).

Since the introduction of sand cone theory, this model has been applied successfully to other scopes. For example, the process of knowledge management for libraries has proved the suitability of the model, replacing the four typical criteria with knowledge creation, knowledge acquisition, knowledge capture and knowledge sharing (Che Rusuli, Tasmin, & Takala, 2012). Leskinen and Takala (2005) applied this concept in managing the success path for a Finnish ice hockey team. In their study, they show that management constitutes the basal sand, and the supplementary layers of sand represented people, resources and processes. The sand cone concept has also been applied to the development of multi-focus strategies for the Finnish Air Force: flight safety is located at the heart (main layer) of the Finnish Air Force's strategy towards success. Other capabilities (e.g., high-quality personnel, know-how and work environment; technology; partnership;

intensive training; social responsibility and quality) are inserted in the upper layers (Takala, Leskinen, Sivusuo, Hirvelä, & Kekäle, 2006).

In this dissertation, the concept of cumulative capabilities in the sand cone model is applied according to technology types, which can be defined based on their conformance to the product life cycle curve. In this context, there are three types of technology: spearhead technology, core technology and basic technology. Spearhead technology entails the initial stage of a product's life cycle, also called the launching phase. In this stage, the product is still in the trial phase and is not yet commercialized. Companies apply core technology to the growth phase, in which the introduction of a new product succeeds in the market and its company commercializes it and tries to maximize its benefit. In fact, core technology can constitute the main source of revenue for a firm. Finally, basic technology comes in the maturity phase of a product's life cycle, at which point the manufacturing firm has maximized its profit from the product and estimates that the demand of the object ultimately decreases to zero. In this phase, the company is ready to outsource production, and the related industry focuses on new ventures, maximizing its revenue or minimizing its loss (Harrigan & Porter, 1989). The three types of technology and their correspondence to a product's life cycle are illustrated in Figure 9.

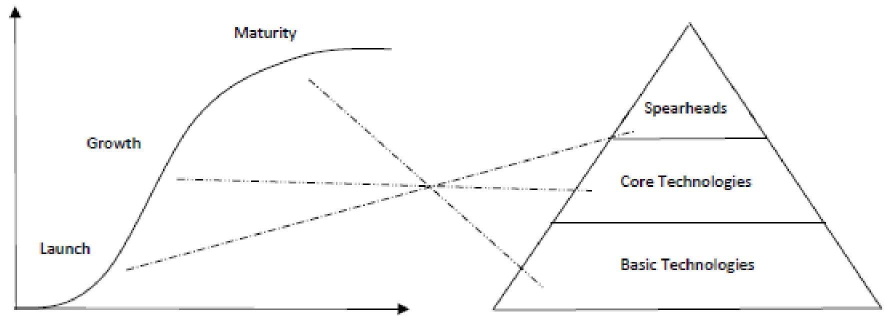

Figure 9. Technology types according to product life cycle (Tuominen, Rinta-Knuuttila, Takala, & Kekäle, 2003)

The notion of technology types and sand cone theory are implemented successfully in supporting the decision-making process related to renovation investment of a local Finnish energy provider (Takala et al., 2016). In that study, AHP (Saaty, 1988) is applied to determine the weight of different criteria and to insert those criteria into different layers of the sand cone model. Considering the goal of renovation investment in the energy distribution system (reducing uncertainty and increasing the reliability of the system), in the next step, the research tries to determine the right type of technology (basic, core, spearhead) in which to invest in order to reach this goal. The method of judgment incorporated in the research is the variability coefficient (VarC), which can be calculated as follows:

$$14. VarC_{C1,C2,C3,C4} = \sqrt{\sum\nolimits_{\substack{C1,(C2,C3,C4) \\ i=B,C\ SH}} \left(\frac{std_i}{mean_i}\right)^2}$$

In the above, *C1*, *C2*, *C3* and *C4* are different defined divisions in the studied case. Based on above formula, the VarC is calculated for all divisions (C_i) of each technology type. In the final stage, to determine which department requires a greater budget for renovation investment, total uncertainty caused by different types of technology is calculated for each department as follows:

$$15. Risk\ related\ to\ technology\ and\ knowlege_{Dep\ A,B,C} = \sqrt{\sum\nolimits_{i=C1,C2,C3,C4} VarC_i^2}$$

Finally, the department that has the highest amount of uncertainty receives the highest renovation budget. In this regard, the company believes in investing more in the least certain department, and addressing this problem could increase the total reliability of the system (Takala et al., 2016).

In this doctoral dissertation, the sand cone model is implemented for different types of technology, and the AHP method is applied to determine competitive priorities. In Publication 2, respondents were supposed to detect the share of each technology type (basic, core and spearhead) regarding the four competitive priorities (quality, cost, time and flexibility) in such a way that the sum of all technology shares for each competitive priority would equal 100% (Takala & Tilabi, 2018). In Publications 3 and 4, respondents were asked to detect the share of different technologies according to different criteria provided in a sense and respond questionnaire in such a way that the sum of all technology shares for each criterion would equal 100% (Tilabi, Tasmin, Takala, Muazu, et al., 2019; Tilabi, Tasmin, Takala, Palaniappan, et al., 2019). In the next stage, to detect the causes of uncertainties in different layers of the sand cone model, the VarC is used for each technology type and is calculated as follows:

$$16. Coef.Var_{Basic} = \frac{Standard\ Deviation_{Basic}}{Average_{Basic}}$$

$$17. Coef.Var_{Core} = \frac{Standard\ Deviation_{Core}}{Average_{Core}}$$

$$18. Coef.Var_{Spear\ Head} = \frac{Standard\ Deviation_{Spear\ Head}}{Average_{Spear\ Head}}$$

Finally, to evaluate the total risk of technology and the risk associated with each type of technology as related to the competitive priorities, the following formula is used:

19.

$$\begin{cases} Total \quad \underset{c_1,c_2,c_3,c_4}{TK\ risk}\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\left(\sum_{b_1,c_1,sh} Coef.Var_i\right)^2\right]^2} \\ Partial \quad \begin{cases} \underset{c_1,c_2,c_3,c_4}{TK\ risk}\ Basic\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\sum_b \left(\frac{std_i}{mean_i}\right)^2\right]^2} \\ \underset{c_1,c_2,c_3,c_4}{TK\ risk}\ Core\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\sum_{core} \left(\frac{std_i}{mean_i}\right)^2\right]^2} \\ \underset{c_1,c_2,c_3,c_4}{TK\ risk}\ Sh\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\sum_{sh} \left(\frac{std_i}{mean_i}\right)^2\right]^2} \end{cases} \end{cases}$$

In the above formula, C_i stands for the four competitive priorities.

Once the total and partial risk associated with each technology is calculated, the SCA indices are calculated using the following formulae:

$$20. Total\ Risk(Geom) = [(1 - SCA)TKrisk]^{\frac{1}{2}}$$

$$21. Total\ SCA\ risk\ level = 1 - Total\ Risk(Geom)$$

3 RESEARCH METHODOLOGY

Research is a systematic investigation to interpret collected data and to understand a particular phenomenon or to answer specific questions (Mackenzie & Knipe, 2006). The aim of any research is to develop knowledge in the chosen field. In order to obtain this goal, the researcher sought to follow the research process that is depicted in Figure 10 (Grunert, Khalifa, & Gmelin, 2004). As the picture shows, the research process has an onion shape. Therefore, before the researcher commences the tasks in the central point, which are data gathering and analysis, several preliminary, external layers should be peeled off (Mayer, 2015). Generally, the research process (i.e., methodology) explains the following issues regarding the research: philosophies and research paradigms, research approaches (deductive, inductive and abductive), methods (qualitative, quantitative and mixed method) and the reasons behind choosing particular tools, such as surveys, case studies, questionnaires, and interviews.

In this section of the dissertation, research methodology is briefly explained in general, and then, the research methodology for both this dissertation and each publication is described and justified.

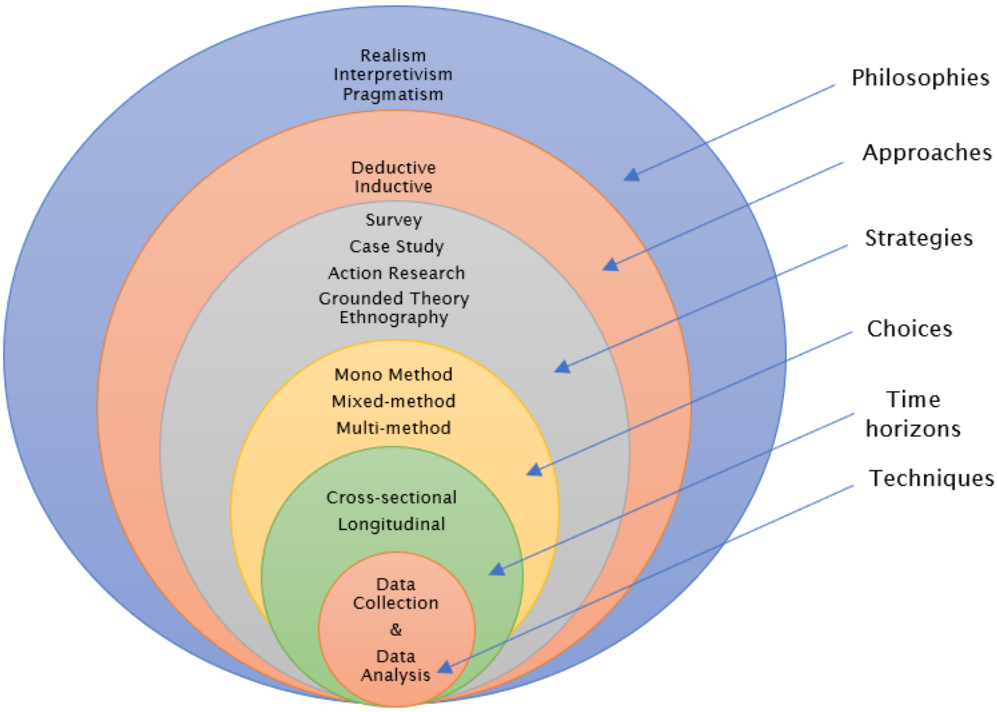

Figure 10. The research onion (adapted from Saunders, Lewis and Thornhill, 2009)

3.1 Research paradigm and philosophical stance

Kuhn and Hawkins (1963) define a paradigm as an accepted model or pattern; in greater detail, research paradigms are a set of practices and common beliefs supported by theories that guide a researcher to understand, investigate and address research problems (Cohen, Manion, & Morrison, 2017). The research paradigm describes the way that researchers investigate and interpret relevant knowledge (Mackenzie & Knipe, 2006), and this paradigm is important because it results in the researchers' philosophical stance and choice of research method (Guba & Yvonna, 1994).

Paradigms vary based on epistemology and ontology. Epistemology answers the question of how knowledge and reality are understood and determines the researcher's opinion regarding what constitutes acceptable knowledge (Crotty, 1998; Neighbors, Larimer, & Lewis, 2004). Ontology, in turn, encompasses acceptable knowledge and beliefs, both objective and subjective, about the nature of reality. In the literature, there are different classifications of research paradigms, but in general, the most common research paradigms are these: positivism, post-positivism, critical theory, pragmatism and constructivism (Guba & Yvonna, 1994; Cotten, Tashakkori, & Teddlie, 1999; Caldas, 2003; Morgan, 2007; Creswell & Tashakkori, 2007).

These paradigms vary mainly based on their point of view towards science, from purely objective to purely subjective or, respectively, from quantitative to qualitative approaches. Positivist philosophies articulate assumptions regarding quantitative approaches and believe that social observations constitute physical phenomena, and therefore, the observer is separate from the entities that are the subject of observation. In that regard, quantitative purists believe that science is objective in nature, meaning that science is time and context free (Nagel, 1998). These purists believe that researchers should omit their biases, remain emotionally detached from the object of their studies and justify their stated hypotheses empirically (Cotten et al., 1999). On the other hand, constructivists and interpretivists believe that there are multiple constructed realities that are neither time nor context-free. They believe instead that it is not possible to fully detach cause from effect. Likewise, we cannot differentiate the knower from the known since what known is highly dependent on the subjective knower. This group prefers detailed, rich, descriptive analysis of the studied case, an analysis called qualitative analysis (Marshall, 1990; Guba & Yvonna, 1994). These two types of purist approaches lead to two different research cultures: one is based on deep and rich observational data, and the other is based on hard and generalizable data (Sieber, 1973). Purists believe that qualitative and quantitative are two fundamentally different approaches, that they are based on different epistemological and ontological assumptions, and therefore, that they are incompatible with each other (Bryman, 2004; Brannen, 2005). On the other hand, some literature proposes mixing these two extremes and applying what is called mixed methodology (Tashakkori & Creswell, 2007), multi-strategy (Bergman, 2014) or multi-method (Creswel, 2008). These authors believe that mixed methodology provides many advantages and helps to minimize the disadvantages of both qualitative and quantitative approaches in research studies. If we consider a continuum with qualitative research at one extreme point and quantitative research at the other extreme, mixed methods covers a sizable area set between these two points (R. B. Johnson & Onwuegbuzie, 2004). Mixed methods research is suitable for a researcher who prefers methodologies that are closer to what is done and used in practice. In this regard, mixed methods qualifies as a third legitimate approach to research and is in the unique position of bridging the gap between qualitative and quantitative research (Onwuegbuzie & Leech, 2006).

Although different literature describes different stances for conducting mixed methods, there is an agreement that the research approach associated with mixed methods is pragmatism, which offers an alternative approach to traditional approaches such as positivism, post-positivism and constructivism. Pragmatists try to interpret each notion by tracing its relative practical consequences. The goal of the pragmatic approach is to mix research approaches in order to provide the opportunity to answer important research questions (Feilzer, 2010). In other words, this approach helps researchers to understand how research approaches could be mixed in a meaningful way (Hoshmand, 2003).

Having chosen the research philosophy, the next layer is to choose the reasoning approach. There are three reasoning approaches: inductive, deductive and abductive. An inductive approach applies empirical material to conducting research, resulting in theory, while the deductive approach formulates hypotheses based on theory and then uses empirical material to examine these hypotheses, proving useful for theory testing in the real world (Grunert et al., 2004). An abductive approach mixes both the inductive and deductive approaches (Dubois & Gadde, 2002). The following table summarizes the differences among research paradigms and methods.

Table 4. Summary of research methods

	Quantitative	Mixed methods	Qualitative
Philosophical assumption	Positivism/post-positivism	Pragmatism	Constructivism, interpretivism, critical theory
Scientific beliefs	Knowledge is objective in nature	Knowledge could both subjective and objective	Knowledge is subjective in nature
Data	Quantitative, i.e., numerical variables data mainly from surveys, structured interviews, datasets etc.	Could be both numerical and verbal data obtained in either a quantitative or qualitative way	Text, verbal and qualitative data obtained from unstructured interviews, observations, etc.
Data analysis method	Statistical analysis	Mixture of text, theme and statistical analysis	Text, image and theme analysis
Scientific reasoning	Top-down, i.e., deductive	Deductive or inductive	Bottom-up, i.e., inductive
Research objective	Theory testing, description and prediction	Theory testing and building	Theory building and exploration

3.2 Case study

A case study is often used to answer “how”, “what” and “why” questions, and it aims to investigate the characteristic of a real-life case (C. B. Meyer, 2001). A case study is useful when an in-depth study of the chosen phenomenon is required. Different data collection methods, such as observation, questionnaires and interviews, are applied for case study research. However, the combination of qualitative and quantitative data leads to better results. Case studies can include single or multiple case studies, but the generalization of a single case study might nevertheless be limited (McCorcle & Bell, 1986; Neighbors et al., 2004 Lichtenstein et al., 2006). Besides the limitations of generalization, the case study method suffers from the unexpected conditions of the chosen case during the process (Dubois & Gadde, 2002). However, choosing the appropriate approach to the research process of the case study helps to overcome these challenges. In order to achieve this goal, one main step is to follow a common approach for all the case companies (Chaiklin, 1991; Lichtenstein et al., 2006).

This dissertation contains four case studies from three different industries in different geographical positions and in different sizes (small, medium and big enterprises).

3.3 Constructivism and pragmatism as the paradigms of this study

This dissertation is based on a paradigm based in constructivism and pragmatism. The goal of a constructive research approach is to solve real-life problems while producing theoretical contributions. Therefore, this approach plays a significant role in filling the gap between theory and practice (Lehtiranta, Junnonen, Kärnä, & Pekuri, 2015). Kasanen and Lukka (1993) articulate that the constructive approach aims to produce new knowledge as a normative application, meaning that the result of this kind of research should guide how a researcher should act in a particular situation to achieve the desired result. Constructive research starts with finding a practical question; afterwards, the researcher starts to solve the problem, propose a solution and create knowledge. Therefore, the process of constructive research is as follows (Kasanen & Lukka, 1993).

1. Find a practically relevant problem that is also valuable to research
2. Gather comprehensive knowledge and understanding about the topic
3. Innovate meaning to construct an idea for a solution
4. Present that the solution works
5. Demonstrate the connection to research and the theoretical contribution of the proposed solution
6. Determine the scope of applicability of the solution

The choice of constructivism for this research is related to the chosen research questions: “how” and “what”. The main goal of this research is to model technology requirements for firms in such a way that guarantees the firms’ competitive advantages. The researcher follows the above steps, applying case studies and an inductive approach to build the model, which helps to construct innovative solutions. Finally, the researcher applies an abductive approach to answer research questions and synthesise the results. However, because the chosen method is a case study, the researcher applies quantitative (numerical) data. From this point of view, mixed method is the ideal method to conduct case studies for this research. The choice of the case study for this research is harmonious with the constructive research approach. Because the obtained theory based on case studies is empirically valid (Eisenhardt, 1989).

The choice of a pragmatic approach for this dissertation is because the topics of this thesis are operations strategy and management. Operations management is an applied discipline and not a pure science; therefore, the research in this field should be usable knowledge for real-world applications. In other words, operations strategy research should identify and solve management problems, propose and implement solutions in practice and improve the operational functions of firms. Operations management is thus a *functional discipline* (Meredith, Raturi, Amoako-Gyampah, & Kaplan, 1989), and this topic is harmonious with the inherent assumption of a constructivist approach that has root in pragmatism, meaning that knowledge is determined by its practical consequences (Lehtiranta et al., 2015).

The dissertation consists of four publications addressing different research questions in the field of operations strategy. Table 5 summarizes the research methodology and the sources of data included in this doctoral thesis.

Table 5. Research methodology and data collection

Publication	Research methodology	Method	Data collection
Publication 1: What is the potential of additive manufacturing in supply chains? A narrative literature review approach	Follows the qualitative method and deductive reasoning; evaluates the potential of one advanced technology on operations management according to its effect on supply chain	Comprehensive narrative literature review and proposing a conceptual framework	Data was collected from existing literature on 3D printing technology

Publication	Research methodology	Method	Data collection
Publication 2: Towards developing a decision-making tool for technology and knowledge priorities	Follows mixed methods, inductive reasoning; assesses the role of technology and knowledge in gaining sustainable competitive advantage	New modelling and case application	Required data were collected from two high-tech start-ups.
Publication 3: Assessment of technology factor in companies' business strategy with the use of sense and respond method	Follows mixed methods, inductive reasoning; evaluates the decision related to technology in sustaining firms' competitive advantage	Case application	Required data were collected through a sense and respond questionnaire from medium-size conventional industries
Publication 4: Technology development process and managing uncertainties with sustainable competitive advantage approach	Follows mixed methods, inductive reasoning; evaluates the whole cycle of innovation, i.e., product and process towards firms' competitive positions	New application of the model, extended modelling, case application	Required data were collected through a sense and respond questionnaire from one international conventional enterprise
Final dissertation (assimilated summary of the publications)	The final doctoral thesis is the integrated summary of the above publications following both qualitative and quantitative approaches. It does not have different data but combines the findings and the results of the four papers. From a methodological point of view, the dissertation follows mixed method based on pragmatism and constructivism as its philosophical stance. Finally, the summary is based on an abductive approach implementing both inductive and deductive reasoning.		

3.4 Reliability, validity and ethical aspects of the dissertation

Generally, validity and reliability guarantee trustworthiness of the research and its results. Validity refers to the integrity of the results, and reliability refers to the consistency and accuracy of the research and findings (Alan Bryman & Emma Bell, 2011). Validity could be obtained through three steps: construct validity, internal validity, external validity (Chaiklin, 1991). Construct validity is related to the degree of generalization from measurement questions to studied construct. To enhance the construct validity of this research, the researcher conducted different case studies in order to answer the research questions, choosing cases from both high-tech and conventional industries and from companies of different sizes (i.e., small, medium and big operations, both local and international) in different countries.

Internal validity refers to the causal relationship in which a certain condition results in others. Publications 3 and 4 applied sense and respond questionnaires including technology and knowledge part, and when delivering the questionnaires, the author made sure that the respondents understood the questions well and interpreted them according to the author's intention. Additionally, during the sample selection phase for each case, the author attempted to collect equal numbers of respondents to fill out the questionnaires.

External validity refers to the degree of generalization of the results and findings to other contexts. In this dissertation, the author conducted multiple case studies for different articles in order to achieve external validity. In Publication 1 the author used secondary data and multiple examples from different companies around the world to generalize the results of the paper. Additionally, for Publications 2, 3, and 4, the author conducted a weak market test (Fama, 1970; Jensen, 1978) in the form of short interviews in which the obtained results were presented to key informants who were asked to share feedback and opinions about the final results.

Reliability is related to the robustness of the research finding that could be obtained within the consistent questionnaire. In other words, reliability indicates that the same result would be obtained if the study were repeated several times using the same measures and procedures (Chaiklin, 1991). The reliability of this study was achieved through the design of the case study: evidence collected for the study included an extensive review of available literature as well as a critical evaluation of previous studies in the area of technology choices and competitive advantages.

The final dissertation is the sum of four articles that underwent the peer review process and have been published in both international journals and a conference paper, a fact that underscores the strengths and the trustworthiness of these findings and results. Therefore, it is reasonable to claim that the knowledge that is presented in this doctoral thesis is reliable and valid (Timilsina, 2017). The results are also in line with the research ethic that is the crux of reliability and validity in any type of research (Easterby-Smith, Thorpe and Jackson, 2015).

4 SUMMARY OF THE PUBLICATIONS

This chapter summarizes the publications that are included in this dissertation, which consists of three peer-reviewed journal articles and one peer-reviewed conference paper. The publications, their main results and their overall objectives are described briefly. All the journal articles focus on technology and knowledge prioritization, relating the content to sustainable competitive advantages, and the conference paper endeavours to determine the context of the study by demonstrating how choosing a particular type of technology influences competitive priorities. All four publications focus on the topic of technology and its role in gaining competitive advantages. In the three journal articles, the author proposed and tested a model to facilitate the technology decision process with the concept of competitive advantage in mind. The cases are chosen from manufacturing firms of different sizes and across a range of geographic locations in order to provide readers with a broad understanding of the topic and also to generalize the results and findings.

The following section presents a summary of each of the four publications.

4.1 Contributions of the candidate

All of the publications have gone through the double-blind peer review process and have been published by internationally recognized journals and publishers. In Publications 1, 3 and 4, the author is the corresponding author, and in all the publications, the author plays a main role in data analysis and writing the respective paper's introduction, literature review, methodology and conclusions. Co-authors also contributed to these publications. In Publications 2, 3 and 4, Takala made contribution in developing the proposed model as well as commenting on the entire structure of the paper. In Publication 2, while the author is primarily responsible for writing and data analysis, Takala contributes to gathering data and proposing models. In Publications 3 and 4, Roismani contributed by providing data and interpreting the results. In Publication 1, Helo aided in developing the paper as well as both commenting on the entire structure of the paper and providing the technical aspects of technology. In addition to all of the above, the other co-authors made minor contributions to the publications, e.g., by commenting on or interpreting the results. Table 6 below presents the general information contained in the publications.

Table 6. Summary of the publications

Publication	Type	Publisher	Corresponding author	Author's role
Publication 1	Peer-reviewed conference paper	University of Aston	Sara Tilabi	Design the structure of the paper, conduct a deep literature review, propose the framework and write the whole paper
Publication 2	Peer-reviewed journal article	Management and Production Engineering Review	Josu Takala	Analyse the data, design the structure of the research and write the whole paper
Publication 3	Peer-reviewed journal article	Management and Production Engineering Review	Sara Tilabi	Analyse the data, design the structure of the research and research question, and write most of the paper
Publication 4	Peer-reviewed journal article	Acta logistica, International Scientific Journal about Logistics	Sara Tilabi	Analyse the data, design the structure of the research and research question, and write the whole paper

4.2 Publication 1: A brief summary

Paper title: What is the potential of additive manufacturing in supply chains? A narrative literature review approach

Research objectives, findings and contributions

The goal of the paper is to define the context for this dissertation. The paper evaluates the role of additive manufacturing technology, which is an advanced technology, on firms' competitive priorities within supply chain. The paper evaluates this effect in terms of both product and process development. In other words, the paper tries to show how additive manufacturing (AM) as an advanced technology can help business in general, and the manufacturing sector in particular, to sustain a competitive advantage and to achieve a higher performance level in terms of cost, flexibility and other factors. The paper applies narrative approaches, namely, the most common forms of literature reviews in management and engineering science, to present a comprehensive overview of this topic rather than addressing specific research questions (Onwuegbuzie & Frels, 2016). Based on Niaki and Nonino (2017) work, studies on the topic of AM can be clustered into eight main categories from a technical point of view to an environmental and economic point of view. This paper focuses mainly on the class of supply chain management and business configuration and ignores technical aspects regarding material development and design.

In order to assess the effect of AM implementation, the research classifies the whole supply chain into three mutually exclusive, totally inclusive main categories: the supply side, the manufacturing side and the demand side. In terms of the supply side, the deployment of AM reduces complexity, leads to better supplier relationship management and procurement (Oettmeier & Hofmann, 2016) and facilitates the outsourcing process (Berman, 2012; Oettmeier & Hofmann, 2017). The impact of AM on the manufacturing side is significant; AM supports on-demand and localized production, low cost and fast delivery (Khajavi, Partanen, & Holmström, 2014). The deployment of AM also affects companies in terms of product development, product customization, manufacturing flow management and return management (Eyers & Potter, 2015; Oettmeier & Hofmann, 2016). AM supports product and process innovation, and it also improves performance measurements such as order fulfilment rate, lead time and stock-out probability (Khajavi, Partanen, Holmström, & Tuomi, 2015; Khorram Niaki & Nonino, 2017). For the demand side, AM makes the role of demand stronger, helping customers to be a part of coproduction of products and reflecting customers' needs and requirements more precisely in product design and manufacturing (S. Shah, Mattiuzza, Naghi Ganji, & Coutroubis, 2017).

In summary, this paper summarizes all the potential effects of AM as an advanced technology. The paper also shows how AM technology could improve different business performance measurements like time, flexibility and cost in practice. The results of the paper help companies and decision makers to implement AM in their businesses and sustain their competitive advantage. However, the main question here is how and when firms should decide to invest in such an advanced technology. These questions are answered in the next three papers.

4.3 Publication 2: A brief summary

Paper title: Towards developing a decision-making tool for technology and knowledge priorities

Research objectives, findings and contributions

The main intention of the paper is to formulate the problem of optimising the choice of technology with sustainable competitive advantage in mind. The paper applies the proposed method based on the sand cone concept in two high-tech start-ups. The study of the proposed model in high-tech companies, which are companies with significant R&D intensity, is important because it is emphasised frequently that business strategists and policy makers should investigate high-tech companies. The assumption behind this stress is based on the opinion that high-tech status, growth and innovation are positively associated (Daunfeldt, Elert, & Johansson, 2016). Despite the crucial role of small and medium enterprises (SMEs) in countries' economic growth, studies show that only a small fraction of SMEs survive more than five years of operation (Song, Podoynitsyna, Van Der Bij, & Halman, 2008). In order to increase the possibility of success for high-tech SMEs, identification of the success factor is vital. Additionally, it is necessary to find efficient ways to improve overall performance by detecting critical success factors and assigning firms' limited resources to these factors (W. W. Wu, Lee, & Tzeng, 2005). Sadeghi (2018) provides comprehensive success factors of high-tech SMEs, which include technological characteristics such as access to a skilled workforce with technical knowledge, the ability to import equipment and technology, and close collaboration with the academic sector. Previous research also examined the effect of intellectual capital and human capital (i.e., with humanity as the source of innovative activities and technology) on high-tech companies' growth and development (Buenechea-Elberdin, Sáenz, & Kianto, 2017). However, the previous research did not examine any connection between technology priorities or formulation and sustainable competitive advantage concepts for high-tech firms. This research attempts to fill this gap by proposing a model based on the sand cone idea.

In this model, respondents were supposed to detect the share of each of the types of technology (basic, core and spearhead) on each competitive priority (quality, cost, time and flexibility). Next, formulae 16–19 were used to detect the technology that caused the high uncertainties and the collapse of the sand cone. Additionally, in this paper, the AHP method was used for manufacturing priorities to calculate MSIs based on formulae 5–7. Two high-tech case studies were investigated thought the proposed model in this paper.

The first studied case in this paper involved the establishment of a new online transportation company that rents scooters. This start-up offered high-quality and environmentally friendly transportation to customers in the city of Warsaw, Poland. The start-up's business model was as follows: using the app, customer could order and rent a scooter from a station, and afterwards, they could return the scooter to the station or leave it on the way to the station. Customers were charged per minute of the scooter rental, though the first three minutes were free. In order to use a scooter, no certificate was needed; the company offered promotions for long-term contracts, and the capacity of each scooter was two people. The main partners of the rental company were a leasing company, the scooter manufacturers, an advertising company, the local government and an eco-friendly organization. The core idea behind this business was to offer high-quality rental scooters, and in order to achieve this goal, the following technology was required: stations with sun panels and navigation systems. The company's initial competitive priorities were safety, flexibility, availability and cost, however, these priorities changed in importance, and safety and cost became paramount.

Spearhead technology caused highest amount of uncertainty for the company due to the VarC calculation. However, uncertainty and the risk associated with technology type reduced by 25% after implementing an improvement proposal and technology development. While spearhead technology was still the main source of risk after implementing the improvement proposal, this risk faces significant future reduction. The studies also detected the critical attributes for company success; in the future, these attributes will mainly pertain to investments in technology such as security of data and information, information system development and the availability of high-quality and reliable information.

The second studied case in this paper analysed the establishment of an entertainment start-up based on a portable escape room concept. The start-up relied on a portable entertainment truck that people would enter and, in order to exit, solve a mystery. The truck could be used in events such as weddings and birthday parties to provide additional entertainment. The start-up primarily incorporated three types of technology: holographic design, an advertisement channel and a motor vehicle. For this start-up, quality was the main competitive priority. Seven respondents, all from different departments within the start-up, filled in the technology and knowledge requirement questionnaire. As in the first case study, spearhead technology proved to be the main cause of uncertainty based on the VarC calculation. After proposing an improvement plan involving an increase in the number of trucks and deployment of a mobile phone app, the total SCA risk level reduced from 0.48 to 0.37. Still, spearhead technology maintains the highest share of risk and uncertainty among all three types of technology. The research detected the attributes that companies should take into consideration for better performance. As in the first case study, most elements of the improvement proposal (quality and reliability of the information, code of conduct and security of data) were linked to technology development.

The main contribution of the paper is the examination of a technique that assists in the decision among high-tech SMEs to further develop technology and knowledge in order to build a sustainable competitive advantage. Based on the research results, while the effect of risk and uncertainty caused by technology and knowledge on SCA cannot be neglected, this risk is not significant for start-ups.

4.4 Publication 3: A brief summary

Paper title: Assessment of technology factor in companies' business strategy with the use of sense and respond method

Research objectives, findings and contributions

This paper extended the proposed model in Publication 2. The main goal of the paper was to propose a more comprehensive technique that would assist in the decision related to technology and knowledge investment. According to Porter (1985), technology is one of the main drivers of competition and is among the most prominent reasons to change the rules of competition. Despite the importance of technology in sustaining competitive advantage, it should be emphasised that technology is not important for its own sake; rather, technology is important if it can help companies to make differentiations or to reduce costs. Therefore, it is crucial for companies to detect the right choice of technology in which to invest. The investment in technology should be aligned with a company's main business strategy and should consider the company's limited resources. This paper serves as a step forward towards this goal by assisting managers in the decision-making process related to technology focus and investment. The paper proposed a technique for building upon the sense and respond method as well as resource management.

The paper has one main research question: In which types of technology should firms invest in order to gain a higher competitive advantage? The paper applies RBV as the main theoretical framework of the paper. Based on RBV, there are strategic resources that a firm can exploit to gain sustainable competitive advantage and earn higher profits (Barney, 1996 ;Peteraf & Barney, 2003). Generally, there are three perspectives regarding sustainable competitive advantage: the I/O model, RBV and the core competencies model (Xiao, Ning, &

Yuan, 2008). The RBV of sustainable competitive advantage, which is applied in this paper, determines the critical attributes in resource allocation through sense and respond methodology (Liu, 2010). In addition to detecting critical attributes in a firm's resource allocation, the technology and knowledge portion of a sense and respond questionnaire is used to determine the optimal choice of technology focus. In order to find the technology focus, the respondents were required to detect the share of each technology type (basic, core and spearhead) in relation to each attribute of the sense and respond questionnaire. Later, formulae 16–19 were applied to find the highest cause of uncertainty and technology focus. Additionally, this paper applied the sense and respond method to resource allocation and in order to detect the critical factor indices presented in sub-chapter 2.4.3.

The paper applies its proposed model to a furniture manufacturing, Malaysian-owned company within a medium-size industry, a company that employed around 250 employees and had been listed in the Bursa Malaysia Stock Exchange since 2000. The company produced high-grade office furniture, including tables, chairs, office cabinets and cubicle partitions, and it had operations both in the local market as well as in China, Japan, the USA, Europe and the Middle East. The company and its products had received international quality certifications like ISO 9001 UKAS Quality Management, PEFC and MTTC.

The results of the sense and respond study showed that the company needed to invest in and improve its "organization system" since most of the criteria in this sector were under resources. The main focus of company's business strategy was time, and the company's strategic position was analyser. As an analyser, the company tried to offer high-quality products to its customers at a reasonable price.

Studying the technology factor for the company showed that the core technology had the highest share, at 41%. Basic and spearhead technology constituted 25% and 33%, respectively. The uncertainty (the VarC) corresponding to each type of technology was 1.94 (for basic), 1.64 (for core) and 1.50 (for spearhead). Although basic technology had the lowest share in this company's competitive advantage, it caused the highest amount of uncertainty for the company. Using formulae 16–19, the risk associated with each technology type was 0.60 (basic), 0.27 (core) and 0.25 (spearhead). The total technology risk was 0.71. Considering the technology and knowledge factor for this company reduced its competitive position and showed higher risk. The SCA value without the technology and knowledge effect was 0.99 (MAD calculation for future BCFI), while the value was 0.90 when the technology and knowledge factor was considered for the company business strategy.

In the study, three main results were obtained: first, time was observed to be the right type of operations strategy for this company to adjust in order to improve performance; second, an investigation was conducted into which company unit followed company business strategies best; and third, the attributes that warranted improvement were detected. Moreover, the proposed model for evaluating technology and knowledge's effect on the firm's business strategy and competitive position was applied for the first time to a medium-size Malaysian company that operated both domestically and internationally. Based on the research results, the proposed model was applicable to the evaluation of the company's strategic decisions and technology investment decisions.

4.5 Publication 4: A brief summary

Paper title: Technology development process and managing uncertainties with sustainable competitive advantage approach

Research objectives, findings and contributions

The paper contributes to the research of process innovation strategy and tries to assist in the decisions related to process development. The paper applies the model from Publication 3 to a large, multinational firm. What makes this paper distinct is the authors' consideration of comprehensive paths for technology implementation (Utterback & Abernathy, 1975) in manufacturing companies and their incorporation of these paths in Tuominen et al.'s (2003) model of classifying technology. According to Utterback and Abernathy (1975) there are two paths of technology development in a firm: product technology development and process technology development. The innovation and development in any organization starts with product development; in this stage, the associated technology is advanced and usually expensive. When the product development technology succeeds in differentiating or reducing the cost of the product, the development and innovation processes start in order to reduce the cost of production and economies. In line with Tuominen et al. (2003), product development includes spearhead technology while process development mainly relates to basic technology. This is presented in Figure 11.

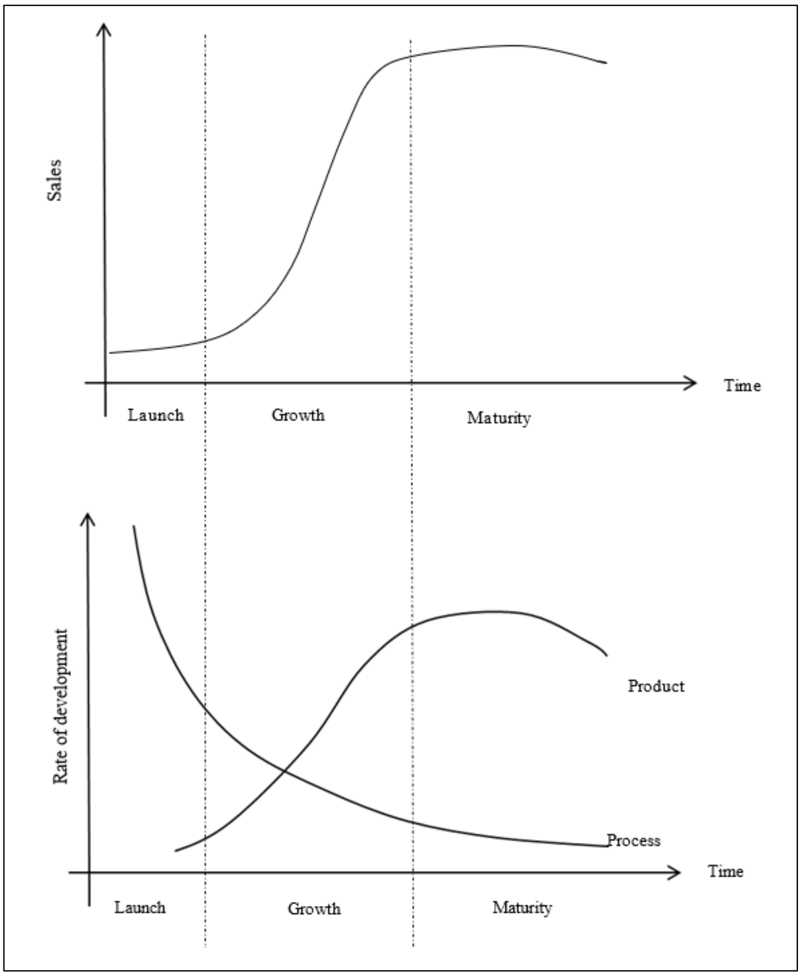

Figure 11. Technology comprehensive development path and product life cycle (Tilabi, Tasmin, Takala, Palaniappan, et al., 2019)

Hervas-Oliver, Sempere-Ripoll, and Boronat-Moll (2014) studied the process of innovation strategy aligned with product development strategy, and they concluded that, because the internal capabilities of a firm are limited, the firm must apply embodied knowledge and technology for developments in the process. As process innovation strategy is production oriented, criteria such as cost, flexibility and capacity should be considered as benchmarks of performance measurement, and the traditional measurement based on sales should be avoided.

The case study centred on a multinational ceramic manufacturing firm based in Malaysia. The resource allocation of the studied case showed that, apart from “reduction of unprofitable time in processes”, all the criteria were located in the balanced area. The company’s business strategy was “analyser”, which proved that they were trying to reduce costs through different means and offering high-quality products. For that reason, the company needed to invest more to eliminate unprofitable time in their process. An investigation of technology usage showed that basic technology was the most dominant technology in the firm, constituting an average of 30 percent of the firm's technology. The uncertainty factor related to technology (VarC) indicated that basic technology caused the highest amount of uncertainty, and regarding technology development in terms of product and process, the results of technology study showed that this company ought to invest more in process innovation rather than in product innovation. In other words, the company should improve its manufacturing processes, including automation. This conclusion is also in line with the company's competitive priorities, which sought to reduce cost and unprofitable time. Investigating the impact of knowledge and technology policy on sustaining the firm's competitive position demonstrated that resource allocation was less sustainable when knowledge and technology were considered. The SCA level was 0.97 in the absence of the technology and knowledge factor and was 0.65 when taking the knowledge and technology factor into account.

This research followed two main objectives, the first of which entailed the implementation and validation of the technique that would assist in the decision-making process related to technology and knowledge. This technique had previously been applied in one medium-size, conventional industry company. The forerunner of this model was also applied in two high-tech start-ups. This study, however, provided the first opportunity for this technique to be applied to assisting in the decision related to technology and knowledge in a large multinational company, and the results showed the technique's suitability for such a purpose. The second objective was to expand the technology classification model to cover both product and process development. The innovation process always starts with innovation in product; once a company can differentiate or offer a higher-quality product, the innovation and development process commences in order to reduce costs or increase capacity. In this regard, process innovation is product innovation oriented (Hervas-Oliver et al., 2014). As product innovation is strongly related to the effective management of firm's knowledge and technology (Tasmin & Woods, 2007), a tool that assists in decisions related to the knowledge and technology requirement is essential. This work is the first attempt to consider product and process development requirements simultaneously in creating a comprehensive decision-making technique.

5 FINDINGS

In this chapter, the results and findings of the four different publications included in this dissertation will be combined, and the synthesised results and findings will be presented in response to the main research questions and the objectives posed in the first chapter, thus justifying the research title. Additionally, this chapter presents theoretical contributions, managerial implications and limitations, and future application of this dissertation.

Table 7. Contribution of articles to technology and knowledge requirement

Title	Contribution to thesis purpose
Publication 1: What is the potential of additive manufacturing in supply chains? A narrative literature review approach	The paper summarizes the potential of 3D printing technology in enhancing different performance measurements and improving competitive priorities. This technology leads to new rules of competition in the business world. 3D printing technology is chosen as one advanced technology, and the paper uses literature review and secondary data to show how advanced technology could assist in winning the competition in advanced and conventional industries. (addressed research question 2)
Publication 2: Towards developing a decision-making tool for technology and knowledge priorities	The paper evaluates the effect of technology and knowledge on firms' competitive advantage in two high-tech start-ups. The paper considers competitive priorities as different layers of the sand cone model and considers three types of technology based on a product's life cycle: basic, core and spearhead. Having set the goal of reducing risk and uncertainties, the paper proposes a model for technology focus. Implementing the model shows that technology has an impact on firms' competitive positions, and conducting a weak market test reveals that the proposed model works well for small-size start-ups and is able to detect some improvement areas at the operational level. (addressed research questions 1 and 2)
Publication 3: Assessment of technology factor in companies' business strategy with the use of sense and respond method	The paper extends the modelling proposed in Publication 2 and incorporates the sense and respond and critical factor indices. The implementation of the model in a medium-size, conventional company shows that technology is an important factor in firms' sustainable competitive positions even though the company competed in a technologically unadvanced market. Implementation of sense and respond and CFIs detected the potential areas for resource investment in this case. (addressed research question 1)
Publication 4: Technology development process and	This paper validates the proposed model in Publication 3 in a large, multinational firm. Additionally, it

Title	Contribution to thesis purpose
managing uncertainties with sustainable competitive advantage approach	considers the whole development cycle in firms, i.e., product and process in technology classification. (addressed research question 1)

5.1 Integration of the publications: Answering the research questions

The goal of this dissertation is to evaluate the role of technology in gaining competitive advantage. Therefore, it has one research question:

> RQ: What is the role of technology in firms' competitive position?

In order to address this main research question, two sub-questions are formulated. These questions and their answers are as follows:

> RQ1. How could the decision-making models related to technology and knowledge investments be applied for strategically sustainable operations?

In order to generate an applicable technology and knowledge strategy, two main issue should be considered: first, a firm's technology strategy should be aligned with its main business strategy and chosen competitive priorities, and second, the results of the technology and knowledge decision should be easily applicable at the operational level. Moreover, the impact of the decision should be easily measurable in terms of different operations. This dissertation proposed a technique that can satisfy both of the above conditions. A preliminary version of this model is presented in Publication 2, and it is further developed in Publications 3 and 4. Three types of technology are considered for firms (basic, core and spearhead), and the study seeks to find the most crucial one in which to invest. The dissertation follows the sand cone approach in the decision-making process related to technology and knowledge rather than trade-off, indicating that this dissertation seeks to find the base of technology requirement. Having established the base of technology requirements, the firm is able to simultaneously and successfully manage the remaining technology types. The chosen performance measurement to find the base is uncertainties and risk caused by a technology type, and this can be calculated via the VarC of each technology type. Incorporation of the proposed model with sense and respond and critical factor indices makes the model capable of building its analysis from operational requirements and proposing operationally applicable solutions. Since the proposed development plan for technology management considered both a limited resource and a general business strategy, it is logical to claim that the proposed model for technology and knowledge decision making follows a sustainable competitive advantage approach.

> RQ2. What is the role of advanced technology in high-tech companies and conventional industries?

Publications 1 and 2 answer this research question. In Publication 1, one advanced technology is chosen, and its effect on different competitive priorities is examined. The paper reveals that the effects of advanced technology on different performance measurements are immense. Since the paper considered the whole supply chain of firms, from supplier to customer, its findings are not limited only to the internal operation of the firms; the developed framework and approach can be applied in setting the general business strategy of each firm. This approach also implicitly recommends that firms look for resources beyond their boundaries and consider how the integration of new technology can provide a means for gaining competitive advantage. The paper presents that the deployment of advanced technology could bring competitive advantage for both high-tech and conventional industries. The main issue pertains to how firms decide to integrate and incorporate the new technology within their supply chain in such a way that it is compatible with their primary business strategy.

In Publication 2, the proposed model for evaluating the effect of technology and knowledge is implemented in two high-tech start-ups. The results show that consideration of the technology and knowledge factor has some influence on a firm's competitive advantage, though the effect is not significant. The reason behind limited effect may stem from the uncertain situation of start-ups; the chance of a gaining long-term, competitive advantage for a start-up is inherently too low. Additionally, start-ups have limited resources, and for technology-intensive enterprises, the chance of success is lower due to rapid changes in technology and shorter product life cycles. However, the implementation of this new technique shows that the technology and knowledge factor increases the potential for success and shows that the proposed model is capable for proposing development plans that can both reduce the risks and uncertainties related to technology and increase the chance of success, which can help high-tech start-ups to achieve sustainable competitive advantage.

5.2 Theoretical contributions

This dissertation extends existing knowledge of RBV, competitive advantage and the sand cone model that all served as the foundation of this dissertation.

- RBV: This dissertation contributes to the body of knowledge discussing the RBV of competitive advantage. The dissertation focuses on knowledge (knowing to do things) as the most critical resource of a firm, considers technology (the process of using knowledge) as a critical capability and one of the factors in creating knowledge, and evaluates the effects of both knowledge and technology on firms' competitive advantage. In this regard, the dissertation does not develop a new theory but proves what is claimed in RBV literature about knowledge and technology by showing the impact of these elements on firms' competitive advantage. This dissertation thus provides a better understanding of RBV.

- Competitive advantage: This dissertation evaluates the influence of technology on firms' competitive advantage. Porter (1985) proposes technology as a great source of competitive advantage, and he also points out that the choice of technology should be aligned with a company's business strategy and selected competitive priorities. However, the current literature rarely proposes how the above can be accomplished in practice. The technique that this study proposes incorporates companies' business strategies and resource allocation, and this technique is easily applicable at the operational level. The concept of sustainability denotes how much technology prioritization supports competitive priority strategy.

- Sand cone model: This dissertation proposes a new application of the sand cone model, which was originally applied to the simultaneous development of manufacturing priorities and stood in contrast to traditional approaches towards competitive priorities such as trade-off (Ferdows & De Meyer, 1990). This dissertation proposed a new application of this model and successfully implemented this model in prioritizing the technology requirements of firms.

5.3 Managerial implications

This study assesses the role of technology and technology-related decisions in sustaining firms' competitive advantages. The research contributes to the facilitation of the decision-making process related to technology and knowledge investment in firms in two main areas: first, proposing a decision-making technique based on the sand cone model to assist in technology and knowledge prioritization, and second, developing a framework to assess the potential of advanced technology in high-tech and conventional industries. The tool that this study developed was implemented in different industries, in different sectors and in different geographical locations, and the weak market test conducted after each case study guaranteed the suitability of the proposed tool for the selected purposes. The chosen approach is considered, in terms of 3D printing technology potential, to be conducive to gaining competitive advantage by evaluating the effects of advanced technology on firms' supply chain structures. The findings of this dissertation help managers to find the right choice of technology in which to invest on based on their competitive priorities and limited resources, to outsource technology and knowledge requirements, to detect the potential development areas regarding their firms' competitive priorities, and to evaluate the potential of spearhead technology in bringing competitive advantage and changing the rules of competition. We believe that the ideas and methods described in this dissertation are applicable to all industries and businesses regardless of sector or environment. However, in practice, the decision-making process in high-tech industries (i.e., technology- and knowledge-intensive firms) is more critical and has a higher impact because technology is the core of competitive advantages for these kinds of firms. As we are in the era known variously as "industry 4.0" and the "Third Industrial Revolution", we are facing advances and changes in technology that have begun to happen faster than at any time in the past. In this regard, a technique that assists in technology choices will prove immensely beneficial to all companies.

As mentioned above, this dissertation is an operations strategy and management dissertation. In alignment with its goal, the dissertation proposed an understandable technique that is applicable in practice to the facilitation of technology management. This technique helps managers and technicians to better understand each other in terms of technological requirements.

5.4 Limitations and future work

Case studies constitute both the weakness and the strength of this study. Conducting case studies provides a deep understanding of the chosen research area and enables the tailoring of the research design procedure based on the chosen research topic.

Generally, the case study method suffers from the limitation of generalization. However, the investigation of carefully chosen cases could result in intriguing findings worth further discussion and investigation. Although the technique proposed in this dissertation was applied to multiple companies, it remains necessary to further evaluate the results and findings through additional case studies. Though this study is based on four case studies, two from manufacturing companies and two from high-tech service start-ups, conduction the same research in the medium- and low-tech service sectors would be necessary in order to generalize the findings. The author also suggests conducting simultaneous case studies within a single industry sector in different countries to better eliminate the effects of variations in countries' technology levels and work culture.

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WHAT IS THE POTENTIAL OF ADDITIVE MANUFACTURING IN SUPPLY CHAINS? A NARRATIVE LITERATURE REVIEW APPROACH

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ABSTRACT:

The study of additive manufacturing (AM) has grown rapidly during the last decade as it is perceived that the technology has the potential to revolutionize the way in which products are produced and delivered to the customer. Additionally, AM is able to create new business opportunities, as well as introduce new rules of competition to the business world. Despite experiencing immense growth in the study of AM, the knowledge of interdependencies across forms of technology deployment and different sectors involved in supply chains is widely dispersed. The initial consequence of this situation is to proliferate fragmented studies duplicating identical efforts, while neglecting certain aspects. Therefore, this article attempts to synthesize the existing research on AM regarding its impact on business and supply chain management with the goal of shedding light on the current situation and open up avenues for further research. This paper applies a narrative approach to conducting a literature review and summarizes the findings in relation to three main categories of the supply chain: supply side, firm side and demand side. Additionally, it offers recent examples of AM deployment in industry and the real world to highlight the trend and potential in the area of AM. Given this trend and potential of AM in business, decision makers (based on their positions in the entire supply chain) are able to make better choices when deploying this technology as a disruptive technology. Being on time and making the right choice of new technology deployments not only prevent firms from losing their competitive advantage (and from bankruptcy in ultimate situations), but also support them to enhance their advantage over their competitors. In particular, they can receive high-level benefits as early or first adopters. This article is a step towards reaching this goal.

Keywords: additive manufacturing, direct digital manufacturing, rapid prototyping, 3D printing, product and process innovation, supply chain.

INTRODUCTION

AM technologies (also known as direct digital manufacturing or 3D printing) are all technologies automatically producing components by setting up or joining volume elements preferably in layers. This technology enables firms to directly manufacture parts from an original digital design (or physical scan) without tooling and setting up, similar to laser printers that do not need type setting to print (Hopkinson et al., 2006) (Gibson et al., 2010, pp. 363-384). This technique, which has its origins in rapid prototyping, is becoming popular in various industries, such as the aerospace, automotive and medical device industries. Considering that the growth rate of AM is estimated to increase to 11 billion euros in 2020, compared with 3.7 billion euros in 2013, this technology is one of the most increasingly popular manufacturing technologies, which has a total market potential of about 130 billion euros (European-Commission, 2014).

Given the expanding number of successful applications of AM, the technology has attracted the attention of the academic community in evaluating its effect as a disruptive technology in various parts of the supply chain with the goal of reinforcing competitive advantages, which is indeed the goal behind the deployment of any technology (Porter, 1985). It is undoubtedly true that scientific publications about AM, particularly its impact on supply chain configuration, has grown rapidly during the last five years; yet, existing knowledge is widely dispersed because of AM's varied nature within the supply chain. Therefore, this paper tries to fill this gap by presenting a comprehensive narrative literature review about the potential of AM in the main parts of supply chains, namely, the supply, demand and firm sides. It also presents the most recent applications of 3D printing in industry to highlight the trend and scope of future research.

The rest of the paper is organized as follows. In the first section, the methodology of gathering materials is presented, followed by a general description of AM technologies and determinative attributes when choosing this technology for a particular industry. Next is a discussion on the new application of 3D printing in industry. In the subsequent section, how products and production are affected by AM technologies is explored. Then, the potential of AM within supply chain configuration is described with regard to four scenarios: 1. simple supply chain (absence of AM), 2. benefits to the supply side, 3. benefits to firms, and 4. benefits to the demand side. The paper closes with a discussion and conclusion.

METHODOLOGY

There are two main approaches to conducting a literature review: systematic and narrative approaches. Systematic literature reviews are employ detailed, rigorous and explicit methods. As systematic literature reviews are based on the selected research questions, the procedure and methods of selecting material are defined explicitly in advance. This approach is most common in the field of health science. On the other hand, narrative literature reviews, which are the most common form of literature reviews, provide a broad overview of a topic, rather than addressing a specific research question (Onwuegbuzie & Frels, 2016, p. 25).

This literature review is based upon the guidelines for performing narrative literature reviews produced by Green et al. (2006). Therefore, the results comprise the author's findings on a given topic (in this case, AM) and synthesize the available resources in order to shed light on the potential of AM within business sectors by summarizing its effect within supply chain management (Green et al., 2006).

Since there are no guidelines for the threshold number of databases (to the best of the author's knowledge), and due to the interdisciplinary nature of the AM literature, this review has been made comprehensive through the use of Scopus and Google Scholar, which are reputable among scholars of technology management, business strategy and supply chain management. We only selected academic articles in English, including articles from conference, scientific reports and information from companies' websites prior to October 2017. We searched using the following keywords: additive manufacturing, 3D printing, rapid prototyping, digital manufacturing and direct digital manufacturing, in combination with the Boolean operators "AND" and "OR" and the terms supply chain management and configuration.

Technology selection

AM (direct digital manufacturing, 3D printing and rapid prototyping) is the process of joining materials to make objects from 3D model data, usually layer by layer. It was originally applied, for the most part, in the fabrication of conceptual and functional prototypes in the late 1980s (Hopkinson et al., 2006). Nowadays, it is applied in many other areas, such as customer-driven medical devices (e.g., dental crowns and hearing aids), the aerospace industry (to decrease weight), the automotive industry, the jewelry industry, architecture and defense (Pérès & Noyes, 2006), (NASA, 2013) (Fitzgerald, 2013). Although the application of 3D printing is growing, there are critical voices asserting the associated challenges of AM in terms of cost and printing time (Times, 2014).

There are various AM processes, which differ in the way that layers are deposited to create parts, as well as the materials that can be used in relation to operation principles. There are two main methods in AM technology: one is based on melting or softening materials to produce the layers, while the other is based on curing liquid materials (Bikas et al., 2016). At present, in general terms, there are seven different options in AM technology: 1. material extrusion, i.e., fused deposition modeling (FDM), 2. material jetting, 3. binder jetting, 4. sheet lamination, 5. vat photopolymerization, i.e., stereolithography (SLA), 6. powder-bed fusion, i.e., SLS or selective laser modelling (SLM), and 7. direct energy deposition. FDM, SLM and SLS belong to the category of melting or softening materials, while the others belong to the second category. The cost of equipment in each process varies from 30,000 to 500,000 US dollars (Holmström et al., 2016). While each method and process have their own advantages and disadvantages, the main criteria that a company applies when choose the best solution are the speed of the machine, the cost of the printed prototype, the cost and range of materials, and color capabilities (Pham & Dimov, 2012, p. 6).

Technology application

While the original application of AM was in rapid prototyping, nowadays, this technology has applications in tool-making and low-volume manufacturing across various industry sectors. The aerospace industry is one of the pioneer industries in terms of adopting AM technology, for example, 3D printing parts for the F-18 Super Hornets and the 787 commercial jetliners, where weight reduction of the final products is important (Hopkinson et al., 2006). Another pioneer industry is the medical industry in terms of producing customized orthopedic implants and braces, hearing aid shells, and dental crowns (Wohlers, 2015).

The technology has a huge potential in the automotive industry as well. For example, Volkswagen Autoeuropa, which is responsible for manufacturing Volkswagen cars, now deploys 3D printing on its production line for printing manufacturing tools, jigs and fixtures. Using 3D printing in Volkswagen has revolutionized the workflow by reducing the number of suppliers the company deals with, lead times, increasing the productivity of personnel, and improving their work conditions ergonomically.

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For instance, a wheel protection jig was previously sourced for 800 euros from an external supplier with a production time of 56 days. But it can now be printed inside the company's facilities for just 21 euros in 10 days. Compared to conventional methods, 3D printing in this company has resulted in a cost reduction of 91% and time saving of 95%, with a return on investment in less than two months (De Vries, 2017).

3D printing technology also has major potential in domestic appliance manufacturing, especially spare parts and aftersales. For instance, in order to improve aftersales service, Electrolux conducted research to address the source of problems affecting both manufacturers and customers. This revealed that the manufacturer stopped producing certain spare parts once production of the actual appliances that used them stopped. While this was due to high production levels, high inventory levels and repair costs, these parts were still used by customers. From a customer point of view, the cost and time needed to repair and replace increased after the product was no longer sold. Therefore, Electrolux decided to deploy on-demand 3D printing of spare parts to overcome the problem identified in its aftersales service (Haria, 2017).

Traditional 3D printers mainly involve size constraints when printing objects. But the combination of 3D printers with robots make it possible to overcome this constraint and print almost everything. For example, a new hybrid manufacturing process combining AM and industrial robotics capabilities is used to make ship propellers in the Netherlands' Port of Rotterdam (the largest port in Europe and one of the most important cargo destinations). The Port of Rotterdam's AM laboratory, which is a pioneer in the deployment of AM in the maritime industry, is trying to develop an 'on-demand' hybrid manufacturing capability for the replacement of different large-scale metal parts of a vessel. This will have a major impact on reducing wasted time and the cost of maintenance across the maritime industry around the world (Autodesk, 2017).

The combination of 3D printing with robots makes it possible to produce "endless" different structures, regardless of size, since robots are able to move across the object as they print. For instance, MX3D, a startup company in the Netherlands, used industrial robots to print a small pedestrian bridge over an Amsterdam canal in 2017. This is a small example, but shows how the combination of 3D printers and robots offers huge potential in construction (Hobson, 2015).

Table 1: Some recent applications of 3D printing

Industry	Example	Main objective
Aerospace	Air duct of F-18 Super Hornets and 787 commercial jetliners (Khajavi et al., 2014)	Reduces inventory, Decreases down time, increases system reliability
Medical and dental	Customized orthopedic implants (Shinal, 2013) and braced, hearing aid shells (Sharma, 2013), dental crowns (Murray, 2012), deployment of AM in Philips' healthcare spare parts (Wullms, 2016)	Promotes customization, improves aftersales services
Automotive	Manufacturing tools, jigs and fixtures are printed on Volkswagen Autoeuropa's manufacturing line (De Vries, 2017)	Reduces lead time and cost
Domestic appliance manufacturer	On-demand 3D printing of spare parts for aftersales service at Electrolux (Haria, 2017)	Improves aftersales services

Industry	Example	Main objective
Maritime	AM in combination with industrial robotics is used to make ship propellers at the Netherlands' Port of Rotterdam (Autodesk, 2017)	Reduces down time and cost, increases parts availability, improves maintenance service
Construction	Printing a small pedestrian bridge over an Amsterdam canal in 2017 (Hobson, 2015)	Combination of 3D printers with robots removes the constrain of size and makes it possible to produce almost everything.
Food	3D chocolate printing machine pioneered by Choc Edge especially for custom-shaped chocolate (Jia, et al., 2016)	Supports customization and provide higher profit for manufacturers.

A percentage breakdown of the use of AM in industrial sectors is presented in the next figure:

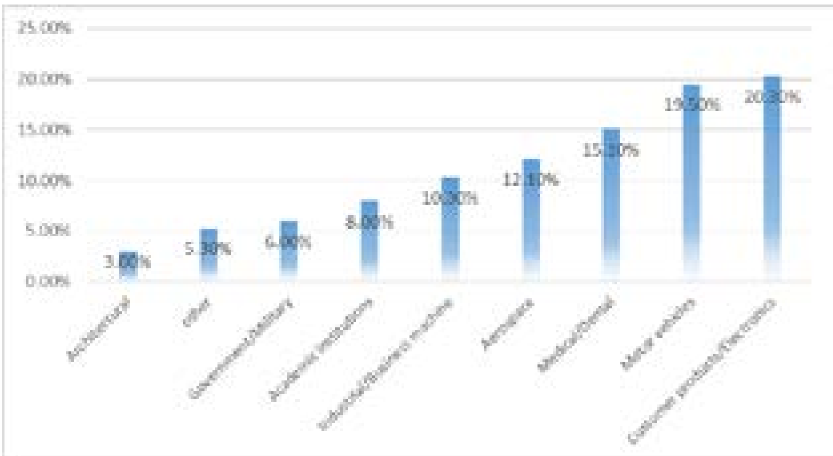

Figure 1: *Percentage breakdown of AM use in industrial sectors using AM (Wohlers, 2012)*

Although AM is a growing method of producing objects, its technology and market are quite new. Initially, it was believed that, given there was no need for tools, AM was economically suitable for low and medium production volumes involving highly customized products (economy of one) (Wohlers, 2015) (Weller et al., 2015). But recent studies on the commercialization of AM systems have revealed that the technology is adaptable to economies of scale in different ways, for example, through increased machine throughput or physical scaling-up (Baumers et al., 2016) (Jia et al., 2016). The general perception is that AM will not completely replace conventional methods, apart from in some specialized markets and industries. For example, a survey by the consultancy firm PricewaterhouseCoopers of the Swedish domestic appliance manufacturer Electrolux showed that 3D printing would play a "dominant role" in the production of spare parts within the next five years (Geissbauer et al., 2017).

In deploying AM as a new technology, the comparison with conventional manufacturing models, essentially in terms of cost, is crucial and decision makers need to conduct a thorough cost-benefit analysis to determine the level of profitability that a firm can achieve with the deployment of AM (Schniederjans, 2017). Cost models for conventional tool-based manufacturing processes often consist of labor and machines (tools), which are amortized over production runs; meanwhile, in AM, other factors, such as the high impact of investments and overheads, should be considered (Ruffo et al., 2006) (Tuck et al., 2008).

AM impact on product(ion):

A typical AM process should consist of seven main stages: 1. design, 2. STL conversion, 3. positioning, 4. 2D slicing, 5. machine warm-up, 6. construction, 7. part removal, 8. support removal, and 9. Final part (Khajavi, et al., 2015).

Figure 2: AM process stages

With the application of AM as a tool where manufacturing is not on a large scale, manufacturers can make most shape parts without typical manufacturing limitations. Additionally, the cost of changing and customizing products is reduced significantly. These fundamental features lead to the following benefits for AM types of production (Holmström et al., 2010): design customization, shorter lead times, lower inventories, reduce waste, small production batches are feasible and producing batches of one becomes economical, production of products that are functionally optimized, quick change design, no tool is needed (this characteristic leads to shorter ramp-up times and expenses).

Generally, the deployment of AM has an impact in two main directions: 1. products and 2. supply chain management and configuration. AM make it possible to produce economically innovative customized products with high value added and facilitates mass customization (Mellor et al., 2014) (Zawadzki & Żywicki, 2016) (Chen et al., 2015). In detail, compared with conventional methods, AM offers many advantages, particularly in design flexibility, the low cost of geometric complexity, dimensional accuracy, assembly not being required, and time and cost efficiency in production runs (Gao et al., 2015). All these capabilities help manufacturers to increase their performance outputs, manage risk, promote innovation and make greater profits (Cotteleer & Joyce, 2014).

AM impact on the supply chain

In terms of the impact of AM within supply chain management, we need to consider four scenarios:

Simple supply chain (starting situation without AM)

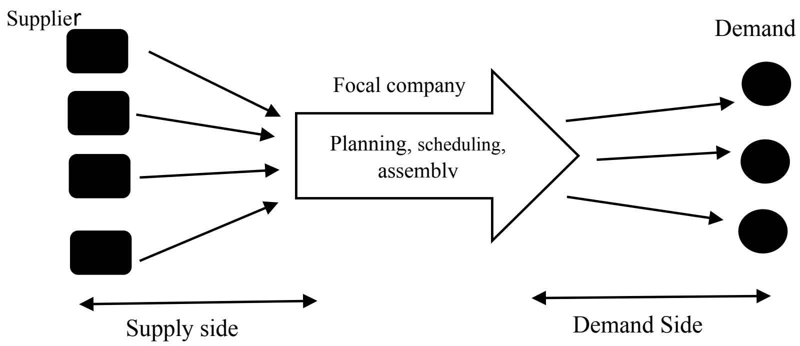

Figure 3: A schematic depiction of a simple tool-based manufacturing system

In the traditional supply chain, a focal firm receives raw materials from several suppliers to produce and deliver standard products to the end customers. The standard activities inside the firm comprise storing raw materials, planning, scheduling and assembly, storing the final products and delivering then to the end customers. The conventional continuous supply line has many drawbacks, from storage to handling. The problem is amplified by increasing product variety. Changing products according to customer requirements can be time-consuming and costly because various suppliers have to be involved and tool changes are necessary (Oettmeier & Hofmann, 2017). Therefore, it is predicted that the application of AM in a business should generally lead to reducing complexity and the better management of the risk of disruption by simplifying the supply chain (Holmström & Gutowski, 2017).

Potential of AM on the supply side

Basically, there are two different options of AM deployment on the supply side: 1. contract manufacturing, when a firm sources ready-made AM parts, and 2. when a company purchases the required materials and capital goods in order to engage in AM itself (Oettmeier & Hofmann, 2016). The first option enables firms to be vertically integrated and probably supports them in dealing with a smaller number of suppliers. It is estimated that it leads to improvements in supplier relationship management for firms, while the focal company needs to rethink its supplier relationship management in terms of procurement processes, quality management in procurement, and quality management by suppliers (Oettmeier & Hofmann, 2017). AM also facilitates outsourcing because product design and production can easily be separated (Berman, 2012) (Oettmeier & Hofmann, 2016).

Another benefit of AM for the supply side is that it could shift the production of small lot sizes to high salary countries, since AM reduces the need for manual labors. This potential of AM has been emphasized in several studies examining the many driving forces behind the rise in manufacturing jobs in Western countries, such as the emergence of AM as a new process of innovation in those countries, rising wage levels in emerging economies and falling business quality in emerging economies (Kianian et al., 2015). Additionally, recent studies have shown that the demand for products from US and other Western counties is increasing around the world; and, even more surprisingly, over 60% of Chinese customers prefer to pay more for products labeled as made in a

Western country that those labeled a "Made in China" (Boston Consulting Group, 2012) (Kianian et al., 2015). Therefore, we believe that AM could be one way of meeting this demand and creating new business opportunities and profits. The deployment of AM not only leads to job creation in Western countries, but also supports their manufacturing sectors by reducing the risk of innovative Western companies' intellectual property being "leaked" to emerging economies, thus damaging competitive advantages of the former (Wang, 2004).

AM should also influence the relationship between the focal firm and its suppliers in terms of their mutual contact, as well as support the focal firm in enjoying a binding (more profitable) contract. In particular, the possibility of manufacturing products within an AM process should influence companies when making "last-time buy" and "final order quantity" decisions, along with preventing high levels of safety stock and saving costs on all selected parts when AM is included in the "last-time buy" process (Wullms, 2016).

Potential of AM for manufacturers

The decision about AM deployment for a firm is very much related to its production and market. It is estimated that 3D printers will at least be applied in some particular industries, thus changing the dynamic of competitive advantage from traditional economies of scales (mass productions) to economies of one (customized products) (Petrick & Simpson, 2013). Generally, AM has been applied economically to produce single units in some industries at a very low rate of volume demand (Economist, 2012). For example, in terms of spare parts and aftersales services, the deployment of AM can improve the quality of such services by decreasing the stock-out probability and saving costs by reducing safety stock levels. Additionally, AM deployment in the spare parts industry supports localized and on-demand production, which results in delivery that is fast and low cost (Holmström et al., 2010), (Khajavi et al., 2014). In Germany alone, AM deployment in the spare parts industry will save three billion euros annually over 10 years (Geissbauer et al., 2017).

There are several studies that show how AM deployment affects a focal firm and its network (Barz & Haasis, 2016) (Holmström & Partanen, 2014) (D'aveni, 2013). Generally, the deployment of AM affects focal firms in terms of manufacturing flow management, product development and customization, and return managements (Eyers & Dotchev, 2010) (Oettmeier & Hofmann, 2016). Additionally, AM affects firms' business strategy and increases their performance by promoting product and process innovation (Khorram Niaki & Fabio, 2017). Besides, it improves other performance measurement factors, such as lead times, order fulfilment and waste rates (Chiu & Lin, 2016). Furthermore, AM deployment supports firms in managing the risk of launching new products by rapid prototyping and innovation process (Khajavi et al., 2015) (Lipson & Kurman, 2013, p. 59). Finally, the deployment of AM promotes e-commerce and introduces new business models (Eyers & Potter, 2015) (Bogers & Bilberg, 2016). For example, the deployment of AM in the 3D printing of chocolate has shifted the dominant business model from retailers to manufacturers, with the latter gaining more profits while the former's profits tend to stagnate (Jia et al., 2016).

Studies also show that the deployment of AM affects the supply chain strategy of the focal firm and supports it in the implementation of a lean and agile supply chain by reducing waste and increasing manufacturing flexibility (Nyman & Sarlin, 2014, pp. 4190-4199) (Thomas & Gilbert, 2014). Since AM changes the operation point to a single-stage manufacturing process (Olhager, 2003), it eliminates all uncertainty about throughput times, production schedules and delivery dates. Thus, it makes managing the work in process easier and reduces inventory levels in the warehouse (Rönkkö et al., 2007) (Holmström et al., 2011) (Arnäs et al., 2013).

Benefits of AM on the demand side

There are several studies that shows how AM can prompt changes on the demand side of a supply chain (Oettmeier & Hofmann, 2017). One of the main effects is the democratization of design/customization processes, which can help customers to be co-producers of products and play an active role in product design; ultimately, AM makes it possible for customers to design and print parts by themselves (Waller & Fawcett, 2013) .

The deployment of AM makes the role of demand stronger in a supply chains by moving it less about stock strategy and more about engineering to order, which is a more demand-driven model (Shah et al., 2017). Additionally, it is able to consolidate demand (Holmström & Partanen, 2014). The adoption of AM also makes production geographically closer to the customer's location, which in practice leads to a quicker response to customer changes and needs, while improving the quality of demand forecasting and order fulfilment (Oettmeier & Hofmann, 2016) (Christopher & Ryals, 2014) (Ford, 2014). The results of this literature review are summarized in Table 2:

Table 2: the impact of AM deployment according to the literature

Authors	Year	Area	Main results of the paper	Typology	Method
Hopkinson & Dickens	2001	Firm	Presents how AM can be applied in the manufacture of parts in thousands by comparing the cost of injection molding with SLA. In particular, it considers five sources of cost for each model: direct machine cost, indirect machine cost, machine operation costs, material costs and tolling costs. Additionally, it considers production details and limitations. Considering all costs, the paper concludes that using AM to manufacture parts in medium and high volumes is a credible idea.	Empirical research	Quantitative case research
Tuomi & Karjalainen	2006	Firm	Presents AM as a solution to overcome the uncertainty and challenges of the product development phase of a product life cycle. It analyses the economics of new rapid manufacturing applications, base-case cost modeling methodology. In detail, it compares the costs of manufacturing an electronic industry product using conventional and AM methods. Results show AM deployment leads to a 13% decrease in net present value (NPV).	Empirical research	Case study by calculating the NPV under different scenarios
Holmström, Partanen, Tuomi & Walter	2010	Firm	Introduces the potential benefits of AM in the spare parts and aircraft industries. Generally, the paper reveals that the supply chain benefits from AM deployment in the spare parts industry in terms of improving service and reducing inventory levels. Considering the supply chain of the F18 air-ducting system, the paper concludes that the on-demand and centralized production of spare parts is the most likely approach to succeed.	Conceptual study	
Eyers & Dotchev	2010	Firm	Examines the potential of rapid prototyping in mass customization, and presents case studies demonstrating the use of rapid processing in mass customization, such as customized hearing aids and customized lamps.	General review	
Berman	2012	Firms	Examines the characteristics and applications of 3D printing and compares it with mass customization.	Review	
Mellor, Hao & Zhang	2013	Firm	Proposes a guideline for the manufacturing sector in order to adopt and implement AM technology by constructing and testing a normative structural model of implementation factors related to AM technology, supply chains, organization operations and strategy.	Empirical research	Qualitative case research
Petrick & Simpson	2013	Firm	Compares the main drivers of economies of scale (mass production) with economies of one (mass customization) in terms of source of competitive advantage, supply chain, distribution, economic model, design and completion. The paper shows that AM supports the economies of one philosophy and can change the competitive dynamics of business by impacting the design, build and deliver stages.	Conceptual study	
Nyman & Sarlin	2014	Firm	Examines in detail how AM deployment can influence supply chain strategies by supporting lean and agile philosophy.	Conceptual study	
Khajavi, Partanene & Holmström	2014	Firm	Examines the deployment of AM in the manufacturing spare parts for F/A-18E/F Super Hornet fighter jets. Using scenario planning, the paper shows when centralized manufacturing is cost-effective and under which conditions decentralized manufacturing implementation is economical.	Empirical research	Quantitative case research

Authors	Year	Area	Main results of the paper	Typology	Method
Holmström & Partanen	2014	Demand, firm, logistics service provider (LSP)	Examines how AM can affect the relationship between LSPs, users and manufacturers of equipment. In detail, it shows how AM offers significant and direct benefits to manufacturers of complex and high-value equipment in particularly challenging settings. Additionally, it can consolidate the demand and bring about new business opportunities for LSPs.	Conceptual study	Brian Arthur's theory of combinatorial technological evolution
Ford	2014	Firm, manufacturer	The US is already a leader in the production and use of AM. For US manufacturers, AM mainly offers potential to the following sectors: motor vehicles, aerospace, business machines, medical and dental, government and military, architecture and consumer products. Challenges when developing and adopting AM in US manufacturing are standards development, material selection and cost, equipment and process. Drivers to develop AM in industry are mass customization, new and improved processes and products, incorporating energy and electronics, creating new structures, 3D scanning, bioprinting, government initiatives and public-private partnerships	Review	
Eyers & Potter	2014	Supply, firm, demand	The paper proposes four e-commerce AM models: B2B/B2C outsourced manufacturing, B2B closed marketplace, B2B regional manufacturing, and C2C network manufacturing. The paper also sets out the required action and intended outcomes for each model.	Systematic literature review	
Huang, Liu, Mokasdar & Hou	2014	Supply, firm, demand	AM improves supply chains in terms of: 1. Customization 2. Increased manufacturing sustainability 3. Simplified supply chains and increased responsiveness	Conceptual study	
Ituarte, Salmi, Partanen & Tuomi	2015	Firm	Shows that Finland is not currently in the position to compete on a global scale in primary sectors of AM value chains, such as AM industrial machine manufacturing and raw material supply. The paper sets out the challenges in the deployment AM in Finland as follows: insufficient awareness of benefits, lack of willingness to share knowledge, weak internal 'cluster' structures, especially after Nokia's collapse in 2000. The paper also presents proposals for action, such as promoting funding strategies for AM, developing a future skilled workforce, and linking funding to technology advisory services.	Conceptual study	Non-structured interviews with industry experts
Rüßmann, Lorenz, Gerbert, Waldner, Justus, Engel & Harnisch	2015	Supplier, firm	Explores AM as one of the components of Industry 4.0. To quantify the impact of Industry 4.0, the paper uses Germany as an example and presents the results of Industry 4.0 deployment in terms of productivity, revenue growth, employment and investment. The paper also states that the next wave of manufacturing will affect producers' entire value chain, from design to aftersales service. It also examines the automobile industry in terms of the next wave of automation.	Conceptual study	
Thomas	2015	Firm	Discusses a supply chain approach to examining costs from a monetary (Hopkinson & Dickens) perspective and a resource consumption (Ruffo et al) perspective. It examines AM adoption and diffusion regarding firms' resources, processes and capabilities. The paper illustrates that AM deployment leads to higher flexibility of firms, while lower unit costs are not always promising.	Conceptual study	Mathematical modeling

Authors	Year	Area	Main results of the paper	Typology	Method
Khajavi, Partanene, Holmström & Tuomi	2015	Firm	AM supports manufacturers in new product development and risk management. In detail, the paper proposes a hybrid production method consisting of conventional and AM approaches to new product development. Using scenario modeling, results show that, while the implementation of conventional production methods is not, in the beginning, significantly costly compared to hybrid methods in terms of the success of products on the market, conventional methods are much costlier when products do not succeed at the first attempt.	Empirical research	Quantitative case research via calculating NPV of multiple scenarios
Jia, Wang, Mustafee & Hao	2015	Firm, demand, retailers	3D printing of chocolate supports customization. It also shifts the dominant profit opportunities in the chocolate industry from retailers to manufacturers.	Empirical research	Agent-based simulation
Ming-Chuan Chiu & Yi-Hsuan Lin	2015	Firm	AM deployment improves supply chain performance in terms of lead time and total cost.	Empirical research	Case research, optimization-based simulation
Christopher & Ryals	2015	Demand, supply	AM shifts the dominant logic of business from production push towards demand pull.	Conceptual study	
Ming-Chuan Chiu & Yi-Hsuan Lin	2015	Firms	AM processes improve the supply chain performance in terms of lead time, total cost, order fulfilment and waste rates.	Empirical research	Case simulation
Kianiana, Tavassoli & Larsson	2015	Supply, firm	Investigates the role of AM in job creation in Sweden. It considers technical factors related to AM and non-technical factors in emerging economies. Results show that AM technology contributes to job creation in both the manufacturing sector and the service sector, mainly in product development stages and in production stages of low-volume batches of complex products. That said, it cannot "bring back" mass production jobs from emerging economies to Sweden.	Empirical research	Case study via semi-structured interviews in Swedish companies
Holmström, Holweg, Khajavi & Partanen	2016	Firm	Examines the potential of AM and proposes a research agenda for manufacturing on three levels: factory level, supply chain management level and strategy level.	Conceptual study	
Oettmeier & Hofman	2016	Supply, firm, customer	Shows that AM has a major impact on manufacturing flow management, supplier relationship management, product development, order fulfilment, demand, customer relationships and customer service management, and returns management.	Empirical research	Two explorative case studies
Zawadzki, Żywicki	2016	Firm	Examines the potential of AM with virtual reality in smart design approaches. The author proposes that smart designs and production controls will be necessary for the smart factories of the future in order to be able to realize mass customization strategies.	Conceptual study	
Wullms	2016	Supply, supplier relationship	AM deployment for suppliers will influence the mutual contract between the focal firm and other suppliers in terms of "last-time order quantity". The focal firm is able to bind more effectively and become more profitable.	Empirical research	Quantitative case research on Philips healthcare products

Authors	Year	Area	Main results of the paper	Typology	Method
Li, Jia, Cheng & Hu	2016	Firm	AM deployment in firms reduces total costs and carbon emissions in the manufacturing process.	Empirical research	System dynamic simulation
Khorram Niaki & Nonino	2016	Firm	Provides empirical insights regarding the effects and drivers of AM in industry. It also reveals how the implementation of AM in metal manufacturing has boosted productivity.	Empirical research	Exploratory study using a sample of 16 heterogeneos companies
Oettmeier & Hofman	2017	Supply, firm, demand, technology adoption	Proposes a conceptual guideline to identify the determinants of AM technology adoption for production. In detail, the paper examines the impact of four factors in the adoption of AM technologies for industrial parts production. These factors are: technology-related, firm-related, market structure-related and supply chain-related factors. The results show that ease of use (complexity), absorptive capacity, compatibility, perceived outside support, and supply- and demand-side benefits have a significant impact on the adoption of AM technology by the manufacturing sector.	Empirical research	Online survey of 934 Swiss companies
Schniederjans	2017	Firms	Applies the diffusion of innovation theory to evaluate the main drives of AM deployment in firms. Results shows that the attitude of top management plays the main role in the potential speed of adoption.	Empirical research	Survey with 270 top management personnel from manufacturing firms across the US
Shah, Mattiuzza, Ganji & Coutroubis	2017	Firms	Investigates AM adoption in the supply chain of small and medium-sized enterprises (SMEs). Results show that SMEs' challenges when adopting AM are: machinery and raw material costs, the uncertainty of the market and this new environment, and the lack of liquidity.	Conceptual study	
Holmström & Gutowski	2017	Firms	Evaluates AM in term of environmental sustainability.	Conceptual study	

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DISCUSSION

Reviewing the current body of knowledge in the area of AM reveals that the main focus of study is on manufacturers (firms) with cost as the main performance measurement, while there are only a few studies evaluating the impact of this technology on the supply and demand sides in creating (or changing) demand. Although there is limited research on how AM separately impacts supply and demand, there is a need for more studies examining the potential of AM on demand and supply simultaneously in a particular industry.

Existing studies also show that, while the adoption of AM is becoming more and more popular, it is likely to be a gradual expansion. While some efforts have been made to evaluate the impact of AM on the manufacturing sector, exploring how this technology changes business models and shifts the profit domain of supply chains is a rare occurrence. For example, Holmström and Partanen (2014) show that the deployment of AM creates new business opportunities for third-party logistics providers and gives them a more important role compared to manufacturers or customers. That said, more research is needed in this area in order to investigate the potential of AM in creating new business opportunities.

Based on the results of this review, the main studies in the area of AM are presented in terms of conceptual papers and only in relation to traditional 3D printing techniques. As the combination of robots with AM is increasingly popular in industry, especially because it removes the size constraints, academic studies are required to examine the potential of such new capabilities for the entire supply chain. Additionally, in terms of traditional printing techniques themselves, more empirical research is needed to evaluate the impact of this technology on supply chains, given that existing studies are mainly conceptual.

Without any doubt, AM is replacing tool-based manufacturing in some specialized industries. Thus, there is a need for more research that can determine the variable that defines the trade-off between conventional methods and AM. Existing studies mainly consider "unit cost", while intangible factors, such as risk, flexibility and sustainability, should be also included.

Finally, existing studies, including this one, mainly consider the positive impact of the deployment of AM on business, while there is limited number of studies about negative effects. For example, while AM deployment supports the creation of innovative jobs, especially in Western counties, it is also eliminating some tool-based jobs, not only in emerging economies but also in the West (Samuel et al., 2013). The main question, then, concerns the social impact of such a phenomenon.

CONCLUSION

The aim of our study was to conduct a comprehensive narrative literature review on the subject of AM regarding its potential for supply chain configuration. In detail, this paper has sought to synthesize current knowledge in the area of AM with the goal of summarizing its impact on different parts of supply chains.

In summary, it seems that AM is an emerging class among manufacturing methods, which has already offered diverse and rich opportunities to the business world. It has also changed the role of value added in the supply chain by creating new possibilities and eliminating existing opportunities. Awareness of the full potential offered by AM, which this article seeks to raise, will support decision makers in business to make the right decisions about technology deployment.

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TOWARDS DEVELOPING A DECISION MAKING TOOL FOR TECHNOLOGY AND KNOWLEDGE PRIORITIES

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Abstract

The main focus of this paper is to propose a method for prioritizing knowledge and technology factor of firms towards sustainable competitive advantage. The data has been gathered and analyzed from two high tech start-ups in which technology and knowledge play major role in company's success. The analytical hierarchy model (AHP) is used to determine competitive priorities of the firms. Then knowledge and technology part of sense and respond questionnaire is used to calculate the variability coefficient i.e. the uncertainty caused by technology and knowledge factor. The proposed model is tested in terms of two start-ups. Based on the initial calculation of uncertainties, some improvement plan is proposed and the method is applied again to see if the uncertainty of knowledge and technology decreases. In both cases, the proposed model helped to have a clear and precise improvement plan and led in reduction of uncertainty.

Keywords

sense and respond method, sustainable competitive advantage (SCA), knowledge and technology (KT), uncertainties, analytical hierarchy process (AHP).

Introduction

The world is changing rapidly so is the business environment. This turbulent environment in business world affects the dynamic nature of competitive advantage among firm and makes the competition more intensified. According to Si, Takala and Liu (2010) "The future competitiveness of manufacturing operations under dynamic and complex business situations relies on forward-thinking strategies" [1]. One of the key drivers of competition is technology change. Any technological modification which could pioneer a firm in an industry is considered valuable. Although the technology factor plays an important role in obtaining profit for a company, it is not important for its own sake. It is important if can help companies to reduce cost or make differentiation or speed up delivery [2].

Technology changes and development could create new opportunities and as well as threats to companies [3]. It also important because it can affect industry structure and create new rules of competition. Understanding the effect of technological changes on the structure of an industry has even more importance in the era of digitalization and industry 4.0 [4]. It is perceived that competing in "high technology" industry is considered as key to gain profit [2]. But it also demands lots of company resource, since it forced companies to adapt to the technical requirements of the market continually [3]. So it is important to look at technological capability of firms with resource based view approach and make decision about technology investment regarding companies' limited resources.

This paper tries to evaluate technology and knowledge factor and connects it to companies' business strategy. Additionally it aims to show how technology and knowledge decision reflect uncertainty. Managing uncertainty in business strategy is very important since it is replacing traditional risk management [5]. Therefore, this article is a step towards modelling knowledge and technology priorities considering business strategy.

Theory background

Business strategy

Quinn 1980 defines strategy "the pattern or plan that integrates an organization's major goals, policies and action sequences into a cohesive whole" [6]. Nowadays firms needs to apply strategies that can grantee their sustainable competitive advantages over others rather than only gaining short term benefit. The notion "sustainable competitive advantages" (SCA) was defined by Porter in 1985. He proposed a positioning theory based on generic strategy. His positioning theory classified business strategy in three main categories: overall cost leader ship, differentiation and segmentation. In cost leadership category, companies seek to deliver product and services at lowest price by different means like optimizing process and standardize their products and services. In differentiation category companies seeks to deliver superior products and services by offering high quality and/or customized products and finally in segmentation group, companies focus on fulfilling unique needs of selected segment of customer based on geography or income level [2]. This categorization was not comprehensive enough because it did not consider firms resources and internal capabilities. Based on Wernerfelt (1984), in finding optimal market for a particular firm, its products and its resources should be taken to account at the same time because resource and product are two sides of a coin for firms [7]. Later on Barney includes the role of resources in company business strategy as they can bring competitive advantages to firm. Because firms' resources are rare, have no direct substitutes, and help companies to achieve opportunities or avoid threats. Regarding companies' resources, competitive strategy is defined as creating value chain that cannot be implemented or duplicated by others easily [8].

Another classification of business strategy could be based on Miles and Snow topology. In this model four business strategy groups are defined: prospector, analyzer, defender and reactor. Prospector are those firm which try to lead their industry, their main focus is to deliver high quality products. Analyzer tries to focus on quality and cost simultaneously and remain steady in their market. Defenders try to minimize cost and focus on a mature product or market operation, they concentrate on process improvement and prefer not to take risks. And finally reactor happens in the absence of any clear strategies [9].

Sense and Respond model (S&R)

This model was introduced by Ranta and Takala in 2007 and assists firm in estimation of what would happen in future. This method is replaced traditional way of planning production and is more based on anticipation customers' need on real time. This method helps firms to collect data regarding their experience and expectation and provides a way for firm about how they see themselves compare others in terms of different attributes. Additionally, it helps firms to see the development of a certain attribute in a specific time frame [10–12].

The sample of questionnaire is presented in the following table.

Table 1
Format of the questionnaire.

Performance measurement	Scale: 1 = low, 10 = high		Compared with competitors			Direction of development		
	Expectation (1–10)	Experience (1–10)	worse	same	better	worse	same	better
C1								
C2								

In this study, the following attribute has been used for performance measurement in sense and respond questionnaire.

Table 2
Sample of performance measurement which has been applied in this study.

	Attributes	
	Knowledge & Technology Management	
1	Training and development of the company's personnel	Flexibility
2	Innovativeness and performance of research and development	Cost
3	Communication between different departments and hierarchy levels	Time
4	Adaptation to knowledge and technology	Flexibility
5	Knowledge and technology diffusion	Cost
6	Design and planning of the processes and products	Time
	Processes & Work flows	
7	Short and prompt lead-times in order-fulfilment process	Flexibility
8	Reduction of unprofitable time in processes	Cost
9	On-time deliveries to customer	Quality
10	Control and optimization of all types of inventories	Quality
11	Adaptiveness of changes in demands and in order backlog	Flexibility
	Organizational systems	
12	Leadership and management systems of the company	Cost
13	Quality control of products, processes and operations	Quality
14	Well defined responsibilities and tasks for each operation	Flexibility
15	Utilizing different types of organizing systems	Flexibility
16	Code of conduct and security of data and information	Cost
	Information systems	
17	Information systems support the business processes	Time
18	Visibility of information in information systems	Time
19	Availability of information in information systems	Time
20	Quality & reliability of information in information systems	Quality
21	Usability and functionality of information systems	Quality

RAL model

In order to integrate sense and respond method to Miles and snow typology, RAL model is used. RAL is abbreviated from responsiveness, agility and leanness. According to Takala 2012, a firm can be optimized in terms of responsiveness, agility and leanness by prioritizing quality, cost, time and flexibility [5].

Fig. 1. RAL model.

Technology and knowledge rankings

Knowledge and technology requirement is added to sense and respond questionnaire to gather information about companies' knowledge and technology priorities. Since the companies' resources are limited, so it is very important to find the technology focus which is align with company business strategy and can grantee firms competitive advantage and profitability. Based on Marone, 1989, technology can provide opportunities and bring competitiveness to firms. Therefore companies should integrate it to their business strategy [13].

Towards gaining sustainable competitive advantage and creating core competences, knowledge and intellectual capital also plays significant role. According to Libut 2001, achieving sustainable competitive advantages is mainly based on knowledge meaning that in order to create value chain, knowing how to do thing is as important as having access to special resources. In order to create value chain, knowledge should be shared effectively within firm while be protected from liking outside. So, in order to gain competitive advantage knowledge, skills and intellectual property should be easily shared inside the firm but difficult to be copied by competitors. This kind of knowledge which is "difficult to express, formalize or share", called tactic knowledge. Tactic knowledge is very much related to firms' experience, organization structure and routines [14].

In order to evaluate knowledge and technology impact on firm business strategy, respondents have to estimate each attribute of sense and respond questionnaire in terms of basic, core and spearhead technology. In other word, respondents should detect the share of these three technologies in term of each attribute while the sum of all the shares is 100%. Here, basic technology means the kind of technology which is commonly used and can be purchased or outsourced. Core technology refers to the technology that is bringing competitive advantage to company currently and spearhead technology refers to future technologies. This three different technologies differs each other in terms of required resource and knowledge. This difference influences a lot in firms' strategy implementation and in particular to the success of high tech based business [15].

Table 3
Technology and knowledge share for different attributes.

	Basic	Core	Spearhead
Performance 1			
Performance 2			
Performance 3			
Performance 4			

Method

In this study, analytical hierarchy process (AHP) model and knowledge and technology part of sense and respond questionnaire is used. AHP method is used to weight the component of RAL method: quality, cost, time and flexibility. Analytic Hierarchy Process (AHP) method is based on pairwise comparison between criteria and was introduced by Saaty in 1980. This method is "a multi-attribute decision instrument that allows considering quantitative and qualitative measures and making tradeoffs" [16].

In order to calculate the partial uncertainty regarding to each type of technology, this paper suggests variability coefficient. The formula is as follow:

$$\text{Coef. Var}_{\text{Basic}} = \frac{\text{Standard Deviation}_{\text{Basic}}}{\text{Average}_{\text{Basic}}}, \tag{1}$$

$$\text{Coef. Var}_{\text{Core}} = \frac{\text{Standard Deviation}_{\text{Core}}}{\text{Average}_{\text{Core}}}, \tag{2}$$

$$\text{Coef. Var}_{\text{Spear Head}} = \frac{\text{Standard Deviation}_{\text{Spear Head}}}{\text{Average}_{\text{Spear Head}}}. \tag{3}$$

The above formula shows the level of deviation among participants' response in terms of each technology type regarding different component of RAL model. After calculating the coefficient of variance (CV) for different type of technology, the next step is to calculate risk level in partial and in total. The following formula is used to calculate the partial and total risk of technology:

$$c_1 : \text{Quality}, c_2 : \text{Time}, c_3 : \text{Cost}, c_4 : \text{Flexibility}$$

$$\begin{cases} \text{Total } TK \underset{c_1,c_2,c_3,c_4}{risk} \text{ (RMS)} = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\left(\sum_{b_1,c_2,sh} \text{Coef. Var}_i\right)^2\right]^2} \\ \text{Partial} \begin{cases} TK \underset{c_1,c_2,c_3,c_4}{risk} \text{ Basic (RMS)} = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\sum_b \left(\frac{std_i}{\text{mean}_i}\right)^2\right]^2} \\ TK \underset{c_1,c_2,c_3,c_4}{risk} \text{ Core (RMS)} = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\sum_{\text{core}} \left(\frac{std_i}{\text{mean}_i}\right)^2\right]^2} \\ TK \underset{c_1,c_2,c_3,c_4}{risk} \text{ Sh (RMS)} = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\sum_{\text{Sh}} \left(\frac{std_i}{\text{mean}_i}\right)^2\right]^2} \end{cases} \end{cases} \tag{4}$$

When all the risk is calculated, next step is to calculate sustainable competitive advantage (SCA) index, using the following formula:

$$\text{Total Risk (Geom)} = [(1 - \text{SCA})\, TK\, risk]^{1/2}, \tag{5}$$

$$\text{Total SCA risk level} = 1 - \text{Total Risk (Geom)}. \tag{6}$$

Case studies and data collection

The data and cases which are presented in this study are gathered during the student work shop in Warsaw University of life science in Poland. The data which are presented here, are based on high tech start up companies in which the decision about technology focus is crucial in companies' success. Additionally they have limited resources as start ups and resource allocation plays critical role in setting their strategy. Considering all above, cases are presented here are fit to examine the proposed method here.

During case studies, different group has started the data collection step by defending main attributes in project (regarding project goal and its mission). Then the next step is to estimate these main criteria in terms of different technology share (basic, core, speared).When the data is gathered, final stage is to calculate the variability of coefficient and risk level and to examine how improvement plan might affect the risk of technology deployment.

Results

Case 1: establishing a new transportation company based online scooter

The mission of this start up is to offer high quality and environmental friendly transportation services for customer and having fun simultaneously. The business model of this start up is as follow: customer can rent a scooter on the station via app and they can leave it whenever they want. Since the process of renting works with net and online application, therefor it is very easy and accessible. Customers are charged based on minutes while the starting three minutes is considered free of charge especially for preparation. No driving licence is needed for driving scooter and only ID card is enought. There is promotion for long term contact and you can have a friend (or company) with you using the scooter each time. This starts up has the following partners: manufactures of scooters, leasing company, local government, advertising company and eco-friendly organizations. Customer target group are: people who follow environmental friendly life style, passengers in rush, people who likes using technology in everyday life. The core idea behind this start up is to offer rental high quality scooter for a short period of time. This business needs some spearhead technology (advance technology) such as: stations with sun panels and tablets with navigation system. The current competitive priorities for company are: safety and flexibility, availability and cost. And in future it slightly changes to: safety and cost, 2. availability and flexibility. Manufacturing business strategy index for past and for future is presented in the following table.

Table 4
Manufacture business strategy for scooter starts up, in past and in future.

	Cost	Quality	Delivery	flexibilty	Inconsistency
Past	0.074	0.513	0.138	0.275	0.004
Future	0.275	0.513	0.138	0.074	0.004

The uncertainty i.e. coefficient of variance associated with each types of technology are calculated based formula (1)–(3) and the final result is presented in Fig. 2. As the pictures demonstrates, spearhead technology reflects the highest level of uncertainty in technology and knowledge decision making process.

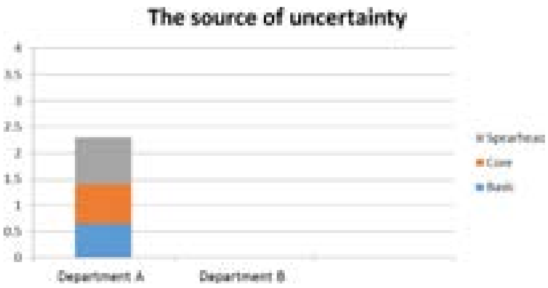

Fig. 2. The source of uncertainty in technology type, current situation.

Considering the available resources and company main goal and to decrease the level of uncertainties the following improving plan has been suggested: 1. to locate ten rental stations in the city centre containing five scooters at each, 2. Customers could return the scooter at the station free of charge otherwise there is extra charge in case of leaving scooter somewhere else in the city. 3. Constantly observe the availability and the location of demand and relocate station to more popular areas if needed. After implementation the improvement plan, the source of uncertainty would look as follow.

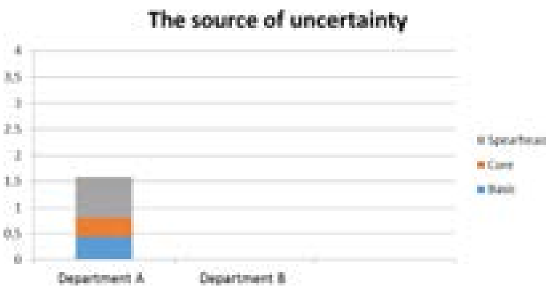

Fig. 3. The source of uncertainty in technology type, after improvement plan.

Comparing Figs. 2 and 3 shows that total uncertainty decreases by 25% after improvement plan. While spearhead technology holds the biggest share of risk and uncertainty in past and after improvement plan. Following the formula (4)–(6) the partial and total risk of technology would be as follow.

Table 5
The summary of risk level.

	Technology and knowledge risk			Total risk (Geom)	Total SCA risk level
	Basic	Core	Spearhead		
Past	0.66	0.74	0.88	1.33	0.36
Future (after improvement plan)	0.45	0.35	0.78	0.97	0.31

The following bar charts show how the source of risk and uncertainties has changed after implementing the improvement plan.

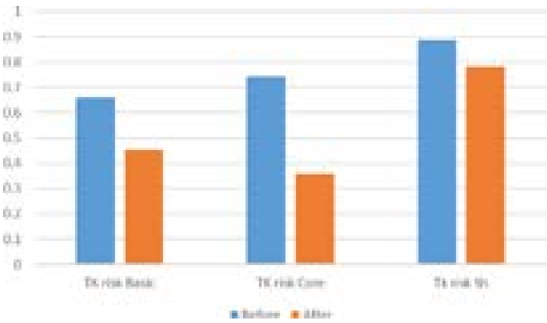

Fig. 4. Comparison of risk share in terms of each technology, current (before) and improved.

Having searched the source of uncertainty among sense and respond attribute, the following criteria are detected as critical before suggestion of improvement plan:
1. Training and development of company's personnel;
2. Short and prompt lead time in order-fulfilment process;
3. Reduction of unprofitable time in process;
4. On-time delivery to customer;
5. Control and optimization of all type of inventories.

After improvement plan, the critical attribute would be:
1. Code of conduct and security of data and information;
2. Information system supports the business process;
3. Visibility of information in information system;
4. Quality and reliability of information in information system.

Case 2: establishing an entertainment start up based on portable scape room idea

The core idea behind this start up is that the group of people enter to a space room (in here truck trailer) and in order to find the exit way, they need to solve a mystery. This scape room is portable and is able to reach to customer place. This entertainment vehicle is suitable for all the ceremony like wedding, birthdays, parties and all sort of events which people needs to be entrained. The spearhead technology in this start up is "holographic design" while truck could be considered basic technology and advertisement channel is core technology. Based on AHP comparison, the business strategy priorities for this company are: 1. quality, 2. delivery, 3. flexibility and 4. cost. They are presented in the following table.

Table 6
Company competitive priorities in past (before improvement plan).

	Cost	Quality	Delivery	Flexibility	Inconsistency
Past	0.057	0.499	0.284	0.160	0.004

Technology and knowledge requirement of this company is filled by seven respondents mainly from marketing, design and logistic department and the results is presented in the following.

Table 7
Knowledge and technology share- before improvement plan.

	Quality			Flexibility			Cost			Delivery		
	Basic	Core	Spearhead	Basic	Core	Spearhead	Basic	Core	Spearhead	Basic	Core	Spearhead
1	80	20	0	30	50	20	60	30	10	80	20	0
2	20	40	40	15	63	22	30	50	20	10	70	20
3	20	50	30	10	70	20	10	60	30	25	35	40
4	10	45	45	0	50	50	10	45	45	20	40	40
5	30	60	10	0	70	30	30	40	30	20	60	20
6	30	60	10	0	70	30	30	40	30	20	60	20
7	80	20	0	30	50	20	60	30	10	80	20	0

Uncertainties i.e. coefficient of variance related to technology before implementing improvement plan is calculated based on formula (1)–(3) and demonstrated in the following bar chart.

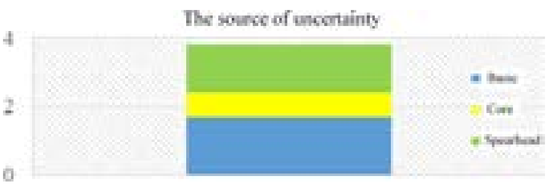

Fig. 5. The source of uncertainty in technology part, before improvement plan.

As the bar chat shows, basic and spearhead technology causes the biggest share of uncertainty in this start up. Some improvement plan has been suggested as follow to decrease the level of uncertainty like: deploy mobile phone app, increase the truck numbers and projects at least one yearly, corporate with fuel company, offering bonus to customer in case of recommending the company to someone else, and implement customer satisfaction survey constantly. After the improvement plan, knowledge and technology requirement for each type of technology would be as follow.

Table 8
Knowledge and technology share- after improvement plan.

	Quality			Flexibility			Cost			Delivery		
	Basic	Core	Spearhead	Basic	Core	Spearhead	Basic	Core	Spearhead	Basic	Core	Spearhead
1	30	60	10	30	50	20	20	60	20	80	20	0
2	30	50	20	15	63	22	30	50	20	70	15	15
3	20	50	30	10	70	20	10	60	30	75	15	10
4	20	50	30	10	50	40	10	45	45	60	20	20
5	30	60	10	10	60	30	30	40	30	65	25	10
6	30	60	10	10	60	30	20	50	30	60	15	25
7	40	50	10	20	50	30	30	60	10	80	20	0

And the uncertainty related to each type of technology is presented in the next figure.

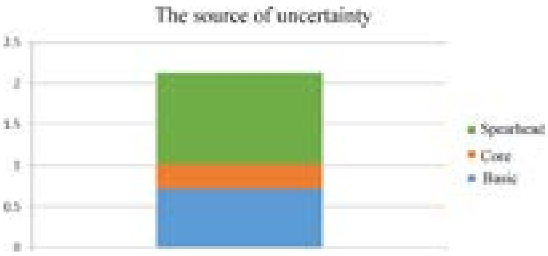

Fig. 6. The source of uncertainty in technology part, before improvement plan.

Comparing Figs. 5 and 6 shows after implementing improvement plan, the main source of uncertainty is spearhead technology.

Based on formula (4)–(6) uncertainty related to technology and knowledge is calculated and presented in the following table.

Table 9
The summary of risk level.

	Technology and knowledge risk			Total risk (Geom)	Total SCA risk level
	Basic	Core	Spearhead		
Past	1.69	0.68	1.4	2.31	0.48
Future (after improvement plan)	0.71	0.30	1.11	1.35	0.37

Having searched the source of uncertainty among sense and respond attribute, the following criteria are detected as critical before suggestion improvement plan:

1. Adoption to knowledge and technology;
2. Design and planning the process and product.

And after improvement plan, critical attribute would be:

1. On time delivery to customer;
2. Quality control of product, process and operation;
3. Utilizing different type of organizing system;
4. Code of conduct and security of data and information;
5. Quality and reliability of information in information system.

Discussion and conclusion

This study tries to present a new decision making to evaluate the technology priorities considering business strategy. This tool, supports decision makers to decide about technology focus regarding companies' business strategy and its internal resource.

The presented SCA model based knowledge and technology here provides decision maker better tool towards gaining sustainable competitive advantages by making right decision regarding different technology level. The technology decision could be increasing investment or out sourcing for example.

Moreover, the model provides the possibility of:

- Observing the right type of operation strategy (cost, quality and time) which could results in company better performance;
- Investigating which company unit follow company business strategy and which not;
- Take better strategic action by knowing the criteria which are unbalanced in terms of resource allocation.

Companies which are presented here are high tech start up. And in both, spear head technology plays significant role in creating uncertainty. Using this new development tools, this start up were able to reduce the risk related to technology deployment for spearhead technology and in total. The proposed model also is connected to sense and respond method which enable companies to detect the focus attribute to maximize their profit regarding company competitive advantage which could be differentiation or cost reduction for example.

Although the effect of technology and knowledge on SCA observed by the proposed model here is not significant, it cannot be neglected. The main role of this paper is to investigate the effect of different technology types on SCA level considering the uncertainty in different technology level. In case study section, the analyses are performed and the recommendations are provided for the decision makers. Moreover, the analytical model presented in this paper could be considered as a great source to observe the weaknesses and strengths of the companies' operations and accordingly to take required actions to keep up the sustainability of the companies' development.

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ASSESSMENT OF TECHNOLOGY FACTOR IN COMPANIES' BUSINESS STRATEGY WITH THE USE OF SENSE AND RESPOND METHOD

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Abstract

The focus of this paper is to propose a method for prioritizing knowledge and technology factor in companies' business strategy. The data has been gathered and analyzed from Malaysian-owned company of medium size type industry, employing around 250 employees and listed in the Malaysian Bourse Stock of Exchange, since 2000. Sense and respond model is used to determine competitive priorities of the firms. Then knowledge and technology part of sense and respond questionnaire is used to calculate the variability coefficient i.e. the uncertainty caused by technology and knowledge factor. The results show that the company is not leading in term of technology (spear head technology share is around 33%). Therefore, the enhancement of technology and knowledge to SCA values is not significantly seen in this study. The usage of the core technologies is around 41% and it might seem relatively enough. In terms of basic technology, while its share is the lowest (around 25%), it has the highest source of uncertainties among technology types. In this case, the proposed model helped to have a clear and precise improvement plan towards prioritizing technology and knowledge focus.

Keywords

Technology and knowledge, sense and respond, sustainable competitive advantage.

Introduction

One vital approach in sustaining business competitive advantage is through technological innovation, hence adapting to current technological shift. Technological changes drive competition in the current business environment. A technological change is not important for its own sake. It is important if it can bring competitive advantage to industry and influence on industry structure. Technological changes shall lead to newly adapted and adopted innovation into work process, product features and service offerings to the market. Organizational innovation is synonymous to new product and process development, is as well seen as an enabler for sustainable competitive advantage [1].

Technology innovation and technology investment are paramount to building and sustaining competitive advantage. Technology has significant role in the value chain of a firm, and it can result in the ability of firm to achieve low cost and differentiation thought its value chain activity [2].

The concept of sustainable competitive advantage has been debated for the past decades. The term "sustainable competitive advantages" was defined by Porter in 1985 as a firm basic type of competitive strategy. He classified three generic enterprise strategies: overall cost leadership, differentiation and segmentation. Later on Barney [3] has made a closer definition by uttering as: "A firm is said to have a sustainable competitive advantage when it is implementing a value creating strategy not simultaneously being implemented by any current or potential competitors and when these other firms are unable to duplicate the benefits of this strategy [3]. Porter [4] argued that sustainable competitive advantage is underpinned by differentiation of distinctive knowledge of product's quality and technology used. This notion has evolved over time to mean maintaining business capabilities that create atmosphere suitable for customers to enjoy greater value [4].

Those competitive advantages that deliver value to customers, uneasy to copy by competitors, and that merit organizational performance are what make up sustainable competitive advantage [5]. Organizational performance is dependent on competitive advantage [6, 7]. Organizational competitiveness in the current economic development is often exploited for survival and stability by firms [8]. An imperative feature of competitive advantage is the manner activities fit and fortify one another [9]. Competitive advantage is thus a combination of resources, interlinked features and activities of an organization better than competitors.

As resource and product are two sides of a coin for firms, Wernerfelt [10] suggests that analyzing a firm from the resource side has more benefit rather than from the product side. He defines resources as "anything that might be thought of as a strength or weakness of a given firm". Resources can bring competitive advantages to the firm because they help companies to achieve opportunities or avoid threats, they are rare or hard to imitate and have no direct substitutes [3]. Even the resource base view theory, according to Wang [11] paid emphasis to internal resources facilitates organizational competitiveness in the environment. These internal resources could be physical assets, knowledge assets as well as human resources capital all put together makes up firms' capabilities [11]. However, some people are of the view that capabilities give rise to competitive advantage and not resources because resources are considered as source of capabilities [12] and as such do not contribute to sustainable competitive advantage [13].

What then firm capabilities stands for? To some is the ability to develop, combine, and restructure internal and external competencies [14], a capacity of deploying organizational resources into a combination of processes to address the dynamism of business environment [13]. Management capabilities can thus be argued that Teece et al. [14] "it's a combination and integration of organizational, functional and technological skills, management of research and development, product and process development, technology transfer, intellectual property, manufacturing, human resources, and organizational learning".

One of the main challenges in sustainable competitive advantage is to consider how much company's resource allocation supports its business strategy. According to Liu [15], the main idea behind the implementation of SCA is to find the critical attributes in resource allocation trough sense and respond methodology. These critical attributes provide us improvement plan to enhance company's strategy and gain sustainable competitive advantages. Broadly speaking, challenges of sustainable competitive advantage as opined by Amit and Shoemaker [13] are identifying, developing, protecting, and deploying resources and capabilities for the sustenance of market advantage.

Considering product life cycle, there are three different level of technologies in any firms: Basic, core, speared head. Considering the effect of technology on resource allocation and critical factor indices, firms are facing with one important question: In which technology they need to invest to gain higher competitive advantages. Answering to this question require to detect which technology supports firm business strategy (in terms of differentiation or cost reduction) and which brings mainly uncertainties in return. Answering this question helps companies to out-source some technology related activities and invest on some other technology innovation to achieve higher competitive advantages.

The goal of this paper is to propose a tool (guide line) for decision maker to evaluate their technology strategy regarding their desired business strategy. The rest of this paper is structured as follow: first it brings theory background about different tools and concepts such as sense and respond (S&R) method, critical factor indices, business strategy and technology and knowledge effect. The sample of questionnaire is described and then the case and results are presented. Finally, discussion and conclusion follow.

Theory background

Manufacturing strategy

Success and survival of business for long term goal depends on its ability to engage in useful production, which requires continuous resources deployment decisions for manufacturing activities. These decisions and action so chosen is regarded as strategy. Strategy can be defined as "the pattern or plan that integrates an organization's major goals, policies and action sequences into a cohesive whole" [16]. Manufacturing strategy as a concept is seen as the exploit of material goods of the manufacturing function to attain competitive advantage [17]. Similarly, manufacturing strategy is understood as a steady pattern of manufacturing decision making that is aligned with firm's corporate strategy [18]. Therefore, it is a tool for holding on to firms manufacturing capabilities as a competitive gain for the realization of organizational goals.

There are different types of strategy topology which mangers and decision makers implement in a business. One of them is miles a snow topology which classifies business strategy in four groups: prospector, analyzer, defender and reactor. This classification supports managers in front of external environment. The definition of these four strategies are [19]:

- Prospector strategy: which tries to lead it's industry with the focus of quality. Prospectors innovate in processes and take risks. Besides, they bring new opportunities to the market.
- Analyzer strategy: tries to remain in a steady state in market but at the same time provide change and innovation. Analyzer focus is to reduce cost and acceptable quality.
- Defender strategy: which focuses on a mature product or market operation. Defenders concentrate on efficiency and process improvement and prefer not to take risks; they strengthen efficiency and maintain their current customers.
- Reactor strategy: this strategy happens in absence of defined goals and objectives. In this type of strategy, there is no sense of direction and decisions are taken to respond immediate problems. Hence this type of strategy is not considered as a separate category.

The priority to the build-up of manufacturing strategies is the competitive primacies that provide linkage between the overall goal of the firm and manufacturing objectives [8]. This situation or decision is dependent on the industry and market the firm operates or intend to venture. Some of the parameters of competitive advantage as opined by Ward [20] include quality, cost, time and flexibility. Once they are present and high in organization, it means the firm has competitive advantage. Firm's competitive environment is considered as one of the major determinants of organizational innovation, which entails cost-efficiency [1]. An organizational innovation is enough scale of operation to leverage against productivity gain.

Sense and respond

Several approaches are employed in managing business sustainable competitive advantages strategies [21]. They are comprised of sense and respond, Critical factor index, and manufacturing strategy. The traditional way of planning production based on the manufacturers has been replaced by anticipation of the customers' need in real time and companies are moving from make and sell approaches to sense and respond (S&R) approaches. It is because operations in the manufacturing age were slower and predictable [22], as there is no room for anticipatory reaction from any quota. "The problem that many of us face is that most of our management techniques were created at a time when this two- way conversation didn't exist".

Sense and respond (S&R) approach is used to assist in forming a picture of what might happen in the future. Tasmin et al. [21] opined that S&R facilitates choice of action towards the foreseeable future undertakings of a firm. This method enables firms to collect data regarding expectations and experiences. S&R orchestrates dynamic, structured and unstructured information within a continuous, adaptive event-based planning process [23]. Besides, it helps firms to understand their position compared to their competitors. Moreover, it helps firms to develop a certain criterion at a given time frame. The following tables shows model of questionnaire for Sense and Respond method [24].

Table 1
Format of the questionnaire.

Performance measurement	Scale: 1 = low, 10 = high		Compared with competitors			Direction of development		
	Expectation (1–10)	Experience (1–10)	worse	same	better	worse	same	better
C1								
C2								

RAL model

The way to integrate Miles & Snow Topology [19] into Sense and Response methodology is to use RAL model. RAL is abbreviated from Responsiveness, Agility and Leanness. A firm can optimize the RAL model components by prioritizing between cost, quality, time and flexibility [25]. The model fundamentally supports firm's operational strategy [21].

Fig. 1. RAL model.

The share of different component of RAL model are calculated as follow:

$$Q\% = \frac{Q}{Q+C+T}, \tag{1}$$

$$C\% = \frac{Q}{Q+C+T}, \tag{2}$$

$$T\% = \frac{Q}{Q+C+T}, \tag{3}$$

$$F\% = \frac{Q}{Q+C+T+F}. \tag{4}$$

Once the component of RAL model is calculated, the next step is to calculate MSI of operational competitiveness in each group.

The MSI model for prospector group:

$$\emptyset \sim 1-(1-Q\%^{1/3})(1-0.9*T\%)(1-0.9*C\%)*F\%^{1/3}. \tag{5}$$

The MSI model for analyzer group:

$$\lambda \sim 1-(1-F\%)[ABS[(0.9*Q\%-0.285) *(0.95*T\%-0.285) *(0.95*C\%-0.285)]]^{1/3}. \tag{6}$$

The MSI model for defender group:

$$\varphi \sim 1-(1-C\%^{1/3})(1-0.9*T\%)(1-0.9*Q\%)*F\%^{1/3}. \tag{7}$$

Strategy detection

The sample of different attributes used in this study are presented in the next table. In the last column, the attributes from (S&R) questionnaire are assigned to one of the multiple key categories of RAL model: Quality (Q), Cost (C), Time/Delivery (T) and Flexibility (F), depending on their most significant effect [8, 24]. These categorizations are performed to integrate Miles & Snow topology into Sense and Respond methodology.

Table 2
Sample of performance measurement which has been applied in this study.

	ATTRIBUTES	
	Knowledge & Technology Management	
1	Training and development of the company's personnel	Flexibility
2	Innovativeness and performance of research and development	Cost
3	Communication between different departments and hierarchy levels	Time
4	Adaptation to knowledge and technology	Flexibility
5	Knowledge and technology diffusion	Cost
6	Design and planning of the processes and products	Time
	Processes & Work flows	
7	Short and prompt lead-times in order-fulfilment process	Flexibility
8	Reduction of unprofitable time in processes	Cost
9	On-time deliveries to customer	Quality
10	Control and optimization of all types of inventories	Quality
11	Adaptiveness of changes in demands and in order backlog	Flexibility
	Organizational systems	
12	Leadership and management systems of the company	Cost
13	Quality control of products, processes and operations	Quality
14	Well defined responsibilities and tasks for each operation	Flexibility
15	Utilizing different types of organizing systems	Flexibility
16	Code of conduct and security of data and information	Cost
	Information systems	
17	Information systems support the business processes	Time
18	Visibility of information in information systems	Time
19	Availability of information in information systems	Time
20	Quality & reliability of information in information systems	Quality
21	Usability and functionality of information systems	Quality

Critical factor index (CFI)

Sensing beforehand then responding correctly to probable events and envisaging what will happen in the future call for a complete decision-making supporting system [27]. "The CFI method is a measurement tool to indicate which attribute of a business process is critical and which is not, based on the experience and expectations of the company's employees, customers or business partners" [24]. It is a decision making tool which supports firm by providing the list of critical attribute. Later Nadler and Takala [27] developed BCFI from CFI principle. Then SCFI method was developed [28]. The calculations are presented in the following formula:

$$\mathrm{CFI} = \frac{\mathrm{std(experience)} * \mathrm{std(expectation)}}{a^*}, \tag{8}$$

$$\mathrm{BCFI} = \frac{b^* \cdot \text{Performance index}}{a^*}, \tag{9}$$

$$\mathrm{SCFI} = \frac{c^* \cdot \text{Performance index}}{a^*}, \tag{10}$$

where

$$a^* = \text{Importance index} \; * \; \text{Gap index} \; * \; \text{Development index},$$

$$b^* = \text{SD Expectation index} \cdot \text{SD Experience index},$$

$$c^* = \sqrt{\frac{1}{n}\sum_{1}^{n}[\mathrm{experience}(i) - 1]^2} \cdot \sqrt{\frac{1}{n}\sum_{1}^{n}[\mathrm{expectation}(i) - 10]^2}.$$

The results of CFIs calculation can be presented in traffic bar charts. There are three different colors for different bars: green, yellow and red. In that bar chart yellow and red color represent over and under resource criteria respectively and green stand for balanced attributes. Both yellow and red attributes are critical.

After calculation CFIs and MSI components, the next step is to calculate SCA levels. By the SCA values, it can be observed how much the resource allocation supports the company's strategy. As the SCA value approaches to 1 the consistency between resource allocation and strategy becomes stronger.

MAPE (absolute percentage error):

$$\mathrm{SCA} = 1 - \sum_{\alpha,\beta,\gamma} \left| \frac{\mathrm{BS} - \mathrm{BR}}{\mathrm{BS}} \right|. \tag{11}$$

RMSE (root means squared error):

$$\mathrm{SCA} = 1 - \left(\sum_{\alpha,\beta,\gamma} \left(\frac{\mathrm{BS} - \mathrm{BR}}{\mathrm{BS}} \right)^2 \right)^{1/2}. \tag{12}$$

MAD (maximum deviation):

$$\mathrm{SCA} = 1 - \max_{\alpha,\beta,\gamma} \left| \frac{\mathrm{BS} - \mathrm{BR}}{\mathrm{BS}} \right|. \tag{13}$$

Where the BS is the result of manufacture strategy index (MSI) and BR is the results of CFIs.

Knowledge and technology ranking

Knowledge and technology requirement section has been added to the sense and response (S&R) questionnaire to gather information about the companies' knowledge and technology rankings. Respondents are required to evaluate each attribute in terms of basic, core and spearhead technologies in percentages while keeping the summation of these three terms to 100%.

Basic technology is referring to the technology that is the most critical for the business. Core technologies include technologies that bring competitive advantages to competitors and enable the company to grow. And spearhead technology focuses mainly on future and is the most potential and brings successful business opportunities in future [25].

Coefficient of variance of technology and knowledge and SCA risk

The following formulas show the level of deviation between the participants' responses in terms of technology share. In fact, this is a measurement to how close are the answers of respondents. The lower the value of an attribute means the results are more reliable [25]

$$\text{Coef. Var}_{\text{Basic}} = \frac{\text{Standard Deviation}_{\text{Basic}}}{\text{Average}_{\text{Basic}}}, \tag{14}$$

$$\text{Coef. Var}_{\text{Core}} = \frac{\text{Standard Deviation}_{\text{Core}}}{\text{Average}_{\text{Core}}}, \tag{15}$$

$$\text{Coef. Var}_{\text{Spear Head}} = \frac{\text{Standard Deviation}_{\text{Spear Head}}}{\text{Average}_{\text{Spear Head}}}. \tag{16}$$

Once coefficient of variance (CV) is calculated for all the attributes in all technology level, then the following formula are used to calculate the risk of different level of technology

c_1 : Quality, c_2 : Time, c_3 : Cost, c_4 : Flexibility,

$$\begin{cases} \text{Total TK} \underset{c_1,c_2,c_3,c_4}{\text{risk}} \text{(RMS)} \\ \quad = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\left(\sum_{b_1,c_1,sh} \text{Coef. Var}_i \right)^2 \right]^2} \\ \text{Partial} \begin{cases} \text{TK} \underset{c_1,c_2,c_3,c_4}{\text{risk}} \text{Basic (RMS)} \\ \quad = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\sum_b \left(\frac{\text{std}_i}{\text{mean}_i} \right)^2 \right]^2} \\ \text{TK} \underset{c_1,c_2,c_3,c_4}{\text{risk}} \text{Core (RMS)} \\ \quad = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\sum_{\text{core}} \left(\frac{\text{std}_i}{\text{mean}_i} \right)^2 \right]^2}, \\ \text{TK} \underset{c_1,c_2,c_3,c_4}{\text{risk}} \text{Sh (RMS)} \\ \quad = \sqrt{\sum_{c_1,c_2,c_3,c_4} \left[\sum_{sh} \left(\frac{\text{std}_i}{\text{mean}_i} \right)^2 \right]^2}. \end{cases} \end{cases} \tag{17}$$

Once the total and partial risk of different technology level is calculated, the next is to calculate SCA risk level considering technology. Next formula is used to do that:

$$\text{Total Risk (Geom)} = [(1 - \text{SCA})\text{TK risk}]^{1/2}, \tag{18}$$

$$\text{Total SCA risk level} = 1 - \text{Total Risk (Geom)}, \tag{19}$$

Case study

In this study, sense and respond (S&R) questionnaire data are collected from a Malaysian furniture industry. Four respondents answered the sense and respond questionnaire.

CFIs and business strategy results

The results of BCFI for future are presented in traffic bar chart in Fig. 2.

As the bar chart presents, most of the criteria in "Organization system" sector are under resource attribute i.e., critical and needed to be improved in terms of resource allocation. On the other hand, most of attributes in "process and work flows" area are balanced.

Fig. 2. Recourse allocation and critical factor based on BCFI for future.

The next is to present the values of the multiple key categories of RAL model (Q, C, T and F). These values are calculated separately based on CFIs values of the classified criteria (Table 3).

As the number in the table shows, the focus of company strategy is time.

Table 3
RAL model elements.

	Quality	Cost	Time	Flexibility
CFI(P)	0.00	0.09	**0.91**	0.16
CFI(F)	0.00	0.16	**0.84**	0.15
BCFI(P)	0.29	0.21	**0.50**	0.16
BCFI(F)	0.35	0.27	**0.38**	0.22
SCFI(P)	0.33	0.16	**0.51**	0.16
SCFI(F)	0.36	0.24	**0.39**	0.21
NSCFI(P)	0.36	0.24	**0.40**	0.23
N SCFI(F)	**0.37**	0.25	**0.37**	0.24

Based on calculated elements of RAL model, the business strategy of company is calculated, and the results shows that company business strategy is mainly analyzer. The following table and figure present company business strategy based on BCFI calculation.

Table 4
The company business strategy.

	Prospector	Analyzer	Defender	Reactor
Past	0.92	**0.95**	0.91	0.91
Future	0.91	**0.96**	0.90	0.91

Fig. 3. The company business strategy.

Company tries to keep its operational strategy type unchanged as analyzer strategy, but in future the share of Analyzer group is slightly higher while the share of prospector group is less.

Results of K/T rankings

Core technology as Company's current competitive technology share seems to be around 41%. The share of basic technology is 25% and Spearhead technology is observed around 33% (Fig. 4).

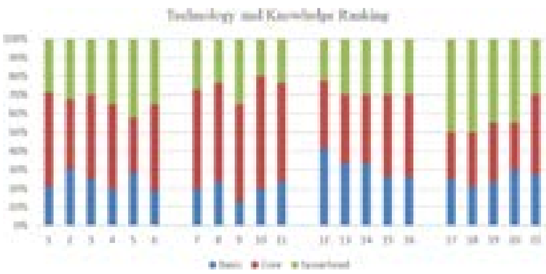

Fig. 4. Knowledge/technology rankings.

Following the formula 14–17, the coefficient of variance of different technology types and it's risk of different technology type are calculated as follows.

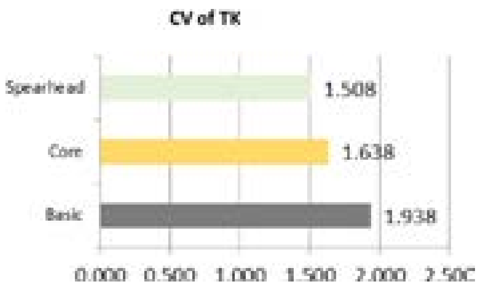

Fig. 5. The coefficient variance of different technology.

As the Fig. 5 shows, the main source of uncertainties in company is basic technology. And the risk of knowledge and technology correspond to basic technology is the highest among these three types of technology.

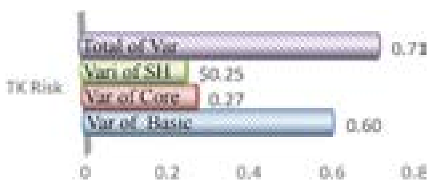

Fig. 6. The risk associated to each technology type.

Table 5
Risk of different technology level correspond different element of RAL model.

	Q	C	T	F
Basic	0.35	0.25	0.29	0.30
Core	0.066	0.159	0.090	0.192
Spearhead	0.131	0.098	0.131	0.133

The SCA level of business strategy of company without and with technology and knowledge effect is presented in the following.

Table 6
SCA level (without T/K effect).

	SCA Level				
	MAPE	RMSE	MAD		GM
P-CFI	0.89	0.78	0.83		0.83
F-CFI	0.73	0.83	0.86		0.80
P-BCFI	0.96	0.97	0.98		0.97
F-BCFI	0.98	0.99	0.99		0.99
P-SCFI	0.92	0.95	0.96		0.95
F-SCFI	0.97	0.98	0.98		0.97
P-NSCFI	0.97	0.98	0.98		0.97
F-NSCFI	0.97	0.98	0.99		0.98

Table 7
SCA level with T/K effect.

	SCA (New T/K effect)			
	Total	Basic	Core	SH
P-CFI	0.66	0.68	0.79	0.80
F-CFI	0.63	0.66	0.77	0.78
P-BCFI	0.86	0.87	0.91	0.91
F-BCFI	0.90	0.91	0.94	0.94
P-SCFI	0.80	0.82	0.88	0.88
F-SCFI	0.87	0.88	0.92	0.92
P-NSCFI	0.87	0.88	0.92	0.92
F-NSCFI	0.88	0.89	0.93	0.93

Comparing two tables above shows that considering technology and knowledge effect, the SCA risk level increases in this company (lower SCA).

Discussion and conclusion

This paper proposes a new method to evaluate the risk of different types of technology. Knowing the risk correspond to different technology type helps manager in the decision making related to technology investment. In fact, it shows which technology supports company business strategy (cost reduction or differentiation) more and which not. The model has been implemented successfully previously in two high-tech starts ups [29] and this research applies that in more conventional industry. Since technology is one of the main drives of competition [2], the decision about that is crucial. Having known that technology could help company to increase the quality of products, reduce cost or make differentiation, the connection between technology and business strategy is clear .The paper applies resource based view (RBV) by barney [3] for assisting technology decision making process having in mind sustainable competitive advantage approaches [15].

The presented SCA model is based knowledge and technology here provides decision maker better tool towards gaining sustainable competitive advantages by making right decision regarding different technology type. The technology decision could be increasing investment or out-sourcing for example.

Moreover, the model process the possibility of:

- Observing the right type of operation strategy (cost, quality and time) which could result in company better performance.
- Investigating which company units follow company business strategy and which not.
- Take better strategic action by knowing the criteria which are unbalanced in terms of resource allocation.

The furniture manufacturing firm (this case study) is a Malaysian-owned company of medium size type industry, employing around 250 employees and listed in the Malaysian Bourse Stock of Exchange, since 2000. It produces high-grade office tables, chairs, office cabinets and cubicle partitions (marketed under AT Office system) for local and export markets to Japan, China, USA, Europe and the Middle-eastern countries. The case company has attained international quality certifications, such as from ISO 9001 UKAS Quality Management, MTTC and PEFC.

The research finding shows that this case company is not leading in term of technology (spear head technology share is around 33%). Therefore, the enhancement of technology and knowledge to SCA values is not significantly seen in this study. The usage of the core technologies is around 41% and it might seem relatively sufficient. In terms of basic technology, while its share is the lowest (around 25%), it has the highest source of uncertainties among technology types.

Although the model introduced in this paper provides an adequate practical value in case of strategic analyses and strategic decision-making process regarding technology and knowledge role in gaining competitive advantages, it still should to be tested with higher number of organizations in different type and size in order to find the best formula to validate the strategic decision (MAPE, RSME or MAP).

Although the effect of technology and knowledge on SCA observed by the proposed model here is not significant, it cannot be neglected. The main goal of this paper is to investigate the effect of different technology types on SCA level by considering the uncertainties in different technology. In case study section, the analyses are performed, and the recommendations are provided for the decision makers. Moreover, the analytical model presented in this paper could be considered as a great source to observe the weaknesses and strengths of the company's operations and accordingly to take required actions to keep up the sustainability of the company's development.

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TECHNOLOGY DEVELOPMENT PROCESS AND MANAGING UNCERTAINTIES WITH SUSTAINABLE COMPETITIVE ADVANTAGE APPROACH

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Keywords: Sustainable Competitive Advantage (SCA), SCA risk level, knowledge and technology effect, manufacture strategy index, product and process development cycle

Abstract: The main purpose of this research work is to assist the decision-making process which is related to technology and knowledge factor within an organization. The data has been gathered and analysed from a particular multinational company that operates in the ceramic manufacturing industry within Malaysia. Four respondents were sought to answer the sense-and-respond questionnaire, including the part on technology sharing. The priority among technology types, including basic, core, and spearhead was decided by the maximum coefficient of the variance. The work has two main contributions: 1. It proposes and validates a tool for decisions and strategies related to technology focus in firms, and 2. expands the notion of technology types from focusing only on product development to one that focuses on both product and process development. The results of the study show that the proposed model which was previously applied in high tech start-ups and local medium-size enterprises is applicable in large industries involved in mass production.

1 Introduction

It is generally acknowledged that nothing is constant, especially in the competitive business environment, except for change. As such, change creates turbulence and uncertainty, along with affecting the respective dynamics and balances involved in any particular process. Complexity increases the danger of making wrong judgments in today's business world [1]. For instance, changes in Manoeuvring Characteristics Augmentation System (MCAS) software that was misaligned with Boeing's 737 MAX sensor caused the entire fleet of 737s to be grounded internationally. These sparks global turbulence in the aviation industry, especially after two of the aforementioned aircrafts crashed. Turbulence thus leads to a shorter product life cycle (PLC), and thus emphasizes the importance of sustaining a competitive advantage in the overall business environment. Indeed, the real goal of any business endeavour is to attain SCA, instead of momentary business advantages. One approach to gauge and attain SCA is via the Resource-Based View (RBV) approach. Through RBV, firms are treated or seen differently, even though they are competing within a similar industry. This perspective is indeed valid and acceptable because, in the RBV, firms are viewed from their respective internal resources. There are few methods to assess and analyse SCA in business environments, such as the Critical Factor Index (CFIs), Sense-and-Response (S&R) method, and manufacturing business strategy.

Ranta and Takala introduced CFIs in 2007 for manufacturing managers to make decisions on allocating and/or reducing critical resources necessary to their respective business processes that were affected [2]. CFI allows decision-makers to sense which business attributes require their response and actions, and this is derived from the experiences and expectations of the firm's employees,

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business associates, and customers. Methodologically, the CFI later evolved and redeveloped into the BCFI and so on. This article introduces the grounding theory and its respective literature of SCA and related findings onto the case study of a ceramic manufacturing firm. Subsequently, the discussion and conclusion based on the research's results will also be presented.

2 Theory background

2.1 Competitive advantage

Competitive strategy means being different and having a unique niche within the business environment. Explicitly, "it means choosing a different set of activities to deliver unique value" [3]. In today's' business world, a company can win over its competitors if it can create marketable differences and manage to preserve them. Based on Miles and Snow typology, there are four strategic positions in which a company should consider taking: Prospector, Analyser, Defender, and Reactor [4]. Once a strategic position of the company is set, all the activities and processes should be built upon and aligned with that. Specifically, the concept of sustainable competitive advantage is based on 1. Finding a unique competitive position for the company, 2. Tailoring activities and processes based on the strategy, 3. Making trade-offs, 4. Fitting across activities, 5. Attaining operational effectiveness. In terms of strategy and sustainable competitive advantages, there are occasions where managers just emulate what their competitors have successfully developed. As such, they might chase each new technology without evaluating its suitability with their main strategy. Although both external and internal factors affect company positions in the markets and its profitability, it is often the case that internal factors are extremely important [3]. Based on the resource-based view (RBV), whatever a company needs to succeed in terms of its resources should exist within the firm. Therefore, the main challenge of a company is how to use its limited resources and angle its process towards gaining competitive advantage [5].

2.2 Technology as a source of competitive advantage

Technology is one of the main drivers of competition. It can change the structure of an industry, create new business opportunities or eliminate businesses. Despite the importance of technology, it should be emphasized that technology is not important for its own sake. Technology is important if it helps firms to reduce costs, create differentiation, and improve the quality of their products. Technology is embodied in every value activity and everything a firm does, involves some sort of technology [6]. Therefore, technology can have a powerful effect on both cost and differentiation. If a firm can discover better technology for performing a process better than other competitors, it can gain a competitive advantage [7].
Abernathy and Utterback (1987) studied the concept of technology in manufacturing and suggested that there are two paths for technology in any organisation, namely product technology and process technology [8]. The development of technology starts with the development of products (product technology), and when it succeeds in making differentiation or increasing quality, the development in the process (process technology) begins to reduce the cost with economies of scale. This is illustrated in Figure 1.

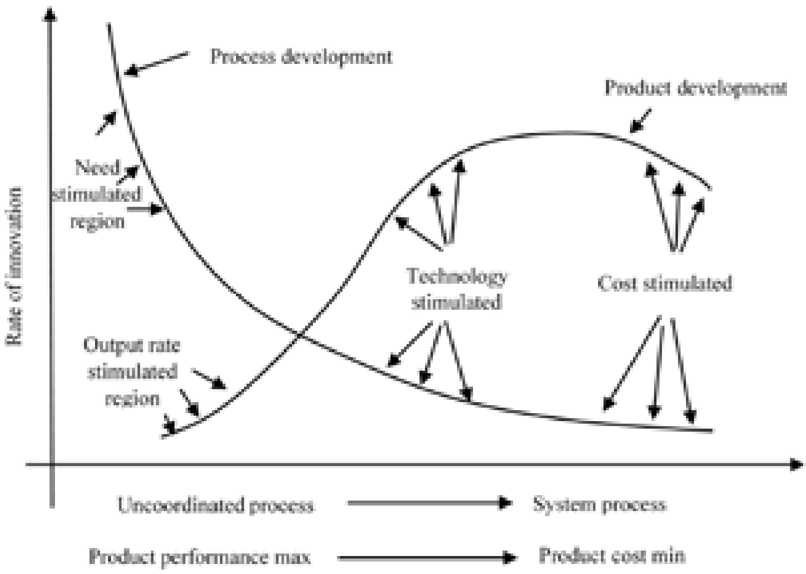

Figure 1 Two paths of technology development: process and product [9]

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Tuominen, Knuuttila, and Takala (2003) studied the development of technology regarding the product life cycle and proposed three types of technology: Basic, Core, Spear-head technology [10]. The relationship between these three types of technology and the product life cycle is demonstrated in Figure 2.

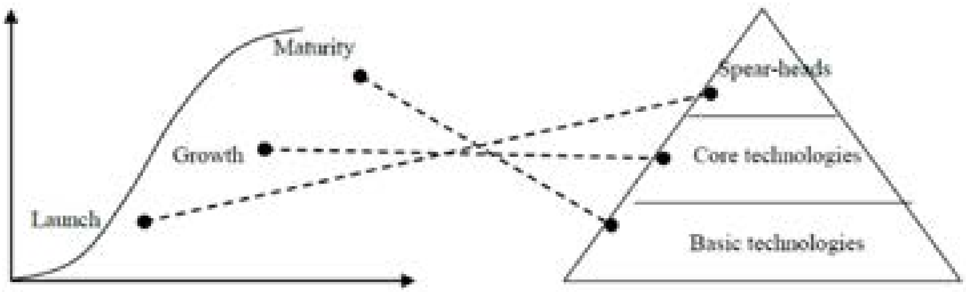

Figure 2 Different technology through product life cycle [10]

Product development starts with spear-head technology. This kind of technology helps a company to differentiate itself in the future and gain a competitive advantage. In the particular ceramic tile manufacturing firm used for this case study, spear-head technology included automated kiln (baking processes) and conveyor-based automatic movement (including sensors). The core technology is the kind of technology that got approved in product development and brought a competitive advantage to the firm in the current situation. Indeed, core technology is the previous spear-head technology which has also developed the process in such a way it is suitable for the economy of scale and yet is cost-effective. In this case, the core technology would be the press-moulding process and its moisture-sensitive controlling mechanism. Finally, basic technology is related to mature technology which might have less cost/benefit trade-off in improving, and sometimes the firm outsources basic technology to focus on core and spear-head technology development. In this manufacturing firm, basic technology includes raw-material control/selection mechanism, painting processes, and packaging operation.

Considering the Tuominen et al., (2003) work, we can draw a more comprehensive picture of the different technologies through the process and product technology development [10], as depicted in Figure 3.

3 Literature gap

A focus on technology and decision about technology investment is a fundamental problem that is faced by the management field. By making the right choices in the technology to invest in and following correct technology strategies, firms can gain and sustain competitive advantage which guarantees their success in the market. Takala, Leskinen, Sivusuo, Hirvelä, and Kekäle (2006) proposed a sand cone model to prioritize different strategy focus, including knowledge and technology, in the Finnish air force [11]. This model was also applied to determine the strategy and knowledge focus of the Finnish ice hockey team [12]. Later on, the sand cone model was also applied to knowledge management strategy in a Malaysian university library [13]. Coccia (2017) developed a framework of technology choices during its evolution in an organization and sought to answer the question of when to apply radical development in technology and when it is suitable to use incremental innovation in technology [14].

There are some researches which follow Barney and Wernerfelt, considers the firms' limited resources, and tries to prioritize the technology and knowledge need of the firm based on the main strategies of the companies in such a way that resource allocation for all the different activities is balanced [15,16]. The main idea behind these research works is to find that type of technology (basic, core, spearhead) which causes the highest amount of uncertainties in the firm and to invest in it to reduce risk and sustain a competitive advantage. In the study by Takala, Zucchetti, Daneshpour, Kunttu, Välisalo, Pirttimäki and Kiiski (2016), the concept of different types of technology (spear-head, basic, and core) is used within the sand cone model, with the authors using the maximum coefficient of variance to decide which types of technology causes the highest amount of uncertainty among different departments [17]. This work built upon the previous works and tried to apply both the RBV and sand cone models in establishing technology requirements. The research was based on this particular assumption that the main source of risk and uncertainty was due to the difference in the attitude of decision-makers in dealing with the subject [18]. Moreover, this research sought to expand the notion of technology in both the product and process development phase. Finally, the proposed mothed is applied in a multinational conventional company for the first time while the previous works focus on technology-based start-ups and local industries.

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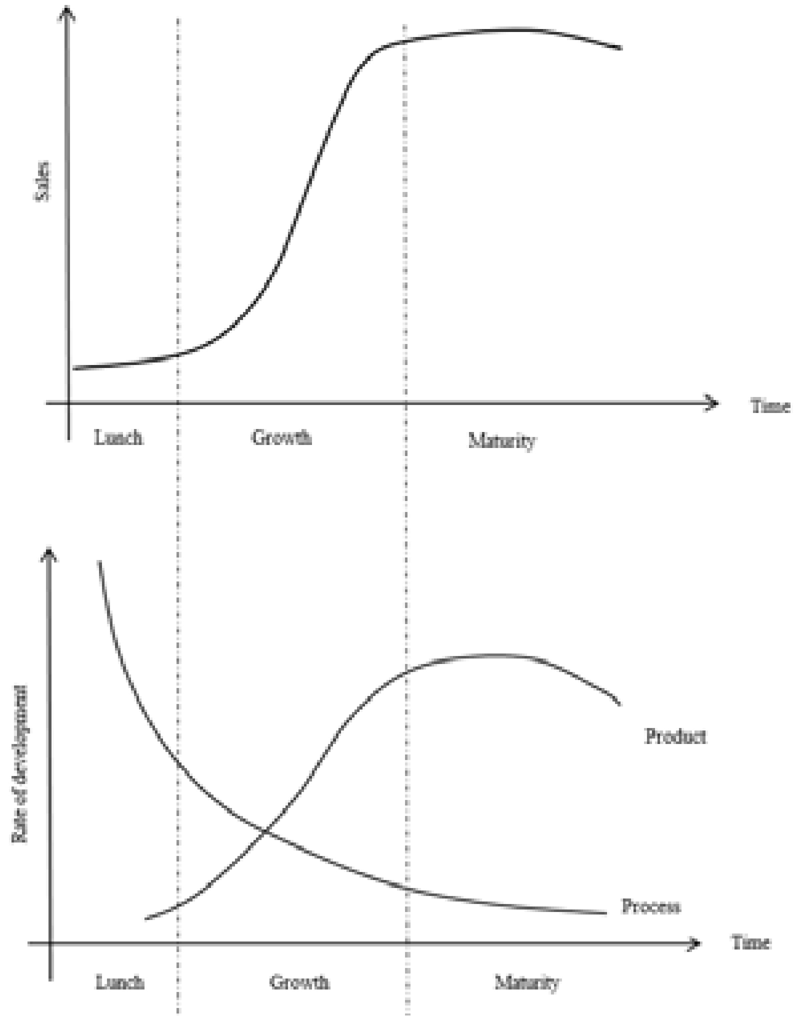

Figure 3 Different technology all over product and process development

4 Method

This research applies the sense and respond questionnaire, a method introduced by Ranta and Takala [2]. The sample of this questionnaire is presented in Table 1. Having filled this questionnaire, respondents evaluate their expectations and experiences regarding each attribute. Also, they are able to compare themselves with competitors and determine the development of each criterion within a specific time frame.

Table 1 Format of sense and respond questionnaire.

Performance attribute	Scale: 1=low, 10=high		Compared with competitors			Direction of development		
	Expectation (1-1)	Experience (1-10)	worse	same	better	worse	same	better
Performance 1								
Performance 2								

In order to integrate sense and respond questionnaire to Miles and Snow topology (which is one of the most popular business strategy classifications), each attribute above is assigned to the component of the RAL model [19] based on the RAL model, prioritizing among quality, cost, time and flexibility is directly related to responsiveness, agility, and leanness [2]. This relationship is demonstrated in Figure 4.

Figure. 4. RAL model [20]

Table 2 presents attributes which are used in this study. It also presents their assignment to the RAL model components.

Table2. Detail attributes of the sense and respond questionnaire

	ATTRIBUTES	
	Knowledge & Technology Management	
1	Training and development of the company's personnel	← Flexibility
2	Innovativeness and performance of research and development	← Cost
3	Communication between different departments and hierarchy levels	← Time
4	Adaptation to knowledge and technology	← Flexibility
5	Knowledge and technology diffusion	← Cost
6	Design and planning of the processes and products	← Time
	Processes & Workflows	
7	Short and prompt lead-times in the order-fulfilment process	← Flexibility
8	Reduction of unprofitable time in processes	← Cost
9	On-time deliveries to customer	← Quality
10	Control and optimization of all types of inventories	← Quality
11	The adaptiveness of changes in demands and in order backlog	← Flexibility
	Organizational systems	
12	Leadership and management systems of the company	← Cost
13	Quality control of products, processes and operations	← Quality
14	Well defined responsibilities and tasks for each operation	← Flexibility
15	Utilizing different types of organizing systems	← Flexibility
16	Code of conduct and security of data and information	← Cost
	Information systems	
17	Information systems support the business processes	← Time
18	Visibility of information in information systems	← Time
19	Availability of information in information systems	← Time
20	Quality & reliability of the information in information systems	← Quality
21	Usability and functionality of information systems	← Quality

Additionally, respondents are requested to evaluate each of the attributes above in terms of the percentage share of technology. They should also determine the share of basic, core, spear-head technology in detail so that all the attributes combine into a sum totalling 100%. The idea behind this corresponds to Porter's point of view, which is that everything a firm does shall incorporate some sort of technology [7].

Once the questionnaire is filled, the next step is to find which technology type causes the biggest amount of disagreement among respondents for each attribute. To find the source of disagreement and uncertainties, variability coefficient regarding each technology is calculated as follow:

$$Coef.Var_{Basic} = \frac{Standard\ Deviation_{Basic}}{Average_{Basic}} \quad (1)$$

$$Coef.Var_{Core} = \frac{Standard\ Deviation_{Core}}{Average_{Core}} \quad (2)$$

$$Coef.Var_{Spear\ Head} = \frac{Standard\ Deviation_{Spear\ Head}}{Average_{Spear\ Head}} \quad (3)$$

In order to evaluate the risk level associated with each type of technology regarding RAL model components, formula 4 is used:

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$$c_1: Quality\,, c_2: Time, c_3: Cost, c_4: Flexibility$$

$$(4)\quad \begin{cases} Total\ \underset{c_1,c_2,c_3,c_4}{TK\ risk}\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\left(\sum_{b_1,c_1,sh} Coef.Var_i\right)^2\right]^2} \\ Partial \begin{cases} \underset{c_1,c_2,c_3,c_4}{TK\ risk\ Basic}\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\sum_b\left(\frac{std_i}{mean_i}\right)^2\right]^2} \\ \underset{c_1,c_2,c_3,c_4}{TK\ risk\ Core}\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\sum_{core}\left(\frac{std_i}{mean_i}\right)^2\right]^2} \\ \underset{c_1,c_2,c_3,c_4}{TK\ risk\ Sh}\ (RMS) = \sqrt{\sum_{c_1,c_2,c_3,c_4}\left[\sum_{sh}\left(\frac{std_i}{mean_i}\right)^2\right]^2} \end{cases} \end{cases}$$

In the formula above, the $Coef.Var_i$ for different types of technology is calculated by formula 1-3. In order to evaluate how the strategy related to knowledge and technology is sustainable, the following formulas are used:

$$Total\ Risk(Geom) = [(1 - SCA)TKrisk]^{\frac{1}{2}} \quad (5)$$

$$Total\ SCA\ risk\ level = 1 - Total\ Risk(Geom) \quad (6)$$

In formula 5, SCA stands for the sustainable competitive advantage of a firm without considering the technology and knowledge.

5 Results

The results of the study show that the resource of the ceramic manufacturing firm is correspondingly allocated among different tasks. Resource allocation based on the Balanced Critical Factor Index (BCFI) is presented in the following bar chart.

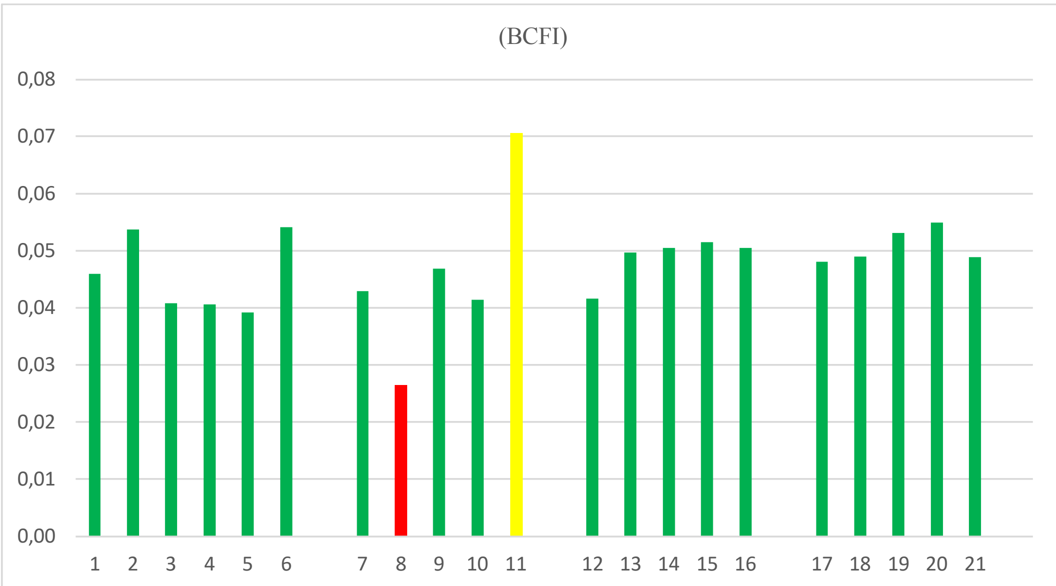

Figure 5 Resource allocation of the company based on the BCFI

As Figure 5 illustrates, only the attribute "Reduction of unprofitable time in processes" is under-resourced and the "Adaptiveness of changes in demands and in order backlog" is an over-resourced attribute. In terms of strategy position, the manufacturing firm is an analyser type, which is based on Miles and Snow typology [21]. The manufacture strategy indices are presented in Table 3 and Figure 6.

Table 3 The manufacturing firm's business strategy indices

PROSPECTOR	ANALYSER	DEFENDER	REACTOR
0.89	1.00	0.90	0.89

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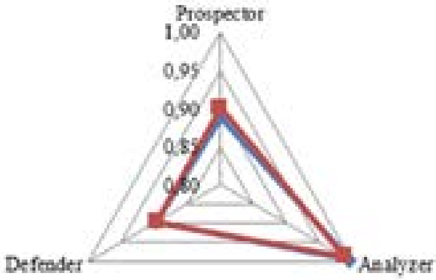

Figure 6 Company business strategy based on Miles and Snow typology

The percentage share of different technology for different attributes are presented in Figure 7.

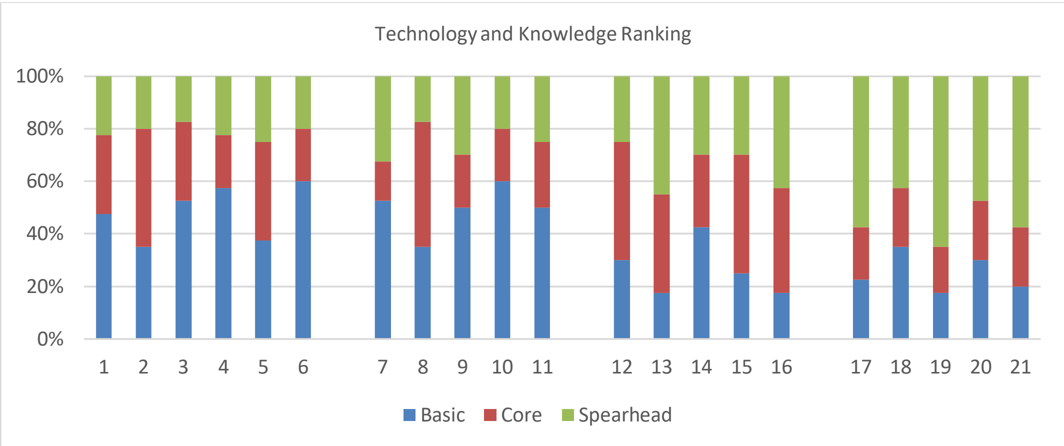

Figure 7 Percentage partition technology share for different attributes

As Figure 7 demonstrates, one technology is not the most dominant one for all the attributes. For example, spear-head technology is the dominant technology for activities related to information systems while basic technology and core technology correspond with dominance in activities related to "knowledge and technology management" and "organizational system", respectively.

The coefficient of variance and risk related to each type of technology is calculated based on formulas 1 to 6 and the results are presented in Figure 8.

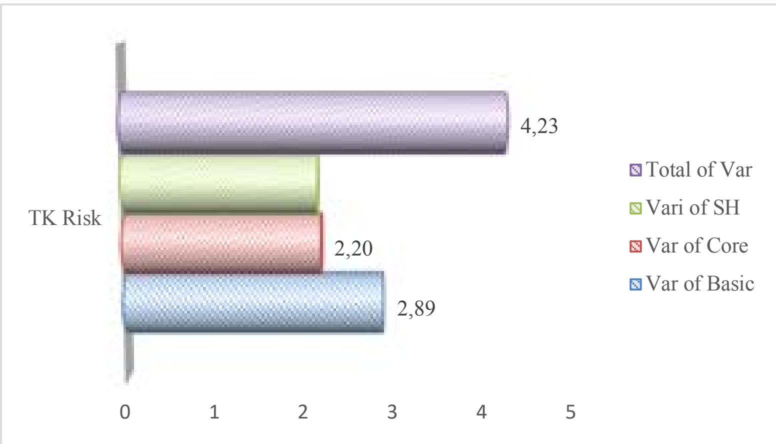

Figure 8 The uncertainties related to different technology and overall variance perspective

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As depicted in Figure 8, basic technology is the main source of risk and uncertainties in the ceramic manufacturing firm. Considering the development of technology in terms of process and product, dominating basic technology shows that the firm should invest more in process development rather than product development. In strategic move and initiative, the firm should invest more in developing manufacturing processes, including automation, and at the same time, look towards reducing the overall operational cost.

Figure 9 presents the impact of technology and knowledge policy in gaining a sustainable competitive advantage for the manufacturing firm. As is presented in figure 9, and taking into consideration the knowledge and technology perspectives, the firm resource allocation and policy is significantly less sustainable compared to the situation in which technology and knowledge factor are excluded.

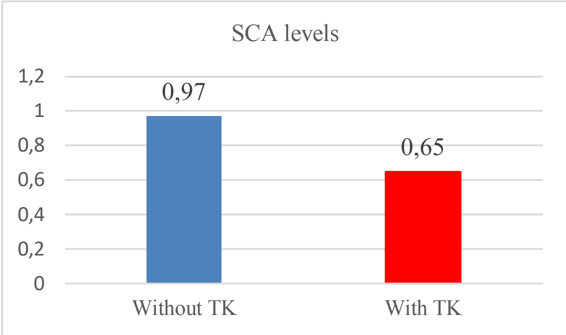

Figure 9 The effect of technology and knowledge factor on the level of SCA

Specifically, the comparison of the total SCA considering knowledge, technology, and sustainability regarding each type of technology is presented in Figure 10. The figure also shows that the decision regarding basic technology is less sustainable as compared to other types of technology.

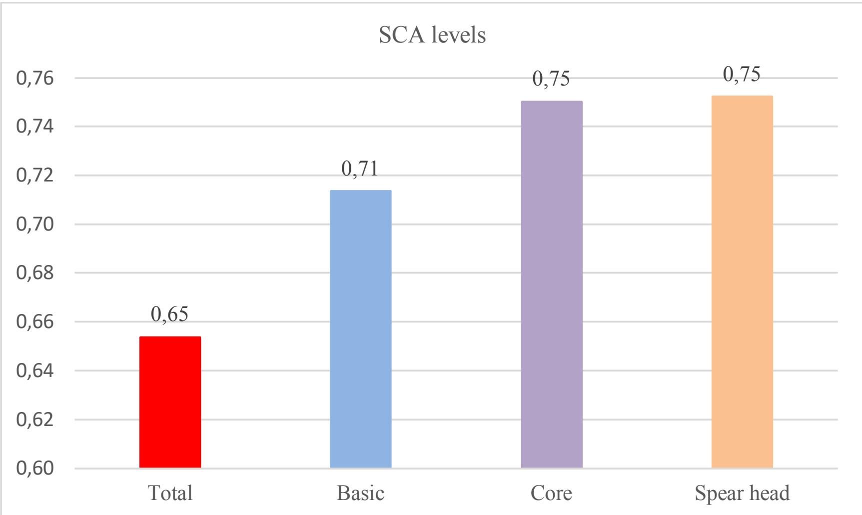

Figure 10 The SCA level with technology and knowledge factor, total and partial

6 Discussion

This research contributes to the field in two main subjects:

1. Developing a tool for technology and knowledge decision-making activities. In this regard, this work is built upon previous works that propose a method to prioritize technology investment and validate it in high-tech start-ups [22]. What is new here is that the proposed model is applied to a multinational large-size firm in a more conventional industry and the obtained results proved that the model is applicable both in general and in a conventional manufacturing industry.
2. The work contributes to current literature related to process and product development phases in the firm. Previous works made a connection only between technology types and product development. However, this work expanded the concept further and related technology types to both product and process development. Based on the current literature, innovation and development in the firms begin with the product. Tasmin and Woods (2007) advocate that product innovation is strongly related to the effective management of a firm's knowledge, process, technology, and its niche market [23]. Once a firm produces a product that can differentiate itself from others, the next stage would be to develop the relevant processes in such a way that producing the new product could also be made economical. The initial phase of product development, which is called the launching phase, is

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closely incorporated with spearhead technology. At this stage, the cost of producing a product is extremely high, with the firm generally having an internal plan to apply it in the future and reduce its cost. In the phase of growth, the ability of new products in making differentiations is proven and the process is optimized in such a way that producing the new product on a large scale is economical. This condition where both product and process development are at the optimal level is related to the core technology. The growth stage of product development is followed by a maturing phase in which neither the product nor the process has the capacity to develop further and the company should reduce the cost of producing its products as much as possible, with a focus on newly invented product and through innovated technology in order to sustain its position in the market. The last phase is very much related to the existing basic technology. This research corresponds to the different types of technology which is embedded in the initial process and product development phase. The domination of basic technology in the studied firm in this research suggests that the firm should focus on the development of this current process rather than developing new products to sustain its position and competitiveness in the market. This result corresponds to the situation of the attribute "reduction of unprofitable time in processes" being an under-resourced attribute. This attribute also belongs to the "Cost" component of the RAL model. Therefore, investing this criterion, and related issues such as better control of work-in-progress, will ultimately reduce costs.

7 Conclusion

Business strategy as a comprehensive plan that integrates a firm's major goals and action plans, positioning it as an essential role in a firm's success. The role of business strategy is more important in today's business world because of rapid change and the turbulent environment in the global business landscape. The concept of technology and the decision related to that is very important because the level of automation in industry is increasing rapidly, particularly with the introduction of new technologies and robots [24]. Since the mid-1990's, sense and respond point of view has replaced traditional "make and buy" attitude in the business world and enabled firms to sense market changes in a timely manner and respond to those changes quicker [25]. Since the introduction of sense and respond philosophy, different research works have been conducted to integrate Miles and Snow typology and to constitute different drivers of competition. The latest effort was to consider technology and knowledge factor in the sense and respond questionnaire and try to propose a method that assists technology and knowledge decision making processes in the organization. This research work was built upon previous works and considers three types of technology in an organization: basic, core, and spearhead, and tries to show which kind of technology is worth investing in, based on firms' overall strategy and resource allocation. The method which is proposed here is based on the sand cone concept and uses the maximum coefficient of variance of each technology type to prioritize different technologies. The data has been gathered from a big multinational company in the industry of ceramic tile manufacturing, and the results of this study show that this method, which was previously tested in high tech start-ups, could also be implemented in other industries as well. From a practical point of view, the paper tries to present and validate a tool that could constitute technology in company business strategy. This tool could fulfil the communication gap between the operational manager who has main knowledge regarding the technology requirement, and the business manager who is the main person responsible for setting firm business strategy. However, the author suggests the implication of proposed tools in other industries and the inclusion of a bigger number of respondents as well. Another direction of future work would be to conduct a case study and implement the proposed tool among the two different samples of a business: top managers and operational managers, in order to see how much their point of view differs.

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Review process

Single-blind peer review process.